Irrigation and Watershed Management

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Worku Atlabachew
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Ethiopian Institute of Agricultural Research

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Evaluation of Coffee Genotypes for Drought Tolerance

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Introduction

Because of population pressure for arable lands in most of coffee growing areas in Ethiopia, coffee cultivation has spread towards marginal areas where water shortage and high temperature constitute significant reduction in coffee yield. Also, in most cases, there is shortage of water resources for irrigation during prolonged dry spells, which affects the growth and development of plants under different forms during the phonological phases of the coffee crop (Abayneh M. and Masresha F., 2014). The critical soil moisture level for coffee at its maturity level is 0.52 (Bruno etal, 2015) and according to (FAO, 2002) the allowable manageable depletion soil moisture level for coffee is 0.40.

Developing drought tolerant coffee genotypes is better option in mitigating climate change impacts on coffee growing areas in Ethiopia. From the promising coffee genotypes in Southern Ethiopia, fourteen cultivars have been tested for their drought tolerance potential.

Agronomic measures against drought control, such as shading, irrigation, high density planting and use of tolerant genotypes that are adapted to climatic fluctuations are alternative solutions against drought in coffee cultivation. Therefore, this study was conducted from 2011 to 2015 to screen drought tolerant Sidamo coffee genotypes under both rain-shelter and field conditions.

Materials and Methods

The study area

The experiment was carried out from April, 2011 to December, 2014 on Sidamo coffee genotypes in a rain shelter at Awada Agricultural Research Sub-Center of the Ethiopian Agricultural Research institution (EIAR). The research Sub-center is located at $6^{0}45'$ N latitude, $38^{0}38'$ E longitude, and at an altitude of 1740masl. The center receives an average annual rainfall of about 1216 mm with monthly mean

maximum and minimum temperatures of 26.49^{0}C and 10.97^{0}C, respectively, and an average relative humidity of 47.2%. Similar screening experiment was also conducted under field condition during 2014 season at Korkie ($6^0$34’N $38^0$39’E and 1800 m.a.s.l) which is 20 km south of Awada.

Experimental design

The experiment was conducted in a RCBD in a factorial combination with three replications. Treatments were 14 Sidamo coffee cultivars c (c85259, c85238, c85237, c85294, c85257, c971, c974, c979, c9718, c9722, c9744, c1377, c75227 and c744) and two watering regimes (well-watered and water-stressed).

Each experimental block consisted of28 plots (14 cultivars x 2 watering regimes); the seedlings were germinated in pots filled with 1000 cm^3 volume of soil. For well watered treatments each cultivar received 100% Etc full irrigation at four days intervals, whereas, for stressed plots water was withheld for 28 days. Each plot consisted of 6 pots of seedlings. Further performances of these cultivars were evaluated under field condition with RCBD in 2014 at Korkie.

Planting material

Pure seeds of the fourteen Sidamo coffee genotypes were prepared from promising and released coffee mother trees from verification plots, and they were sown in nursery, managed according to recommended nursery management standards. Vigorous and healthy seedling of 8-month old, after they developed greater than 8-pairs of fully expanded leaves have been chosen, then uniform seedlings were planted to the pots of 10liter volume and transported to the rain-shelter and then evaluated for some physiological and morphological mechanisms such as plant height, girth diameter, number of nodules give, associated with drought tolerance under controlled rain shelter. At the beginning of the trial, young tree of promising and released Sidamo coffee cultivars and those land races in verification plots have been evaluated at stations for their response to moisture stress during the peak dry spell and rate of recovery at the end of the wet season using method of visual scoring both at greenhouse and field condition.

Parameter measurements

The first response measurements were made after four days of moisture stress period and continued for one month at every two days interval for stress, destructive biomass were taken at the end of the stress period and after recovery, it was separated into leaves, stems and roots. Plant height was measured as the distance between the stem base and the apical bud by using ruler with 1m length after stress and recovery rate. Girth was measured with a digital caliper in the stem base region. The total leaf area was determined with the leaf area meter. Number of nodes and leaf number were determined by physical counting from destructed seedling at start, end of stress and recovery periods.

Total dry mater yield was determined from stem, leaf and root dry weights. The dry root and shoot material (stem and leaf) was obtained from samples that were dried in an oven at 70ºC until a constant weight. Relative leaf water content was determined from fresh leaf weight, turgid weight and dry weight. Three well developed leaves by observation were sampled from each plot and placed in a distilled water for 24 hrs in cool and dark place, then turgid leaf weight was measured the samples more dried in an oven at 70^{o}cuntil constant weight attained. Relative leaf water content was then calculated as follows (Tesfaye S.G *et al*, 2013).

$$RLWC = \frac{(FLW - DLW)}{(LTW - DLW)} x100$$

Whereas: - FLW= Fresh leaf weight (gram)
LDW= leaf dry weight (gram)
LTW=leaf turgid weight (gram)

Leaf thickness (LT) was calculated from leaf dry weight (LDW) and leaf area (LA). (Tesfaye S.G *et al*, 2013)

$$LT = \frac{LDW}{LA} \qquad (2)$$

Whereas: LT=leaf thickness (mm)
LTW= leaf dry weight (gram)
LA= leaf area (cm^2)

Stress scoring was measured visually every day, at 8.00am and at 1:00 pm. Score values were given in 1 to 5 scale, where 1 given for when all leaves green and turgid, 2 when most leaves still turgid, but younger leaves show leaf folding, 3 when all leaves wilt or fold, 4 when leaves are turning pale green and showing severe wilting and 5 when leaves are turning brown and dry, mostly drooping)
Furthermore, the degree of leaf folding, rolling, cupping, rate of leaf fall and branch death, rate of recovery (production of new flushes) were recorded based on visual observation and counting.

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) and tested for significance using least significance difference (LSD) by SAS software.

Results and Discussion

Results indicated that there was highly significant difference in scoring ($P<0.001$) by the genotypes tested for drought tolerance. C75227 scored 1.58 in maintaining its greenness despite drought was subjected to it, and c9744 scored 2.99 (Table 1) wilt score as indicated it was drought sensitive cultivar. Scoring measurement was recorded in August - September 2011/12 main rain season in the study area and the duration may have its own effect on the extent of greenness of the cultivars and in 2013 wilt, scoring measurement was taken during November 2012 – January 2013.

Scoring was also measured at field condition screening in 2013 and there was significant difference observed ($P<0.05$) between the genotype tested. Both c85238 and c1377 scored the best value 1.00. As shown from the green house and the field condition evaluations c85238, c1377, c979, c9722, andc974 performed better than the rest of the genotypes.

There was also significant difference observed in total dry matter, stomatal conductance and root to shoot ratio ($P<0.01$) among the genotypes. C9722 scored the maximum value 11.76 g of dry matter whilst c85237 scored minimum value 5.75g from the over years evaluation c979, c9722, c974, c1377 and c85238 have shown consistent higher total dry yield matter. c974 scored highest ratio with 0.94 and minimum ratio was scored 0.63 by c85259 and c75227 scores the highest magnitude 12.89 mmohm^{-2}s^{-1} and cultivars c85294 scored the minimum value 7.66 mmohm^{-2}s^{-1} .From both years evaluation c85238, c979, c1377 andc974 are selected as best performing with respect to RSR parameter.

There was no statistically significant difference observed in leaf thickness between the genotypes but maximum leaf thickness 17.72x10^{-3}mm has been obtained by c85294 and 12.98x10^{-3}mm minimum leaf thickness was obtained from c744. Therefore from both years evaluations c85238, c744andc9722 are selected as better genotypes.

There was significant difference in relative leaf water content and leaf retention capacity ($p<0.01$) among the genotypes subjected to drought stress. **c85257** scored the highest relative leaf water content 63.46% whilst **c744** obtained the least relative water content 50.53%. In addition, from both years evaluation **c85259, c974, c1377, c85257, c85294**and**c979** have shown the highest relative leaf water content. **c85237** retained 51.28% of its leafs during the stressed time and **c974** also scored the second highest value next to best cultivar and **c971** scored the minimum value 22.41%.

On field evaluation of coffee genotypes

As shown in Table 2, the result indicated that there was highly significant difference in plant height, Number of primary branch, Canopy diameter, Coffee yield and number of bearing branch ($p<0.01$) among coffee genotypes at field condition. Maximum plant height 288.87cm was obtained from **c9722**. **c85238** scored highest number of primary branch 96.80 and maximum number of bearing branch was scored by **c85294** (Table 2). highest canopy diameter 174.35cm was obtained from **c1377** on field condition at Korkie, and maximum coffee yield 12.53q/ha obtained from **c85238** followed by **c971** genotype with yield of 11.90q/ha. Moreover, on leaf elongation rate coffee genotypes of **c979** and **c85238** scored maximum 2.37mm/day and minimum 0.81mm/day respectively despite there was no statistically significant difference observed among the genotypes.

Table 1. Evaluation of Sidama coffee genotypes for drought Tolerance at Awada rain sheltered

Genotype	STC***	SCO***	PH***		LT[ns]	LRC***	RLWC***	RSR***	TDM***
85259	8.53[efg]	2.70[fg]	50.25[bc]	0.65[ab]	15.68[ab]	40.44[bcd]	58.66[ab]	0.63[f]	7.47[fg]
85238	8.86[efg]	1.58[a]	43.35[g]	0.70[a]	17.58[a]	36.35[efg]	51.59[cd]	0.91[ab]	11.17[ab]
85237	9.36[de]	2.97[i]	55.66[a]	0.66[ab]	13.11[b]	51.28[a]	51.36[cd]	0.73[de]	5.75[h]
85294	7.66[g]	2.72[fg]	45.55[def]	0.58[ab]	17.72[a]	37.80[def]	59.31[ab]	0.84[bc]	8.56[ef]
971	10.67[b]	2.86[hi]	48.10[cd]	0.65[ab]	13.56[ab]	22.41[i]	54.91[bcd]	0.83[bc]	9.05[cde]
974	10.30[bc]	1.77[ab]	51.76[b]	0.65[ab]	13.40[ab]	50.59[a]	57.30[abc]	0.94[a]	10.18[bc]
9722	8.09[fg]	1.98[b]	48.04[cd]	0.67[ab]	17.40[ab]	35.29[fg]	54.66[bcd]	0.79[cd]	11.76[a]
9718	9.54[cd]	2.80[gh]	47.87[cde]	0.63[ab]	15.65[ab]	38.88[cde]	50.53[d]	0.76[cd]	7.25[g]
75227	12.89[a]	2.17[c]	50.99[b]	0.54[b]	14.48[ab]	42.28[b]	54.11[bcd]	0.65[f]	7.21[g]
744	12.18[a]	2.53[e]	44.42[fg]	0.62[ab]	12.98[b]	33.28[gh]	50.25[d]	0.83[bc]	6.70[gh]
9744	8.93[def]	2.99[i]	38.78[h]	0.68[ab]	15.08[ab]	42.12[cb]	59.54[ab]	0.66[ef]	8.71[de]
979	10.93[b]	2.02[bc]	51.15[b]	0.60[ab]	14.79[ab]	41.49[cb]	59.51[ab]	0.91[ab]	9.77[cd]
1377	9.24[de]	2.38[d]	56.03[a]	0.61[ab]	14.93[ab]	30.99[h]	53.90[bcd]	0.90[ab]	9.73[cd]
85257	8.80[efg]	2.61[ef]	46.78[def]	0.58[ab]	13.86[ab]	39.66[bcde]	63.46[a]	0.77[cd]	5.76[h]
LSD	0.93	0.14	2.48	0.143	4.5	3.38	6.56	0.08	1.15
CV%	5.7	2.94	3.06	13.49	17.79	5.21	7.05	5.79	8.05

*STCstomatal conductance*SCO Extent of wilting (scale value), TDM = total dry matter (g), PG = plant girth (cm), PH= plant height (cm), LT = leaf thickness (mm), LRC= leaf retention capacity (%), RLWC = relative leaf water content (%) and RSR= root to shoot ratio (%)

Table 2. Agronomic performance of coffee genotypes at field condition at Korkie, Sidama Zone

Treatment	PH**	NPB***	NBB*	NBB*	CD**	RRns	LEns
c85259	255.53de	80.90ef	56.0bc	70.8ab	150.00cd	69.6	1.51
c85238	268.90abcd	96..80a	70.8ab	63.0ab	152.83c	74.5	0.81
c85237	260.00de	81.69def	59.1ab	59.1ab	146.50cde	77.1	2.34
c85294	267.80bcd	84.80cde	76.0a	59.1ab	150.00cd	72.8	1.67
c971	245.53e	81.30ef	51.7bcd	39.7cd	140.83ef	77.8	1.51
c974	284.43ab	96.23a	59.1ab	54.8bcd	163.63b	80.9	1.76
c9722	288.87a	90.66abc	35.8d	57.8abc	163.43b	82.4	1.82
c9718	266.53bcd	88.76bc	63.0ab	58.4abc	148.57cd	78.5	1.51
c75227	271.10abcd	88.43bcd	70.8ab	35.8d	162.33b	56.4	1.12
c744	244.43f	76.00f	57.8abc	76.0a	137.74f	71.5	1.53
c9744	264.43bcde	81.56def	54.8bcd	56.0bc	145.83de	75.7	1.43
c979	282.20abc	91.80ab	58.4abc	57.1abc	166.16b	80.3	2.37
c1377	274.43abcd	88.27cd	39.7cd	51.7bcd	174.35a	73.7	0.82
c85257	263.33cde	83.76cde	57.1abc	70.8ab	140.00ef	62	1.74
LSD	20.52	6.95	19.4	20	6.98	ns	ns
CV (%)	4.59	4.81	20	19.4	6.3	12.3	35.6

NB:PH is plant height (cm), NPB = number of primary branch, NBB number of bearing branch, CD canopy diameter (cm), RR survival rate (%) and LE elongation rate (mm/day).

There was positive relationship among varieties in total dry matter at seedling stage and canopy diameter at field condition (r = 0.52), grain yield (r = 0.70), number of primary branch at field condition (r = 0.55). There was also relationship observed between extent of wilting at seedling stage and total dry matter at seedling stage (r = -0.64), number of primary branch at field condition (r = -0.69), canopy diameter at field condition (r = -0.57) and plant height at field condition (r = -0.51). The strong relationship was obtained from extent of wilt score at seedling stage and grain yield at field condition (r = -0.80)

Exposing the genotypes to soil moisture stress for 28 days significantly affected total dry biomass indicating that the growth performance of coffee varieties is significantly affected by soil moisture deficit and stress. This confirms that drought stress has significant effect on morphological and other growth characteristics of coffee plants (Abel C. et al 2014). For most of the varieties, there was a reduction in total dry biomass during period of soil moisture deficit. Reduction in total dry biomass could largely be due to the loss of water, which considerably contributes to the total dry biomass of the coffee plants. This water is important in maintaining tissue elasticity in plants and its loss is evident in the morphological characteristics of plants such as wilting and leaf folding (DaMatta 2004).

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Effect of Growth Stage Moisture Stress on Maize (*Zea mays*) Yield and Water Use Efficiency

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Introduction

Maize (*Zea Mays L.*) is very sensitive to water stress (Pandey *et al*., 2000). Payero *et al.* (2008) reported that water stress can effect growth, development and physiological processes of maize plants, which reduce biomass yield. In general, the life cycle of the maize crop depends on the availability water, the water deficit at any phonological stage i.e. vegetative, reproductive and maturity stages have different response and can damage the grain yield (Cakir, 2004).

Therefore, determination of the effect of stage wise deficit irrigation on water productivity is important to utilize the limited water resource without significantly affecting irrigated crop yield. Taking into account the scarcity of irrigation water and the sensitivity of the crop for moisture deficit, this research was aimed to determine the effect of moisture deficit on water productivity of irrigated maize at different growing stage.

Materials and Methods

The study site

The experiment was conducted at Haru agricultural research sub-centre during the growing season of 2014 and 2015. It was found in west Wellaga Zone Gimbi area. The rainfall pattern of the area is bimodal with a short rainy season from February to March and the main rainy season from June to September. The most dominant soil type of the area is clay loam.

Experimental treatments and design

A field experiment was carried out in three seasons of 2014 and 2015. This experiment was laid out in RCBD with three replications. The treatments are presented in Table 1 consisted of fifteen soil moisture stress levels and a check which imposed at four growth stages.

Table 1: Treatments combination

Number	Treatments
1	Irrigate all growth stages (Check)
2	Irrigate all stages except initial stage
3	Irrigate all stages except development stage
4	Irrigate all stages except mid-season stage
5	Irrigate all stages except maturity stage
6	Irrigate all stages except initial and development stages
7	Irrigate all stages except initial and mid-season stage
8	Irrigate all stages except initial and maturity stages
9	Irrigate all stages except development and mid-season stages
10	Irrigate all stages except development and maturity stages
11	Irrigate all stages except mid-season and maturity stages
12	Irrigate only at maturity stage
13	Irrigate only mid-season stage
14	Irrigate only development stage
15	Irrigate only initial stage
16	No irrigation (Control)

Each plot had area of 3m X 3m = 9m^2, which consists of 5 rows. The hybrid BH-660 maize cultivar (*Zea mays* L.) was used as seed source. The recommended spacing of 75 and 25cm between row and plant was employed; two maize seeds were planted per hill, which consists of 53,333 plants population/ha. Each experimental treatment was fertilized with recommended fertilizer application, that was 150 kg/ha and 200 kg/ha of DAP and Urea respectively. The full dose of DAP was applied at sowing, whereas Urea was applied by splitting into two parts, half first and the rest just at 35 days after weeding. All cultural practices were done to all treatments in accordance to the recommendation made for the area. Irrigation water was applied as per the treatment to refill the crop root zone depth close to field capacity.

Data collection

Yield, yield component and growth parameters were recorded and the treatments were compared based on grain yield and yield components, which includes plant height, ear height, above ground biomass yield, grain yield and yield response factor. In addition, water use efficiency of the crop was estimated.

Grain yield was calculated by harvesting the total number of plants in the net plot (5.625 m^2) and grain yield per plot was measured using electronic balance and then adjusted to 12.5% moisture and converted to hectare basis. Above ground biomass was determined by harvesting fifteen plants from the net plot area at physiological maturity, weighed after sun drying to a constant weight, and converted to hectare basis. The yield response factor (Ky) of maize was estimated using the following equation which is formulated by Doorenbos and Kassam (1979).

$$\left(1-\frac{Y_a}{Y_m}\right)=Ky\left(1-\frac{ET_a}{ET_m}\right) \quad (1)$$

Where: Ya = actual yield (kg/ha), Ym = maximum yield (kg/ha), ETa = actual evapotranspiration (mm), ETm= maximum evapotranspiration (mm), and Ky = yield response factor

The crop water use efficiency was calculated by the ratio of harvested yield per total water used.

$$WUE = \frac{harvested\,grain\,yield}{total\,water\,used} \quad \ldots\ldots (2)$$

The data were statistically analyzed combined for both years by SAS software. SAS software version 9.2 for windows was used for analysis (SAS Institute, 1996). Whenever the treatment effects were found significant, GLM test at 1 and 5% was performed to assess significant difference among treatments means.

Results and Discussion

Plant Height

The analysis of variance revealed that there is a highly significant (P<0.01) difference among treatments due to moisture deficit at different growth stage. As shown in Table 2, irrigating all growth stages gave the highest over years mean plant height followed by irrigating all growth stage except initial stage and irrigating all stage except maturity stage. The minimum plant height was obtained from no irrigation treatments. From the result, moisture stress (at development and mid-season stage with any of the combination reduced plant height significantly. Sammis *et al.*, (1988) reported that plant height could change at different level water deficiency. The result of the experiment was also in agreement with the findings of (Bozkurt *et al.*, 2006; Cakir, 2004; Istanbulluoglu *et al.*, 2002) who reported that, plant heights were reported to be higher with full irrigation and slightly deficit irrigation throughout the crop growing season.

Grain Yield

The result of over years mean indicated moisture stress happened at different maize growth stages had a significant effect on grain yield (Table 2). The over years analysis of mean grain yield indicated that irrigating during all four growth stages gave a maximum grain yield (8357.7 kg/ha) followed by irrigating all stages except initial stage (6887.6 kg/ha). However, the minimum grain yield was obtained from no irrigation (1021.6 kg/ha) followed by irrigating only initial stage (1826.7) which showed statistically no significant difference. The result revealed that when moisture stress happens both at development and mid-season stages in combination, yield, and yield parameter influenced extremely. These results are consistent with findings of Farre and Faci (2009), Ko and Piccinni (2009) and Mansouri *et al.*, (2010), who showed that grain yield was affected by irrigation water amount. Some researchers stated that yield decreased with reduced irrigation (Viswanatha *et al.*, 2002). Moisture stress at flowering and pollination could result in unfilled kernels on the cob. This can reduce grain yield by 6% to 8% each day the plant is stressed. If the plant is stressed after flowering, kernel size is reduced (NWS, 2009). Former report by Farshad *et al.*, (2008) also showed lowest grain yield was obtained by applying water stress at silking growth stage, which is equivalent with the mid-season stage. Moreover, different stress level at different stages affect the yield of maize and even different cultivars have different tolerance level for moisture stress leads to a decrease of chlorophyll content which will reduce the amount of food produced in the plant (Adel *et al.,* 2013). The yield obtained from irrigating only one stage was much lower than those of the yield obtained during stress occurring at individual growing stage of initial, development, mid-season and late season stages. From the above result, it could be seen that it is better to stress the crop at its specified growing stage especially at initial and maturity stage rather than totally stressing. The ability of crops to recover the effect of early water stress has also been observed in other studies (Kirda *et al.,* 1999). These studies revealed that under limited water condition, it is better to start by subjecting the crops to stress early in the season. By doing so, the crop adapts to limited watering conditions with the stress not being severely concentrated in any one-time period.

Above ground dry biomass yield

Moisture stress at different growth stages had a highly significant influence ($p<0.001$) on maize above ground dry biomass production. The above ground dry biomass yield of maize ranged from the highest 1.4 t/ha to the lowest 2.1 t/ha in full irrigation treatments and no irrigation treatments, respectively (Table 2). From the result, irrigating maize at all growth stages provided the highest above ground dry biomass yield. Stressing the maize at all growth stages and only irrigating the initial stage were relatively scored the lowest above ground dry biomass. These findings were in agreement with the experimental results reported by Pandey *et al.,* (1983b). Lower leaf production and dry matter is attributed to water stress (El-Bagoury and Shakeen, 1977). Stone *et al.,* (2001) and Moser *et al.,* (2006), also reported that biomass was reduced by moisture stress. The combined stress imposing at different growth stages significantly reduced the above ground dry biomass of maize. However, imposing moistures stress during initial stage was not significantly reduced above ground dry biomass. This agrees with work of Ersel *et al.,* (2010) on maize, the trend of biomass production shows decreasing with increasing of moisture stress indicating well irrigated maize yields higher biomass production. Similarly, Rusere *et al.,* (2012) investigated that, with increasing moisture stress, the dry matter production of the crop decreases directly by decreasing cell division and enlargement and indirectly by reducing rate of photosynthesis.

Water use efficiency

The water use efficiency was significantly affected by imposition of moisture stress at different growth stages (Table 2). As application water becomes reduced, the water use efficiency significantly increased. Irrigating all four-growth stages had recorded the lowest water use efficiency due to maximum irrigation application. Whereas, the combined moisture stresses imposition at different growth stages could highly increase water use efficiency. Stressing maize during three-growth stage (mid, development and late season) can considerably increase the water use efficiency. The maximum crop water use efficiency was obtained from irrigating only initial stage (2.65 K.g/m^3) whereas; the minimum was obtained from irrigating all four growth stages (0.50 K.g/m^3). Yensew and Tilahun (2009) noted that practicing deficit irrigation by reducing the amount of water per irrigation results in a decline of grain yield, increase in irrigated area and high water use efficiency. Previous studies indicated that crop water use efficiency ranged from 0.41 to 2.71 kg/m^3 (Pandey *et al.,* 2000; Kar and Verma, 2005; Dagdelen *et al.,* 2006; Mengü and Özgürel, 2008) which is in agreement with the current findings.

Yield response factor (Ky)

The magnitude of K value indicates the sensitivity of the irrigation protocol for water stress and subsequent yield decrease. Form the result shown in Table 3; the highest K_y was 1.15, 1.09 and 1.07 attained at the treatment of irrigating all stages except development and mid-season, development stage and mid-season stage, respectively. The higher K_y values could be an indication of severity water stresses at that stage on maize grain yield. The lowest 0.54 was observed at irrigating all stage except initial stage indicating that the water deficit at this stage did not affect maize grain yield significantly. This implies that the rate of relative yield decrease resulting from water stress is proportionally lower to the relative evapotranspiration deficit. From Table 3, moisture stress happened at development and mid-season stages the yield reduction rate is extremely higher than stressed the crop at initial and maturity stage. According to Kirda *et al.*, (1999), the K_y value for field crops goes from 0.2 to 1.15 which agrees with the reported result.

Table 2: Agronomic performance of maize on moisture stress

Treatment	Grain yield (kg/ha)	Plant height (cm)	Above ground biomass (t/ha)	Crop water use efficiency (kg/m^3)
Irrigate All Growth Stages	8357.7^{a}	209.8^{a}	1.4^{a}	0.50^{h}
Irrigate All Stages Except Initial Stage	6887.6^{b}	192.5^{b}	1.3^{b}	0.57^{h}
Irrigate All Stages Except Development	4411.8^{de}	179.5^{c}	7.8^{ef}	0.57^{h}
Irrigate All Stages Except Mid-Season Stage	4575.5^{d}	172.6^{d}	7.1^{f}	0.95$^{e\text{-}g}$
Irrigate All Stages Except Maturity	5705.0^{c}	191.3^{b}	1.1^{c}	0.94^{fg}
Irrigate All Stages Except Initial & Development	4674.4^{d}	153.1^{e}	7.2^{fg}	0.97$^{e\text{-}g}$
Irrigate All Stages Except Initial & Mid-Season	5376.0^{cd}	153.5^{e}	8.1^{de}	1.28^{de}
Irrigate All Stages Except Initial & Maturity	5391.7^{cd}	169.3^{d}	8.7^{d}	0.84^{gh}
Irrigate All Stages Except Development & Mid-Season	3011.6^{ef}	131.6^{g}	5.3^{h}	0.72^{gh}
Irrigate All Stages Except Development & Maturity	3456.9^{ef}	142.8^{f}	8.0^{de}	0.82^{gh}
Irrigate All Stages Except Mid-Season And Maturity	4059.5^{de}	139.0^{f}	8.2^{de}	1.84^{c}
Irrigate Only At Maturity Stage	3213.2^{ef}	73.3^{i}	4.5^{i}	1.35^{d}
Irrigate Only Mid-Season Stage	3872.7^{e}	83.1^{h}	4.4^{i}	1.22$^{d\text{-}f}$
Irrigate Only Development Stage	3770.1^{ef}	82.3^{h}	3.4^{j}	2.29^{b}
Irrigate Only Initial Stage	1826.7^{g}	69.5^{i}	3.2^{j}	2.65^{a}
No Irrigation	1021.6^{gh}	57.3^{j}	2.1^{k}	-
LSD at 5%	1025.2	5.6	0.68	0.34
CV %	18.77	9.5	9.8	21.15

*Means followed by the same letters in a column are not significantly different from each other at a 5% probability level

Table 3: Maize yield response factor on moisture stress condition

Treatment	Y_a / Y_m	ET_a / ET_m	$1-\left(\frac{Y_a}{Y_m}\right)$	$1-\left(\frac{ET_a}{ET_m}\right)$	K_y
Irrigate All Growth Stage	1.00	1.00	0.00	0.00	-
Irrigate All Stage Except Initial Stage	0.88	0.78	0.12	0.22	0.54
Irrigate All Stage Except Development	0.55	0.59	0.45	0.41	1.09
Irrigate All Stage Except Mid-Season Stage	0.54	0.57	0.46	0.43	1.07
Irrigate All Stage Except Maturity	0.68	0.66	0.32	0.34	0.94
Irrigate All Stage Except Initial & Development	0.56	0.44	0.44	0.56	0.79
Irrigate All Stage Except Initial & Mid-Season	0.64	0.41	0.36	0.59	0.61
Irrigate All Stage Except Initial & Maturity	0.65	0.53	0.35	0.47	0.74
Irrigate All Stage Except Development & Mid-Season	0.30	0.39	0.70	0.61	1.15
Irrigate All Stage Except Development & Maturity	0.41	0.40	0.59	0.60	0.98
Irrigate All Stage Except Mid-Season And Maturity	0.49	0.36	0.51	0.64	0.80
Irrigate Only At Maturity Stage	0.38	0.31	0.62	0.69	0.90
Irrigate Only Mid-Season Stage	0.46	0.42	0.54	0.58	0.93
Irrigate Only Development Stage	0.45	0.35	0.55	0.65	0.85
Irrigate Only Initial Stage	0.10	0.15	0.90	0.85	1.06

Where Y_a – actual grain yield, Y_m – maximum grain yield, ET_m – maximum evapotranspiration, ET_a – actual evapotranspiration and K_y – yield response factor

Conclusion

From the experiment, the maximum grain yield was obtained from full irrigation followed by irrigating all stage except initial stage. Whereas, the minimum was obtained from no irrigation and irrigating only initial stage. For crop water use efficiency the maximum water productivity obtained from irrigating only initial stage, but the minimum was obtained from full irrigation. In addition, stressing the maize plant at development and mid-season stage resulted in high yield loss. Therefore, it can be concluded that imposing moisture stress at initial stage was not significantly reduced the maize grain yields and dry biomass yield production however, it exhibited lower water use efficiency. Moreover, stressing moisture at development and mid-season crop growth stage while irrigating the rest of growth stages leads to wastage of water used for irrigation by decreasing the productivity of water in relation with the yield obtained. To enhance maize crop productivity both in irrigated and rain-fed agriculture, application of irrigation water to enhance the soil moisture at development and mid-season growth stage is vital where supplementary irrigation from available water source is possible. Therefore, in area where irrigation water is scarce one can use with holding irrigation water at initial stage strategy to save considerable amount of water but the water resource is not scarce application of full crop water requirement is recommended.

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Determination of Optimal Irrigation Scheduling for Maize at Ambo

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Introduction

Maize is fairly sensitive to water stress (Pandey *et al,* 2000) and Cakir R, (2004). Excessive moisture stress is the most limiting factor in maize production (Bolanos J and GO Edmeas 1993).Maize requires 600-700 mm water for optimum growth and yield depending upon climatic conditions (Reddy, 2006).

There is scarce information regarding appropriate management of irrigation water and crop management practices for the rapidly expanding small-scale irrigation farms in the country. Therefore, this study was aimed to find out optimal irrigation water and soil management options for multifaceted soil water problems of irrigated agriculture.

Materials and Methods

The study area

The experiment was conducted at Ambo Plant Protection Research Center during the growing season of 2013/14 to 2014/15 for two consecutive years. The site is situated on 38^o 07' E longitude and 8º 57'N latitude and 2225m altitude. The area experienced bimodal rainfall with a mean annual precipitation of 1115 mm. The mean maximum and minimum temperature of the area is 25.4^{o}C and 11.7^{o}C respectively. The soil texture has been classified as clay soil. As the graph show that the ratio between monthly precipitation (input) to output (monthly evaporation) is less than unit starting from January to May and end of September to December therefore irrigation is required during this month's for the area (Fig 1)

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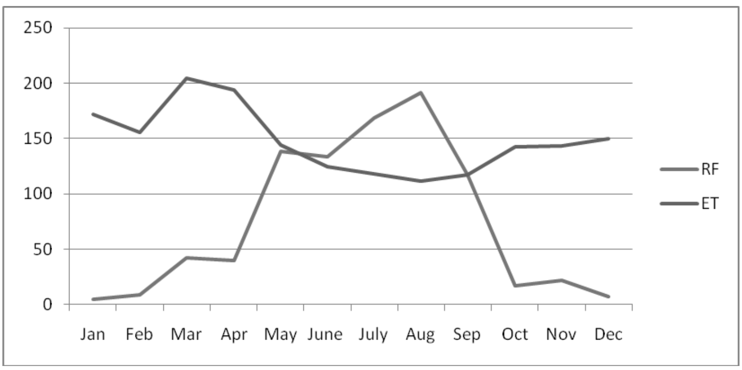

Figure 1. The average monthly evapotranspiration and rainfall relationship during study years

Experimental design and treatment combinations

The experiment was designed as a single factor experiment in randomized complete block (RCBD) arrangement with three replications. The experiment included five levels of soil water depletion levels (SMDL) as a treatment and the five level of ASMDL are (60% FAO recommended ASMDL, 80% FAO recommended ASMDL, FAO recommended ASMDL 120% FAO recommended ASMDL and 140% FAO recommended ASMDL). For maize crop recommended allowable soil moisture depletion level is 55 % and the other treatments allowable soil moisture depletion levels were calculated based on this value.

Table 1:- Treatments description

Treatment	Description
ASMDL 1	60% of ASMDL(-40% of ASMDL3)
ASMDL 2	80% of ASMDL(-20% of ASMDL3)
ASMDL 3	ASMDL* (control)
ASMDL 4	120% of ASMDL(+20% of ASMDL3)
ASMDL 5	140% of ASMDL(+40% of ASMDL3)

Soil moisture depletion level) ASMDL (allowable

Experimental procedure and management

Jibat (AMH 851) maize (*Zea mays* L.) Variety was sown during the last week of November for three consecutive years from 2012/3 to 2014/15. A row spacing of 0.75m and plant spacing of 0.25m were used. Maize plots were fertilized with 46kg/ha, P as DAP and 23kg/ha, N as Urea at sowing and 23kg/ha, N was applied as Urea when maize plant reached at knee height. The plot size used was 4.5 m x 5 m. Furrow irrigation method was used, and the amount of water applied was measured using 3 inch Parshal flume. Crop water requirement was calculated using CROPWAT program based on the FAO Penman-Monteith method and based on the soil moisture depletion level irrigation scheduling was done as per the five soil moisture depletion levels. Soil water level was monitored by using the gravimetric soil moisture content determination method. All other agronomic practices were kept normal and uniform for all the treatments including pre-irrigation and irrigation after germination as establishment irrigations.

Data collection

Six maize plant rows were sown per plot and Grain yield and dry biomass data were collected from the four central rows. While plant height data was collected from five randomly selected maize plants after 135 days from sowing after physiologically matured. Above-ground biomass weight recorded after the maize harvested with cob. Data on maize yield and yield parameters like plant height, total biomass, grain yield and 1000 seed weight was collected.

Water use efficiency (WUE)
WUE is the ratio between bean yield (t ha-1) and seasonal crop evapotranspiration (mm), as can be seen in the equation as follow:

$$WUE = \frac{Y}{ETc}$$

If the yield Ya is expressed in kg and the water use ETc is expressed in m3 m-2, then WUE has units of kg m-3 on a unit water volume basis or g kg-1 when expressed on a unit water mass basis (Stanhill, 1986; Howell et al., 1990).

Economic analysis
The cost benefit analysis was carried out using partial budgeting, in which net income for each treatment was calculated to select treatment with better financial status. Total cost (TC) refers to sum of all fixed costs and variable costs. Total return (TR) corresponding to the value of seasonal maize yield was calculated using the following formula: assume that current price of maize crop used was 4 Birr/kg

$$TR = Y * P$$

Where Y is crop yield (kg) and P is average market price (Birr/kg). Net income (NI) in Birr was calculated by subtracting the total costs (TC) in Birr from the total return (TR) in Birr for a given treatment:

$$NI = TR - TC$$

Data analysis
The three years over year yield and yield component data were subjected to ANOVA test using SAS software to evaluate the overall variability and effects of yield and yield component parameters were considered as significant when $p \leq 0.05$. Least Significant Difference (LSD) test was applied for statistically significant parameters to compare means among the treatments.

Results and Discussion

The over year yield and yield component data were collected as per the procedure and the analysis results were presented on the table below. As the over year analysis result shows that application of the five different irrigation depletion level had no significant difference on yield and yield component of maize. Even if there is no significant difference among the treatments in the table below the maximum grain yield, above ground dry biomass and WUE values were recorded from the application of 20 % more ASMDL value of FAO recommended ASMDL. The maximum grain yield of 9020 kg/ha obtained from 120 % FAO recommended ASMDL had a 5.4 % yield increment with that of the control treatment. Also maximum WUE value of 2.06kg/m^3 recorded from 120 % FAO recommended ASMDL had a 5.8 % increment with the control.

Table 2:- over year analysis result of yield and yield component maize data

Treatment	GY (kg/ha)	DB (kg/ha)	TSW (g)	WUE (kg /m^3)	PH (cm)
ASMDL 1	8248	16591	387.3	1.82	206.2
ASMDL 2	8541	16994	383.8	1.91	198.2
ASMDL 3	8846	17163	383.5	1.95	199.2
ASMDL 4	9320	18144	408.2	2.06	204.1
ASMDL 5	8282	16475	416.1	1.85	201.7
Means	8647.3	16591	395.8	1.92	201.9
LSD (5 %)	NS	NS	NS	NS	NS
CV (%)	12.25	13.01	7.25	13.54	4.94

GY- maize drain yield, DBM- above Ground Dry Biomass, TSW- Thousand seed weight WUE- water use efficiency, PH- Plant height

Economic analysis

Since the yield and yield component data, of maize crop had no significant difference among treatments further economic analysis is required to give a recommendation. The economic analyses of the experiment was done by partial budgeting, by determining the labor cost required per irrigation event starting from diverting the water from the source to the field, furrow and canal cleaning and irrigation application. From the table below 5 hr required per single irrigation event for all experimental treatments.

Table 3. Activities performed for a single irrigation event per treatment and labour required

Activity	No. of labour	Time in hour	Total hours	Labour cost per day or per 8hr in birr	Total cost per treatment in birr
Diverting the water from the source	2	2	4	30	15
Furrow cleaning	1	½	½	30	1.5
Canal cleaning	1	½	½	30	1.5
Total cost					17

To determine the total labor cost required for all irrigation events of the different treatments count the number of events as per the treatments and multiply by the total cost paid for labor during a single event. As shown in the table below maximum number of irrigation events was recorded for 60 % ASMDL while the minimum events happened for treatment receiving 140 % ASMDL. Maximum labour cost of 45333 birr/ha was calculated from a treatment having frequent irrigation while the minimum cost of 17630 birr/ha was calculated from treatment receive irrigation at longer interval.

Table 4. Labour cost per treatments

Treatment	Number of events per treatments	Labour cost for a single event (Birr)	Total labour cost per treatment for 22.5 m^2 plot area with three replication (Birr)	Total labour cost per treatment (Birr/ha)
ASMDL 1	20	17	306	45333
ASMDL 2	18	17	272	40296
ASMDL 3	16	17	221	32741
ASMDL 4	14	17	170	25185
ASMDL 5	11	17	119	17630

Cost benefit analysis

Cost benefit analysis was done by subtracting the income obtained from maize yield from the labour cost required per treatments. For this calculation assume that unit price of maize was 4 birr/kg). As shown in the table below maximum net benefit value of 15498 birr/ha was obtained from 140 % ASMDL followed by 12095 birr/ha from 120 % ASMDL treatment. While in the case of two frequent irrigation events the net return become negative value.

Table 5. Cost benefit analysis

Treatment	Yield (kg/ha)	Total income obtained from maize yield (birr/ha)	Labour cost (birr/ha)	Cost benefit analysis (income obtained from maize yield – Labour cost)(Birr/ha)
ASMDL 1	8248	32992	45333	-12341
ASMDL 2	8541	34164	40296	-6132
ASMDL 3	8846	35384	32741	2643
ASMDL 4	9320	37280	25185	12095
ASMDL 5	8282	33128	17630	15498

Conclusions and Recommendations

Increasing the allowable soil moisture depletion level from 60 % to 120% increase grain yield and water use efficiency of maize crop but increasing allowable soil moisture depletion level from 120 % to 140 % and reducing from 80 % to 60 % result in yield as well as water use efficiency. Since the result had no significant difference among the five treatments, to make a recommendation further economic analysis was required. Frequent irrigation results a negative net benefit value while irrigating the field with longer irrigation intervals give higher net return without a significant yield and yield component data even if maximum yield and water use efficiency value obtained from 120% ASMDL that gives better yield and water use efficiency.

Therefore, application of 140 % ASMDL is best with higher net return value, also the soil of the study area is Vertisols so frequent irrigation will result a water logging problem. In addition to this further research is required to select the exact soil moisture depletion level of the study area.

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Response of Tomato to Deficit Irrigation at Ambo

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Introduction

Tomato (*Solanumlycopersicon*L.) is one of the most important vegetable crops and is one of the most demanding in terms of water use (Peet, 2005). Most of the time tomato is produced through furrow irrigation in smallholder schemes. An important adaptation of furrow irrigation is Alternate Furrow Irrigation (AFI) in which furrows are irrigated alternately rather than consecutively during irrigation water application. This is a form of partial root-zone drying (PRD) system which has been found to increase the production of various vegetables in the ASAL areas (Fereres et al., 2007; Jones, 2004) as well as saving irrigation water. The application of DI strategies to this crop may significantly lead to save irrigation water (Costa *et al*., 2007). Furthermore, studies have shown that water deficit occurs during certain stages of the growing season improves fruit quality, although water limitations may determine fruit yield losses (Patane and Cosentino, 2010).

Therefore, with the above research findings this experiment was conducted to select best regular deficit irrigation level as well as best water saving furrow type to improve tomato production.

Materials and Methods

The study area

The experiment was conducted at Ambo Plant Protection Research Center from 2013/4 to 2014/5 for two consecutive years. The geographical location of the site was 38^{o} 07' E longitude and 8^{o} 57'N latitude and 2225m altitude. The area experienced bimodal rainfall with a mean annual precipitation of 1115 mm. The means maximum and minimum temperature of the area is25.4^{o}C and 11.7^{o}C, respectively. The soil texture has been classified as clay soil.

Experimental design

The experiment was designed as a two factor factorial experiment designed in randomized complete block (RCBD).The two factors were furrow irrigation systems and deficit irrigation application levels. The treatments were three irrigation systems i.e Alternate Furrow Irrigation (AFI), Fixed Furrow Irrigation (FFI) and Conventional Furrow Irrigation (CFI) and three levels of deficit irrigation applications (Table 1) were 50% ETc, 75% ETc, and 100% ETc. The optimal irrigation schedule (ETc) was computed with

Cropwat model. The amount of irrigation water to be applied at each irrigation application time measured using Parshall flume.

Table 1 Combination of experimental treatments

Treatment	Combination
T1	Alternative furrow (AF) irrigated at 100% Etc
T2	Alternative furrow (AF) irrigated at 75% Etc
T3	Alternative furrow (AF) irrigated at 50% Etc
T4	Fixed furrow (FF) irrigated at 100% Etc
T5	Fixed furrow (FF) irrigated at 75% Etc
T6	Fixed furrow (FF) irrigated at 50% Etc
T7	Conventional furrow (CF) irrigated at 100% ETc
T8	Conventional furrow (CF) irrigated at 75% Etc
T9	Conventional furrow(CF) irrigated at 50% Etc

Alternate furrow irrigation (AFI) meant one of the two neighboring furrows was alternately irrigated during consecutive irrigation events. Fixed furrow irrigation (FFI) meant that irrigation fixed to one of the two neighboring furrows. Conventional furrow irrigation (CFI) or traditional irrigation meant irrigating all furrows during consecutive watering. Where, full irrigation (100% crop water requirement) implies the amount of irrigation water applied as estimated using Penman Monteith with CROPWAT computer program. And 75% (ETc) and 50% (ETc) irrigation level meant 25% and 50% less of full irrigation requirement, respectively.

Data collected

Secondary data

The secondary data collected during this research include climatic data of 20 years on Rainfall (R.F.) min & max temp, Relative humidity (RH), wind speed (WS) and sunshine hours (SH). Irrigation efficiency for furrow irrigation, root depth of tomato crop, tomato crop growing stages and their respective length of period and soil Infiltration rate data was also collected.

Primary data

Soil data was analyzed to obtain the soil parameters like soil texture, bulk density, field capacity and permanent wilting point. By using the above primary and secondary data, crop water requirement of tomato was calculated with CROPWAT model.

Fruit yield and yield component

Yield data were collected from three central rows of tomato planted plot. Plant height number of fruit per plant and cluster number were collected from five plant sample of the three central rows. Yield and other yield component parameters were collected and the analysis was done using the appropriate SAS software.

Water use efficiency (WUE)

The term water use efficiency is used to describe the relation between growth (particularly dry matter production) and water use (Oweisand Zhanga1998). Water use efficiency (WUE) is expressed as the crop dry matter or yield production per unit of water used by the plants.

$$WUE = \frac{Y}{ETa}$$

Where Y is the crop yield (kg/ha), ETa is the actual evapotranspiration (mm) and WUE is water use efficiency with dimensions of kg m^{-3}

Crop growth and production can also be increased through an improvement of the "water utilization efficiency" which is defined by Haman *et al.* (2002), as the yield per unit of water.

Data analysis

The experimental data was analyzed with SAS software.

Results and Discussion

Yield data were collected from three central rows of tomato planted plot and plant height, number of fruit per plant, and cluster number were collected from five-plant sample of the three central rows. Yield and other yield component parameters were collected and the analysis was done using the appropriate SAS software.

The two years over year analysis of tomato fruit yield and WUE shows a significant difference on the use of different furrow system as well as on different deficit levels of irrigation at $P < 0.05$. Table 2 showed that the maximum yield is obtained at conventional furrow and 100% Etc which has a significance difference compared to fixed furrow and 50% Etc but it has no significance difference compared to Alternate furrow and 75% Etc. When we see the water use efficiency in table 3, it shows high significance difference and 50%Etc and Alternate Furrow irrigation have the highest water use efficiency. Conventional furrow and 100% Etc have the least water use efficiency. Therefore, the above data analysis shows application of 75 %ETc for the amount of irrigation water applied and Alternative furrow (AF) for irrigation types perform well in accordance with yield and WUE of tomato with saving of more water and no yield reduction .It will save 25 % water applied as compared to farmer practice or application of conventional furrow system and application of 100 % ETc.

According to Patane*et al.* (2011), the adoption of DI strategies in which a 50% reduction in ETc was applied for the whole or partial growing season to save water helped to minimize fruit losses of tomato and maintain high fruit quality, also Zegbe- Domínguez*et al*. (2006) did not find a reduction in tomato fruits yield of field-grown processing cultivar through the application of deficit irrigation. Although, the effects of DI on tomato fruits yield may be different, many investigators such as Kirda*et al.* (2004) and Topcu*et al.*

(2006) have demonstrated that DI saves substantial amounts of irrigation water and increases WUE.

According to Makau*et al* (2014), less cumulative irrigation water was applied to the alternate furrow irrigation (AFI) treatment than the conventional furrow irrigation (CFI). The AFI treatment was supplied with cumulative irrigation water, which was 60-62% of that supplied to the CFI treatment. This amounted to water savings of 38-40%. The alternate furrow irrigation is a form of partial root drying (PRD), which has shown significant water savings in various crops. Sepashah and Ahmadi, (2010) have indicated in their review on PRD that irrigation water may be reduced by 30-50% with no significant yield reduction. Partial root drying caused a reduction in applied water ranging between 30 and 34% in sugar beet (*Beta vulgaris*), maize (*Zea mays*) and potato (*Solanumtuberosum*L.) without causing significant reductions in the yields Sepashah and Ahmadi, (2010); Liu *et al*., (2006). The range of water saving reported in this study is therefore similar to that reported by other studies. Irrigation water saving through use of AFI can be crucial in expanding smallholder irrigation, which can lead to increased production.

Table 2. Analysis of tomato yield

Yield (kg/ha)				
Deficit levels	Furrow type			
	AFI	FFI	CFI	Deficit mean
50 % Etc	44838	39220	46264	43441[b]
75 % Etc	46037	44223	51124	47128[ab]
100% Etc	53347	43533	58526	51802[a]
Furrow type mean	48074[a]	42325[b]	51971[a]	
LSD (5 %)	5063.7			
CV (%)	15.78			

WUE (Water Use Efficiency)

Table 3. Analysis on WUE of tomato

WUE (kg/m^3)/ha				
Deficit levels	Furrow type			
	AFI	FFI	CFI	Deficit mean
50 % Etc	27.25	20.08	14.2	20.51[a]
75 % Etc	18.65	15.08	10.47	14.73[b]
100% Etc	16.22	11.15	8.98	12.12[c]
Furrow type mean	20.71[a]	15.44[b]	11.22[c]	
LSD (5 %)	1.59			
CV (%)	14.89			

Plant height and number of tomato fruit per plant

Five plant samples from the central rows of tomato plot were taken to determine the above plant parameters. The statistical analysis showed that both furrow application system as well as deficit level had no significant effect on plant height (Table 4). Furrow type had no significant effect on fruit number but application of different deficit irrigation level affect fruit number per plant and maximum fruit number obtained through the application of 100 % ETc level and minimum number of fruit obtained from the application of 50 % ETc level but number of tomato fruit per plant obtained through the application of 75 % ETc level at par with both 100 % ETc and 50 % ETc level (Table 5).

Table 4. Analysis on plant height of tomato

Plant height (cm)				
Deficit levels	Furrow type			
	AFI	FFI	CFI	Deficit mean
50 % Etc	48.22	49.33	51.37	49.64
75 % Etc	50.83	50.03	48.50	49.79
100% Etc	49.57	48.77	52.10	50.14
Furrow type mean	49.54	49.38	50.66	
LSD (5 %)	NS			
CV (%)	6.35			

Table 5. Analysis on number tomato fruit per plant

Number of fruit per plant					
Deficit levels	Furrow type				
	AFI	FFI	CFI	Deficit mean	LSD (5 %)
50 % Etc	20	24	21	21[b]	4
75 % Etc	25	22	28	25[ab]	
100% Etc	32	26	25	28[a]	
Furrow type mean	25	24	25		
LSD (5 %)	NS				
CV (%)	21.9				

Conclusions and Recommendation

The over year analysis of the two years result of this study show that AFI is water saving irrigation method that can be suited for tomato production without a significant fruit yield loss with a maximum water productivity. Implementation of AFI will lead to 38-40% more water being available to irrigate more land. Also application of 75 % ETc level save 25 % water to without a significant effect on fruit yield of tomato with greater values of water use efficiency.

Therefore, from this experimental finding, application of alternate furrow irrigation is best water saving furrow application system as compared to conventional furrow irrigation system and application of 75 % ETc level is best mechanism to save the amount of water applied for crop production as compared to 100 % ETc level without adverse effect on yield of tomato. As the analysis of this research indicated alternate furrow irrigation with 75 % ETc level for deficit level is recommended.

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Response of Spearmint (*Menthaspicata* L.) to Deficit Irrigation

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Introduction

During the dry season water is limiting resource for spearmint production due to both physical and economical water scarcity since irrigation water is pumped from underground source from wells which need high fuel cost. To improve spearmint production and water productivity under scarce water condition, practicing deficit irrigation provides vital role in the study area.Many studies have shown that deficit irrigation to some extent can lead to increase water productivity without significantly affecting the yield of the crops under production (FAO, 2002; Fereres and Soriano, 2006). Different studies have shown that deficit irrigation can be used for the production of spearmint in areas where water scarcity is high with acceptable biomass and essential oil yield reduction. Spearmint is a suitable crop for sustained deficit irrigation management strategy (Romulus *et al*., 2009).

Therefore, there should be a means to maximize the productivity of water without significantly affecting the economic yield of a crop and increasing the irrigated land with the available water resource. So the field experiments were conducted for two off-season of 2011/2012 and 2012/2013 at Koka Central Rift Valley Ethiopia and evaluated the response of spearmint crop to deficit irrigation level to enhance water use efficiency without significantly affecting the economic yield of the crop. The practicality of deficit irrigation for spearmint was assessed based on the yield of spearmint fresh biomass, dry biomass, fresh leaf yield, dry leaf yield, essential oil yield, water use efficiency, and wet harvesting index.

Materials and Methods

Description of the Experimental Area

Field experiments were carried out at Koka Research Station of WondoGenete Agricultural Research Center Ethiopia 8°26’ N latitude, 39°2’ E longitude and 1602masl altitude during 2011/12 and 2012/13 dry season to study the response of spearmint (*Menthaspicata L.)* to deficit irrigation. Climate in this area is semiarid with total annual precipitation of 830.9mm and 131.8mm of rainfall expected in the dry season from October to March (Table 1).

Table 1. Long-term monthly climatic data of the experimental area

Month	T_{max} (^{O}C)	T_{min} (^{O}C)	RH (kpa)	U (m/s)	N (%)	RF (mm)
January	27.4	11.3	1.34	4.04	75	13.5
February	28.3	12.6	1.39	4.08	76	26.1
March	30.0	14.4	1.50	4.64	74	51.5
April	30.3	15.2	1.64	3.80	71	58.5
May	30.9	15.1	1.63	3.98	68	48.5
June	30.0	15.5	1.70	4.91	65	72.7
July	26.7	15.0	1.74	4.30	54	212.7
August	26.3	15.1	1.75	3.15	53	202.4
September	27.8	14.9	1.79	2.30	57	104.3
October	28.3	12.7	1.48	3.50	73	21.1
November	27.4	11.3	1.30	4.09	83	9.9
December	26.1	11.0	1.26	4.19	76	9.9

Source: FAO. 2005. New-LocClim, Local Climate Estimator.

The soil type of the experimental area was clay in texture and the available water holding capacity per unit meter of the soil profile in the root zone is 170 mm. Some physical characteristics of soil, such as field capacity, wilting point and total available water holding capacity of the experimental site are presented in Table 2.

Table2. Physical characteristics of soil at the experimental site

Soil texture	Bulk density (g/cm^3)	Field capacity (%)	Permanent wilting point (%)	Available water holding capacity (mm/m)
Clay	1.17	34.5	17.5	170

Treatment and Experimental Design

Randomized Complete Block Design (RCBD) with three replications was used following the procedure of Gomez and Gomez (1984). The plot size used was 3.00m X 3.00 m. Nine treatments of different deficit irrigation level were factorially combined and randomized in plots as follows: 1) 100%ETc in alternate furrow, 2) 75%ETc in alternate furrow, 3) 50%ETc in alternate furrow, 4) 100%ETc in fixed furrow 5) 75%ETc in fixed furrow, 6) 50%ETc in fixed furrow, 7) 100%ETc in conventional furrow (control), 8) 75%ETc in conventional furrow and 9) 50%ETc in conventional furrow irrigation application system.

Experimental Procedure and Management Practice

Stolen of spearmint (*Menthaspicata*) was planted on the first weeks of January 2012 for the first year and on the last weeks December 2012 for the second year trial in 50 cm apart furrows with continuous planting. The row length was 3 m and each plot consisted of six ridges and six furrows. The regular tillage and agricultural operations were followed. All other agronomic practices were kept normal and uniform for all the treatments. Crop water requirement (CWR) for the 100%ETc with conventional furrow irrigation application method was calculated using CropWat version 8.0 for windows irrigation software. Based on the calculated CWR, Irrigation water was applied according to the treatment percentage and the method of furrow irrigation. Fixed furrow and alternate furrow treatments received half of the water calculated since only half of the furrows in the plot irrigated. The irrigation water applied was measured using two inch Parshall flume. Soil samples before and after irrigation for both harvesting cycle was taken from control treatment plots to check the moisture content before and after irrigation not to go above field capacity and below allowable moisture depletion level.

Data Collection

Representative five samples in 50cm length within the middle raw were harvested 120 days after planting for the first harvest and 60 days after the first harvest for the second harvest for both seasons. After harvesting, data on fresh biomass yield and leaf fresh yield were taken. Data of dry biomass yield and dry leaf yield also collected after the sample is dried under oven at $105^{O}C$ for 2 hour. The essential oil yield also collected after the sample extracted at Wondo Genet Agricultural Research Center, Natural Product Laboratory using hydro distillation method. Based on the obtained yields and amount of irrigation used, water use efficiency and wet harvest index were calculated.

Calculation of water use efficiency and wet harvest index

Water use efficiency (WUE) indicates the seasonal increase in oil yield from a unit increase in consumed water (kg oil per m^3 water used). It is calculated as follow:-

WUE = EOY / TW =
Where: WUE is water use efficiency (kg/m^3) EOY is the essential oil yield (kg/ha)

TW is the seasonal total water use (m^3/ha)

Wet Harvest Index (WHI) is the ratio of the marketable oil yield to the harvested spearmint fresh biomass (wet mass basis). It is an indication of the oil concentration in the harvested green mint hay. It is calculated as follows:-

= WHI = EOY/ FBM
Where: WHI is the wet harvest index (decimal)

EOY is the essential oil yield (kg/ha)

FBM is the fresh biomass yield (kg/ha)

Data Analysis

The collected data were statistically analyzed using statistical analysis system (SAS) software version 9.0 with the General Linear Model (GLM) procedure. Mean separation using least significant difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

Results and Discussion

Fresh biomass

The result indicated that there was significant ($p<0.05$) difference on pooled mean of fresh biomass yield due to different levels of deficit irrigation. Maximum fresh herbage yield of 12093kg/ha was obtained due to 100%ETc with conventional furrow application method followed by 50%ETc with conventional furrow of 9335kg/ha and the least yield of 5892kg/ha was obtained when irrigation water is deficit to 50%ETc with fixed furrow irrigation water application method per harvesting cycle (Table 3). Application of deficit irrigation to 50%ETc with fixed furrow method reduce yield of fresh biomass by 51.3% from the control whereas, deficit irrigation to 50%ETc with conventional furrow method reduce the fresh biomass yield by 22.8%. This may be due to creeping nature of the crop; localized moisture stress on non irrigated furrows and sides will reduce plant population per area. The study indicated the fresh biomass yield decrease with increase in deficit level. This indicated that the water applied based on crop water requirement has a direct influence on fresh biomass production. This is in agreement with former findings of Romulus *et al*. (2009) on spearmint, Bahreininejad*et al*. (2013) on *Thymus daenensis* and Said-Al Ahl and Hussein (2010) on organo plant and Sharmin*et al*. (2009) on Japanese mint.

Dry biomass

Different deficit levels and furrow application method has a significant influence ($p<0.01$) on dry herbage biomass production. The mean dry biomass at different deficit level showed decreasing trend due to decreasing of irrigation water applied. Generally the maximum dry biomass yield of 3746kg/ha per harvesting cycle was obtained due to 100%ETc with conventional furrow application method. Whereas, the least dry biomass yield of 1828kg/ha per harvesting cycle was obtained due to deficit irrigation to 50%ETc level with fixed furrow application method. This shows a decreasing of 51.2% from the control treatment. Next to the control, 75%ETc with conventional furrow application treatment scored higher dry biomass yield of 2611kg/ha per harvesting cycle (Table 3). The trend of dry biomass production fairly decreasing as the amount of water applied decreases. This is due to higher biomass production for well irrigated plots since irrigation was applied based on crop water requirement and moisture stress is reduced.

Fresh leaf yield

The pooled mean of two year data showed that deficit irrigation had influenced fresh leaf yield production significantly ($p<0.05$). The fresh leaf yield production demonstrated decreasing trend due to increasing deficit level. The highest fresh leaf yield of 8133kg/ha per harvesting season was obtained in control treatment followed by 50%ETc with conventional furrow application method treatment yielding 6520kg/ha per harvesting cycle which is statistically the same with both control and 75%ETc with conventional furrow treatments (Table 3). As the amount of water applied decrease to 50%ETc with conventional furrow application method, fresh leaf yield was reducing only by 19.8% from the control. While the minimum fresh leaf yield of 4214 kg/ha, per harvesting cycle obtained when irrigation water is deficit to 50%ETc and applied in fixed furrow method that indicates that the yield of fresh leaf yield reduced by 48.2% from the control treatment. This may be due to fixed furrow irrigation method restricts the expansion of the creeping spearmint plant by constantly creating localized water stress with un-irrigated furrows.

Dry leaf yield

There was highly significant difference in dry leaf yield at 1% level of significance due to different levels of deficit irrigation. Maximum dry leaf yield of 2441.1kg/ha per harvesting season was obtained when spearmint irrigated with 100%ETc with conventional furrow application method which fairly decrease with increased level of deficit level, reaching minimum dry leaf yield of 1206.8kg/ha per harvesting season when the crop is irrigated with 50%ETc with fixed furrow application method (Table 3). This leads to a decrease of 50.6% than the maximum yield obtained by the control treatment.

Table3. Two-year average yield of spearmint due to deficit irrigation per harvesting cycle 2011/12 and 2012/13

Treatment	Fresh biomass (kg/ha)*	Dry biomass (kg/ha)**	Fresh leaf yield (kg/ha)*	Dry leaf yield (kg/ha)**
AF 100%ETc	8519^{b}	2441^{b}	5862^{bc}	1580.9^{bc}
AF 75%ETc	8429^{bc}	2433^{b}	5951^{b}	1699.3^{b}
AF 50%ETc	7181^{bc}	2080^{bc}	5139^{bc}	1390.1^{bc}
FF 100%ETc	8510^{b}	2043^{bc}	5754^{bc}	1254.2^{c}
FF 75ETc%	8627^{b}	2558^{b}	6152^{b}	1742.5^{b}
FF 50%ETc	5892^{c}	1828^{c}	4214^{c}	1206.8^{c}
CF 100%ETc	12093^{a}	3746^{a}	8133^{a}	2441.1^{a}
CF 75%ETC	9073^{b}	2611^{b}	6315^{b}	1767.5^{b}
CF 50%ETc	9335^{b}	2396^{bc}	6520^{ab}	1553.7^{bc}
CV (%)	17.3	13.9	16.3	15.4
$LSD_{0.05}$	2586.5	590.7	1692.7	432.08

Essential oil yield

Essential oil yield is the most economic yield of spearmint which is a composed of 21 components. The major constituents are carvone, d-limonene and dihydrocarvone (Jasim*et al.*, 2007). The pooled mean of two year data showed that deficit irrigation was significantly ($p<0.01$) influenced the essential oil yield produced (Table 4). The yield vary from 37.0kg/ha per harvesting cycle in control treatment to 22.2kg/ha per harvesting cycle in 50%ETc with fixed furrow application method treatment. The result showed that deficit irrigation to 50%ETc with fixed furrow application method and 50%ETc with alternate furrow application method reduce the essential oil production by 40% and 39.2%

respectively. However, deficit irrigation in conventional furrow application to 50%ETc reduces the oil yield by only 14.9% which is statistically the same with the oil yield obtained by the control treatment. Generally, essential oil yield shows decreasing trend as the amount of irrigation water reduced. The result indicated that there is positive relation with water content of the soil and the essential oil yield. This is in line with former reports of Bahreininejad*et al.* (2013) on *Thymus daenensis*, Said-Al Ahl and Hussein (2010) on oregano and Sharmin *et al*. (2009) on Japanese mint.

Wet harvesting index

The pooled mean of two year data showed that the influence of different level of deficit irrigation was not significantly affected the wet harvesting index of spearmint (Table 4). However, higher average value of $3.88x10^{-3}$ due to deficit irrigation to 50%ETc with fixed furrow application method and minimum average wet harvesting index of $3.16x10^{-3}$ in control treatment. Wet harvesting index was not significantly influenced both years in both harvesting cycle.

Water use efficiency

In moisture stressed area, the water use efficiency is among the main parameters to decide the level of irrigation water amount applied as far as agricultural water management is concerned. It is an increase in the economical part of the crop yield due to a unit increase of irrigation water amount applied. Our finding showed fairly an increasing trend as the deficit level increase due to reduction of applied irrigation water amount especially within the same irrigation methods. The pooled mean of two year study showed that different levels of deficit irrigation significantly ($p<0.01$) influenced water use efficiency. Better water use efficiency of $16.3x10^{-3}kg/m^3$, $15.9x10^{-3}kg/m^3$ and $15.9x10^{-3}kg/m^3$ was recorded at 50%ETc with alternate furrow, 50%ETc with fixed furrow and 50%ETc with conventional furrow treatments respectively (Table 4). In contrary to this, lower water use efficiency of $9.4x10^{-3}kg/m^3$, $9.9x10^{-3}kg/m^3$, $10.9x10^{-3}kg/m^3$ and $11.1x10^{-3}kg/mm$ was achieved when spearmint was irrigated by 100%ETc with fixed furrow, 100%ETc with conventional furrow, 75%ETc with conventional furrow and 100%ETc with alternate furrow treatments respectively. Water use efficiency was increased by 68.4%, 65.4% and 63.3% from the control treatment due to deficit irrigation to 50%ETc with alternate furrow method, 50%ETc with fixed furrow method and 50%ETc with conventional furrow method. Water use efficiency increased as amount of water applied reduced due to deficit irrigation except in 50%ETc with conventional furrow treatment, which is more efficient than the lower irrigation water receiving treatments of 75%ETc fixed furrow and 75%ETc alternate furrow treatments. The result indicated that deficit irrigation practice to enhance water use efficiency in spearmint production. This is in agreement with former report FAO (2002) on wheat, cotton and other crops, Ismail (2010) on bird pepper (*Capsicum annuum* L.) production, Romulus *et al*., (2009) on spearmint and R. Huang (2006) on maize production.

Table4. Two year average yield of spearmint due to deficit irrigation per harvesting cycle 2011/12 and 2012/13

Treatment	Essential oil yield (kg/ha)**	Wet harvest index (decimal X10^3)	Water Use Efficiency (kg/mm X10^3)**
AF 100%ETc	29.4bc	3.62	11.1cde
AF 75%ETc	27.2bcd	3.41	12.8bcd
AF 50%ETc	22.5d	3.33	16.3a
FF 100%ETc	25.4cd	3.23	9.4e
FF 75ETc%	28.9bc	3.56	13.9abc
FF 50%ETc	22.2d	3.88	15.9ab
CF 100%ETc	37.0a	3.16	9.9de
CF 75%ETC	29.8bc	3.40	10.4de
CF 50%ETc	31.5ab	3.55	15.9ab
CV (%)	12.2	9.9	15.0
LSD0.05	5.96	ns	3.35

*Means with the same column followed by the same letters are not significantly different. *significant ($p<0.05$), **significant ($p<0.01$), ***significant ($p<0.001$), ^{ns} not significant ($p<0.05$).*

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Response of Hararghe Coffee Variety to Soil Moisture Stress at Seedling Stage

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Introduction

Drought stress is the main climatic limitation due to the erratic nature of rainfall amount and distribution, and the increasing frequency of drought. This production constraint, which is expected to become more challenging, inhibits a profound limitation on the growth, yield and quality of coffee. Overall, drought is the major climatic limitation for coffee production (Da Matta and Ramalho 2006).

Drought tolerant species/varieties generally differ morphologically and/or physiologically, with mechanisms allowing greater production under restricted water supply 10. In line with this, some varieties of coffee were found to differ in their growth responses to water deficit in Uganda, Zimbabwe, Colombia, and Brazil. The existence of high genetic diversity for arabica coffee for yield and yield components, disease resistance, and other traits related to drought resistance has also been reported in Ethiopia. Varietal differences in biomass allocation to the stems and leaves, and leaf area were reported for coffee.

The presence of various strategies for tolerance to drought stress among populations of wild coffee growing in different agro-ecological zones of Ethiopia was also indicated. The specific leaf area, leaf dry weight, and leaf water content have been indicated as indirect indicator of drought resistance in coffee. A study on Robusta coffee showed that the root systems were deeper in drought-tolerant clones than in drought-sensitive ones and another study associated drought tolerance with a larger root dry mass.

Coffee is sensitive for moisture at seedling stage (from seedling up to 2 years old) than young stage (after 2 years old). Therefore, we need to identify and analysis of coffee genotype association with drought tolerance especially at the seedling stage to overcome the stress period. In this study released and promised Harerege coffee genotype were used to evaluate their performance for moisture stress at seedling stage. The objective of this activity is to identify drought tolerant coffee varieties for moisture stress areas. The ultimate goal of the study was to identify coffee genotype helpful for combating water stress at early stage.

Materials and Methods

Description of the experimental area

The experiment was conducted at Jimma research center for the consecutive two years in a green house and field condition. The Jimma research center is located at $7^0$46' N latitude, $36^0$0' E longitude, and at an altitude of 1753m above sea level. The center receives an average annual rainfall of about 1530mm with monthly mean maximum and minimum temperatures of 25.9^0C and 11.3^0C, respectively.

Experimental material and procedure

For these study, Harerege coffee cultivars were selected from the known, released, coffee berry disease resistant selections that involved 14 Harerege and 1 check cultivar (i.e. H-618/98, H-622/98 , H-674/98 , H-739/98 , H-822/98, H-823/98 , H-856/98, H-981/98, H-980/98, H-968/98, H-929/98, H-915/98, H-858/98, H-857/98 and 74110) respectively, selected from three types of canopy classes, were tested for their responses to water stress in a Randomized Complete Block Design (RCBD), with the varieties completely randomized within each of the four blocks. Each experimental plot contained 30 plants. As per nursery recommendations, each seedling of these varieties was grown in a growth medium of topsoil, compost and sand mixture contained in black polythene bag. Watering (at 2-day interval) and all other routine nursery management activities were based on nursery recommendations from JARC until eight months. Eight months old seedlings were subjected to water stress by withholding watering under open sunlight conditions for one month. During the stress period, the entire seedbed was covered every night and during rainy or foggy conditions with transparent white plastic sheets. Following moisture stress, 20 seedlings were left in each experimental unit from the destructive data measurement for stress responses and re-watered for 15 days to observe the recovery capacity of the varieties.

Data collected

Sensitivity of coffee genotypes to soil drying was assessed visually at two-day-intervals since the first wilting symptom was observed. The degree of leaf folding or wilting was scored using 1 to 5 during morning and noon score at 1:00 pm and at 8.00am respectively. Each plant in a plot was assessed and the plot was given a mean stress score value. Besides, the ability of plants to recover during the night time and maintain leaf turgidity early in the morning on the next day was also considered in the evaluation.

After imposition of stress for 30 days, seedlings were re-watered, at every three day intervals for three weeks after the commencement of re-watering; number of plants producing new growths (flushes of buds and new leaves) and no of plants recovered and died was counted to estimate genotypic differences in rate of recovery from the soil drying treatment during recovery period.

Leaf retention was also measured from total no of seedling before stress and total no of shaded leaves after stress, accordingly:

$$\text{Leaf retention} = \frac{\text{T.Number of leave before stress - Number of leaf shaded after stress}}{\text{Total Number of leave before stress}} \text{ X100}$$

Non- destructive plant growth parameters such as plant height, leaf area, stem girth, internodes length, growth rate, number of wilted seedlings and percentage of rolled leaves were recorded from a central parts of each plot. Leaf area was calculated by the methods adopted by Yakob*et al.* (1993). It was calculated.

$$Y = L \times B \times K$$

Where, Y – Estimated leaf area (cm^2), L – Leaf length (cm)
B – Maximum leaf breadth (cm) and K – Correction factor = 0.7

Likewise, destructive plant growth parameters such as fresh and dry weight of shoots/ stems, roots and leaves; root to shoot ration length of tap roots and lateral roots, root volume and total dry matter were recorded by uprooting six randomly selected seedling next to the border from each plots.

Leaves immediately detached from the plant used for the estimation of leaf relative water content (RWC), leaf water deficit and leaf thickness. For estimation of relative leaf water content in the leaf, discs of leaf tissue were weighted to get the fresh weight (wf), soaked in water for one day to eliminate any water deficit and reweighed to get turgid weight (wt) and finally oven dried at 70 ^{0}c for 24 hours and weighed to get the dry weight (wd). RWC was obtained from the equation given below (Baker, 1984):

$$RWC = \frac{Wf - Wd}{Wt - Wd} \times 100 \qquad LWD (\%) = 100 - RWC$$

Leaf thickness (LT) was calculated by (Bowyer and Danson 2004) Lt = Wd/Y

Data collected were statistically analyzed using statistical analysis system (SAS) software version 9.0 using the general linear programming procedure (GLM).

Results and Discussion

Stress Scoring

The analysis of variance revealed that there is a significance differences among Harerege coffee genotypes on morning and noon scoring imposing for thirty days under water stress condition. However, there was no significance difference for well-watered treatment since all variety maintains its leaf turgidity (Table, 1). Variety H-857/98 and H-981 showed high moisture stress tolerance symptoms where as variety H-915/98 and H-929/98 are sensitive for moisture stress by visual scoring method. From the data H-857/98, H-981/98, H-856/98 and 74110 shows moisture stress tolerance symptoms. H-822/98, H-858/98, H-618/98, H-823/98 and H-674/98 show a moderate soil tolerance level. Whereas, variety H-622/98, H968/98, H-739/98, H-980/98, H-929/98 and H-915/98 are show moisture stress sensitive symptoms.

Table1. Morning and noon leaf wilting score of Harerege coffee genotypes

Variety	Morning score		Noon score	
	Well-watered (1-5 Scale)	Water stressed (1-5 Scale)	Well-watered (1-5 Scale)	Water stressed (1-5 Scale)
H-618/98	1	1.86^{c-g}	1	1.93^{b-d}
H-622/98	1	2.01^{b-f}	1	2.67^{a}
H-674/98	1	1.96^{c-f}	1	2.01^{b-d}
H-739/98	1	2.31^{a-c}	1	2.31^{a-c}
H-822/98	1	1.81^{d-g}	1	1.89^{cd}
H-823/98	1	1.89^{c-g}	1	1.91^{cd}
H-856/98	1	1.78^{e-g}	1	1.88^{cd}
H-981/98	1	1.67^{fg}	1	1.78^{cd}
H-980/98	1	2.25^{a-d}	1	2.31^{a-c}
H-968/98	1	2.15^{b-f}	1	2.24^{a-c}
H-929/98	1	2.43^{ab}	1	2.58^{ab}
H-915/98	1	2.56^{a}	1	2.67^{a}
H-858/98	1	1.82^{d-g}	1	1.95^{b-d}
H-857/98	1	1.49^{g}	1	1.65^{d}
74110	1	1.79^{d-g}	1	1.92^{b-d}
LSD (0.05)	-	0.46	-	0.66
CV %	-	13.84	-	18.62

**** Figures followed by same letters with in a column are not significantly different at P = 0.05*

Plant growth parameters

Root dry matter yield

There were a significant variability among Harerege coffee genotypes in dry root biomass under well watered conditions. Accordingly, the heaviest dry root were produced from H-929, and followed by H-915. Whereas, under stressed treatments, non-significance difference were observed among genotypes, but heaver dry root were recorded from H-980 and H-981 and medium from H-857 (Table, 2). Moreover, When compared stressed to well-watered plants, the maximum dry root weight loss was measured from H-915 (69.85% loss), H-929 (64.86% loss), H-823 (64.1% loss), H-74110 (61.8% loss) and H-968 (60.9% loss), while the minimum dry root reduction was visible in H-857 (17.3 loss), H-981 (13.1%) and H-980 (17.2%) (Table 2).This implies that the low reduction in root dry weight may associate with accumulation of more biomass to roots than shoot, it was true in the case of variety H-981, it was highly maintained its root development under prolonged moisture stress by exhibiting greater dry root weight and minimum magnitude of dry root reduction, thereby, extracting limited water from the bottom of pots.

Shoot dry matter yield

There were no significance differences among coffee genotypes under both well-watered and stressed conditions. Even though statistically not significant,H-857 and H-856 had produced heaver dry shoot biomass and the least produced from H-915 and H-929 under water stress conditions (Table 2). When compared stressed to well-watered coffee seedlings, H-929 (53.7% loss), H-915 (53.4% loss), and H-823 (47% loss) coffee genotypes lost maximum shoot dry weight under stressed conditions ,while the least shoot dry weight loss were observed in H-856 5%), 74110 (13.4%),H-618 (16.7%).

Table 2. Root dry and shoot dry biomass yield of Harerege coffee genotypes

Variety	Root dry weight (g/plant)		Shoot dry matter yield (g/plant)	
	Well-watered	Water stress	Well-watered	Water stress
H-618/98	2.51[de]	1.69	5.25	4.37
H-622/98	2.81[c-e]	1.37	5.78	4.53
H-674/98	2.82c-e	1.41	6.18	3.70
H-739/98	3.91[bc]	1.67	5.84	3.67
H-822/98	2.68[c-e]	1.60	5.39	3.61
H-823/98	3.01[b-e]	1.08	6.02	3.15
H-856/98	2.67[c-e]	1.34	5.38	5.08
H-981/98	2.41[e]	2.09	7.37	4.32
H-980/98	2.96[c-e]	2.45	6.09	4.42
H-968/98	3.44[bc]	1.34	5.21	3.39
H-929/98	5.9[a]	2.07	9.09	4.20
H-915/98	4.32[b]	1.30	6.42	2.99
H-858/98	1.95[e]	1.47	4.22	3.00
H-857/98	1.89[e]	1.56	4.01	5.27
74110	2.56[e]	0.98	4.87	4.21
LSD (0.05)	1.33	ns	ns	ns
CV %	26.18	30.70	27.5	31.40

**** Figures followed by same letters with in a column are not significantly different at P = 0.05*

Total Dry Matter Yield

As shown in table 3, there were no significant differences among coffee genotypes in total dry biomass under stressed treatments, but H-857 (6.88g), H-980 (6.8g), H-856 (6.4g), H-618 (6g) and H-981(6g) coffee genotypes produced maximum total dry biomass and minimum produced from H-915 (4.3g) and H-858 (4.4g) genotypes. This implies that the total dry biomass produced from H-857 was not affected by soil moisture when compared to well water treatment; rather it accumulates maximum dry total biomass under moisture stress conditions than well water.

Root to shoot ratio

The shoot to root was significantly varied among 15Harerghe coffee genotypes under stressed conditions. Accordingly, the highest root to shoot was produced from H-929(0.55g/g) and H-980(0.55g/g) under water stressed conditions while H-981 (0.39g/g) , H-857(0.31g/g) and H-823 (0.4g/g) had produced moderate root to shoot ratio, where as the least root to shoot was produced from 74110(0.23g/g)..

Table 3.Total dry biomass and root to shoot ratio of Harerege coffee genotypes

Variety	Total dry biomass (gm/plant)		Root to shoot ratio	
	Well watered	Water stress	Well watered	Water stress
H-618/98	7.763bc	6.067	0.4657bcd	0.38919c
H-622/98	8.587bc	5.897	0.48789bcd	0.31756cd
H-674/98	9bc	5.107	0.43121bcd	0.43942abc
H-739/98	9.75bc	5.34	0.61551ab	0.47407abc
H-822/98	8.07bc	5.21	0.50661abcd	0.44011abc
H-823/98	9.027bc	4.56	0.4993abcd	0.45085abc
H-856/98	8.05bc	6.433	0.48312bcd	0.32073cd
H-981/98	9.777bc	6.067	0.32973d	0.39501c
H-980/98	9.057bc	6.877	0.51885abcd	0.55314ab
H-968/98	8.65bc	4.755	0.68684a	0.40131bc
H-929/98	14.99a	6.577	0.60721ab	0.56195a
H-915/98	10.747ab	4.317	0.69241a	0.45359abc
H-858/98	6.173c	4.477	0.45881bcd	0.44636abc
H-857/98	5.57c	6.833	0.41117cd	0.31968cd
74110	7.757bc	5.17	0.5938abc	0.23048d
LSD (0.05)	4.28	ns	0.19	22.86
CV %	28.9	19.77	22.3	0.16

*** *Figures followed by same letters with in a column are not significantly different at P = 0.05*

Physiological Parameters

Leaf area

Fifteen genotypes were not differed in leaf area under both watered and stressed seedlings (Table 4). Even though statically non-significant among genotypes, widest leaf area had produced from H-968 (402.5mm2), followed by H-822 (398mm^2), 74110 (390mm^2) while H-981 (251mm^2), and H-915/98 had produced the narrow leaf area under well-watered conditions. Under stressed treatments, H-822 (364.8mm^2), H-980 (317mm^2), H-856 (325mm^2) had produced wide leaf areas while H-857 (238.9mm^2), H-739 (mm^2), H-858 (189.3mm^2), 74110 (209.7mm2) coffee genotypes were produced narrow leaf area.

Leaf thickness

Among all coffee seedling genotypes there were considerable variability in leaf thickness under stressed treatments (Table 4). Under well watered treatments the thickest leaf was recorded from H-915, H-929, H-968, and H-981 genotypes, while the thin coffee leaf was produced from H-823, H-622, H-968, genotypes. Similarly, in stressed treatment, H-915 had produced the thickest leaf and H-981 produced moderate leaf thickness. This implies that all genotypes continued in reducing their leaf thickness as drought progresses. However, some Hararghe coffee genotypes cope with increasing soil moisture loss in reducing their leaf area. For example, H-857 was exhibited minimum leaf thickness loss and it may adjust for drought in reducing its leaf area.

Table 4. Leaf thickness and leaf area of fifteen Harerege coffee genotypes

Variety	Leaf thickness (g/mm^2)		Leaf area (mm^2)	
	Well-watered	Water stress	Well-watered	Water stress
H-618/98	0.0070[c-e]	0.0046[d]	289.4	241.00
H-622/98	0.0069[c-e]	0.00463[d]	330.3	262.47
H-674/98	0.0066[de]	0.00515[b-d]	325.6	281.80
H-739/98	0.0109[a-c]	0.00499[b-d]	251.0	215.53
H-822/98	0.0068[de]	0.00606[a-c]	392.2	364.77
H-823/98	0.0058[e]	0.00454[d]	338.5	352.00
H-856/98	0.0075[b-e]	0.00480[cd]	345.0	326.47
H-981/98	0.0120[a]	0.00517[b-d]	281.1	300.78
H-980/98	0.0105[a-d]	0.00636[ab]	333.5	317.00
H-968/98	0.0060[e]	0.00426[d]	402.5	246.47
H-929/98	0.0110[a]	0.00494[cd]	386.6	278.37
H-915/98	0.0126[a]	0.00690[a]	238.7	270.56
H-858/98	0.0069[c-e]	0.00497[b-d]	306.6	189.28
H-857/98	0.0056[e]	0.00462[d]	374.8	238.85
74110	0.0065[ed]	0.00463[d]	390.6	209.74
LSD (0.05)	0.004	0.0014	ns	ns
CV %	29.00	16.37	27.17	31.80

****Figures followed by same letters with in a column are not significantly different at P = 0.05*

Relative leaf water content

The present study revealed that, all genotypes showed an average relative water content ranging from 69% (H-981) - 90 %(H-929), While H-857 produced good relative leaf water content, but the varieties are not statistically different from each other's (Table 5). Previous studies have shown that when leaves are subjected to drought, they exhibit large reductions in relative water content (Decov *et al.,* 2000; Efeoglu *et al.,* 2009; Nayyar; Gupta, 2006) but from table 5 results the genotype try to tolerate the drought without reducing their leaf water content. Additionally, genotypes and their interactions not significantly affected relative water content in all varieties, as stress intensified.

Leaf retention

There were no significance difference between genotypes in leaf retention under stress condition, accordingly, most genotypes retained their older leaves stead of shedding and sprouting new; however 100% leaf retention was realized from 74110 and followed by H-857 with high score of 92% leaf retention and only 8% leaf shade was exhibited while H-929 had almost shaded about half of its leaves. In field-grown clones of Robusta coffee, leaf shedding in response to drought stress occurred sequentially from older to younger leaves, suggesting that the more drought-sensitive the clone, the greater the extent of leaf shedding (DaMatta, 2004).Greater leaf retention capacity and lower rate of leaf fall may be an important attribute linked to drought tolerance and may have a positive impact on crop yield under water stress conditions (Ludlow and Muchow, 1990; Rosario *et al*., 1992; Joshi, 1999; Lima *et al*., 2002).

Rate of recovery

From the result in table 5, it was observed that there is no significant difference between varieties for rate of recovery after re-watering. Generally, all genotypes recovered well after resuming irrigation. However, of the accessions seriously affected by moisture stress, only H857/98 and 74110 recovered quickly from the effect of moisture stress, while H915/98 recovered more slowly. Moore (1987) noted that plant recovery ability after drought is more important than drought tolerance. In the present study, recovery ability was rapid in some drought-susceptible accessions, such as H622/98. This observation is in agreement with Sundara (1987), who reported that recovery could be rapid, with normal growth resumed, if moisture stress has not adversely affected plant biomass and roots.

Table 5. Relative leaf water content, leaf retention and rate of recovery of fifteen Hareredge coffee genotypes

Variety	Relative leaf water content (g/g)	Leaf retention (%)	Rate of recovery (%)
H-618/98	89.69	81.00	95.83
H-622/98	90.01	62.33	100.00
H-674/98	87.53	75.33	100.00
H-739/98	84.32	68.00	95.83
H-822/98	83.15	75.33	95.83
H-823/98	86.07	87.00	100.00
H-856/98	83.81	83.00	100.00
H-981/98	69.37	89.00	100.00
H-980/98	83.38	71.00	95.83
H-968/98	88.89	69.00	100.00
H-929/98	91.09	59.33	91.67
H-915/98	86.12	68.33	87.50
H-858/98	82.66	73.33	100.00
H-857/98	87.72	92.00	100.00
74110	86.19	100.00	100.00
LSD (0.05)	Ns	ns	ns
CV	11.11	23.06	7.71

****Figures followed by same letters with in a column are not significantly different at P = 0.05*

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Water Requirement and Optimal Irrigation on Onion Yield and Productivity

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Introduction

Water is essential for crop production and best use of the available water must be made for efficient crop production and high yields. This requires a proper understanding of the effect of water-rainfall and irrigation- on crop growth and yield under different growing conditions (FAO, 1986). Irrigation can be defined as replenishment of soil water storage in plant root zone through methods other than natural precipitation. Irrigation is seen to have found its roots in the history of mankind since earliest beginning. It helps reduce the uncertainties, particularly the climatic uncertainties in agriculture practices. The problem of irrigation consists of when to irrigate, and how much to irrigate.

Crop water requirements (CWR) encompass the total amount of water used in evapotranspiration. FAO (1992) defined crop water requirements as 'the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment'. The irrigation water requirement represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and water to compensate for non-uniformity of water application. For the calculations of the Crop Water Requirements (CWR), the crop coefficient approach is used (Allen et al., 1998).

The onion (*Allium cepa* L.) crop belongs to the plant family of Alliaceae and is one of the earliest vegetable crops grown. The use of onion is worldwide among all nationalities and cultures. It is available in most markets of the world in all seasons of the year. Onion is used widely in Ethiopia and many parts of the world for flavoring and seasoning foods, as vegetable and for medication. Thus, onions form an essential part of the daily diet, creating year round demand.

Irrigation scheduling is directly related to profitable onion production and sustainable agricultural practices. Research at the Oregon State University Malheur Experiment Station has demonstrated that onion yield and grade are very closely related to irrigation practices, especially the criterion used to schedule irrigations. Careful attention to irrigation scheduling can help assure high onion yields, better bulb storability, and better internal quality. Onions need frequent irrigation to maintain high soil moisture (Shock et al., 1998). Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas (Vučić, 1976; Hedge, 1986; Olalla et al., 1994; Al- Jamal et al., 1999). If shortage of readily available soil water is eliminated and the technological and biological characteristics of the crop are taken into account, it is possible to achieve high and stable yields of irrigated onions, at the level of 40 t ha-1 or higher (Halim and Ener, 2001; Meranzova and Babrikov, 2002; Kanton et al., 2003; Pejić et al., 2008). Therefore, the aim of this research is to estimate the crop water requirement of onion and to evaluate the responses of onion to irrigation regime (when and how much) and also to identify WUE under optimal irrigation regime.

Materials and Methods

Site Description

The study was conducted at Holetta Research Center. The study area lies at an altitude of 2069 - 3378 meters above sea level and at a latitude range of $8^0$56'N to $9^0$13'N and longitude range of $38^0$24'E to $38^0$36' E. The annual rainfall of the study area ranges between 818-1226 mm. The climate of the study area is described with the air temperature ranging from 6^0C to 23^0C with the mean of 14 ^{0}C.

Experimental procedure and management practice

Onion *(Allium cepa),* Adama Red variety were planted on 10^{th} and 15^{th} of February 2013 and 2014, respectively. Planting was performed by hand. Plot size was 1.4 m wide and 4 m long. The distances between plants are 0.1 m and the distance between each band size is 0.6m. The distances between plots and between replications were 1 m and 1.5 m respectively. Onion plots were fertilized with the recommended rate of 200kg/h P as DAP and 150kg/ha N as Urea during sowing and flowering stage. Plants were initially grown in nursery and transplanted to the experimental plot and it was well-watered to have suitable germination and favorable plant stand. Furrow irrigation method was used, and the amount of water applied was measured using Parshall flume. Irrigation scheduling was done based on soil water depletion replenishments using the CROPWAT program. Crop water requirement was calculated using CROPWAT program based on the FAO Penman-Monteith method. Soil water level was monitored by using the gravimetric soil moisture content determination method. Soil sample was taken from well irrigated plots just before irrigation to check the moisture content at management allowable depilation level and two day after irrigation to check the moisture content to field capacity level. The regular tillage and agricultural operations of growing onion of the location were followed. All other agronomic practices were kept normal and uniform for all the treatments including pre-irrigation and one irrigation after germination.

Experimental set up and treatment application

Irrigation treatments included five levels of soil water depletion depending on FAO soil moisture depletion level. These are Available Soil Moisture Depletion Level (ASMDAL), 60% ASMDAL, 80% ASMDAL, 100% ASMDL, 120 % ASMDAL and 140% ASMDAL. Irrigation scheduling was based on the percentage depletion of available soil water in the root zone. The experimental treatments were laid out in Randomized

Complete Block Design (RCBD) with three replications, in which the soil moisture depletion levels (SMDL) was randomly assigned to the experimental plots.

Table 1.Treatment setting for field experiment

Treatment	Description	Irrigation Applied (mm)
T1= ASMD1	60% ASMDL	258.61
T2= ASMD2	80% ASMDL	344.81
T3= ASMD3	ASMDL*	431.01
T4= ASMD4	120% ASMDL	517.21
T5= ASMD5	140% ASMDL	603.41

**ASMD is available soil moisture depletion level according to FAO (33)*

Data collection

The collected data includes metrological and climatic data (rainfall, maximum and minimum temperature, relative humidity, wind speed, sunshine hour); physical properties of soil and water; date of planting, emergence, flowering, fruiting and maturity; date of irrigation; soil moisture content before irrigation; amount of irrigation applied in each irrigation event; plant height and yield. The method of data collection was both primary and secondary data collection methods.

Crop water requirement

With the aid of the CROPWAT software, the crop water requirement of onion calculated for the various growth stages. The data inputted were historic (1981-2009) monthly climatic data meteorological station, soil physical properties of the irrigation scheme such as texture, field capacity, permanent wilting point and available water capacity as well as the infiltration capacity of the soils. Other inputs required by the model include the crop type, information on growth stages and their periods up to maturity, effective rooting depth and days to maturity. The summarized climate information and soil physical properties of the study area and the calculated crop water requirements of onion are shown in the Table 2 and Table 3.

Water productivity

Water productivity was estimated as a ratio of above ground dry matter at maturity or grain yield to the total Etc through the growing season and it was calculated using the following equation (Zwart and Bastiaanssen, 2004).

CWP =(Y/ET) …….equation 1

Where, CWP is crop water productivity (kg/m^3), Y crop yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Data Analysis

Data collected were statistically analyzed using statistical analysis system (SAS) software version 9.0 using the general linear programming procedure (GLM). Mean separation using least significant difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

Table 2. Long-term climatic data of Holeta Catchment (1981-2009)

Month	Maximum Temperature (^{0}C)	Minimum Temperature (^{0}C)	Relative humidity (%)	Wind speed (km/hr)	sun shine (hr)	Rainfall (mm)	Reference Eto (mm/day)
Jan	23.4	3.7	50	4.15	8.53	18.45	3.61
Feb	24.1	5.3	50	4.58	8.33	34.95	3.98
March	24.5	7.0	52	4.93	7.35	58.85	4.17
April	23.4	8.5	56	4.91	6.69	76.49	4.03
May	24.5	8.1	55	4.76	6.96	64.54	4.02
June	22.4	7.8	68	3.45	5.34	115.91	3.21
July	20.3	9.2	80	3.11	3.03	245.78	2.57
August	19.5	9.1	81	2.87	2.95	257.27	2.57
September	20.5	7.6	72	3.30	4.59	126.31	2.99
October	21.8	4.7	56	4.23	7.42	22.84	3.59
November	22.6	2.3	50	4.42	9.00	9.71	3.59
December	23.1	2.2	49	4.10	8.95	5.61	3.44
Mean	22.5	6.3	60.0	4.1	6.6	86.4	3.5

Table 3.Soil data for the study area at different soil depth

Soil sample	Texture	Bulk density (g/cm^3)	Field capacity (%)	Permanent Wilting point (%)	Total available water
30cm depth	Clay loam	1.1	31.52	22.19	30.80
60cm depth	Clay loam	1.1	32.56	25.03	49.70

Results and Discussion

Crop water requirement

The result showed the crop water requirement of onion in the study area is 431mm and the net irrigation requirement is 329.12mm (Table 4).

Table4. Crop water requirement and net irrigation requirement

Growing stage	Days	Kc	CWR	Net IR
Initial	15	0.7	47.25	44.39
Development	30	0.88	117.93	91.09
Mid	30	1.05	132.92	99.83
Late	35	1	132.91	93.81
Total	110		431.01	329.12
Planting date (dd/mm) = 15/02				

Doorenbos and Kassam (1986) have reported that onion yields of 35 - 45 ton/ha could be obtained with 350 - 550 mm of water using furrow irrigation. They advise that soil water depletion should not be allowed to drop below 25% of available water for optimum yield. Results are also in agreement with those of Halim and Ener (2001) who recorded seasonal ET of onion in irrigated conditions from 394 to 438 mm and from 177 to 266 mm in conditions without irrigation for a yield of 35.8– 43.1 and 13.9 – 17.4 ton/ ha, respectively, under arid climatic conditions in Turkey. Kadayifci et al. (2005) also reported that seasonal ET of onion in Turkey ranges from 350 - 450 mm for bulb yield of 40 ton/ha.

Figure 1 shows same rainfall pattern in all three data (average of 29 years, study year and locClim data). But the rainfall at the experimental year is below the average of 29 years and locClim data). This indicates the average rainfall obtained during the experimental year is low. The maximum rainfall is obtained during June, July and August. The evapotranspiration curve lies above the rainfall except the main rainy season from June to September.

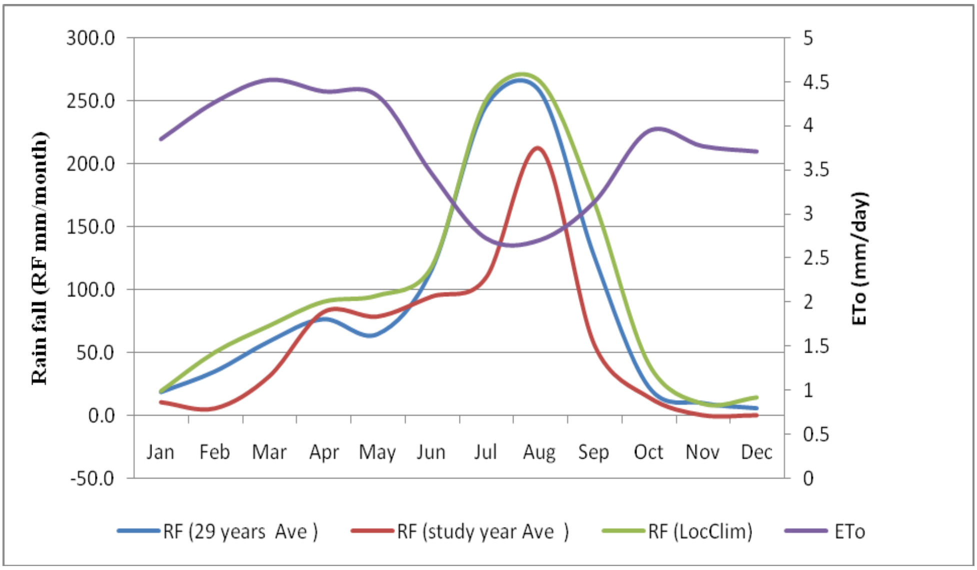

Figure1. Monthly Rainfall and Eto data of the study area

Figure 2 showed that the evapotranspiration of the area is above the rainfall from January –May and from October - December. From mid of October - mid of February and mid of February –May and half of October is dry period and moist period of the study area respectively. During this period irrigation is needed depending on the crop type and growing period.

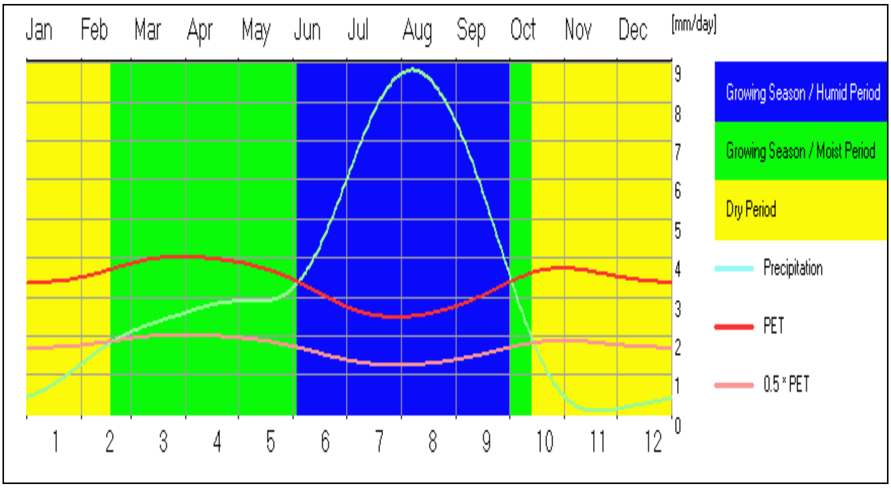

Figure 2. Daily Rainfall and Eto of the study area from LocClim

Irrigation scheduling

CropWat model and FAO 33 has been used to calculate the optimal irrigation of onion and Available soil moisture depletion level (ASMDL). Then, two year field experiment was implemented to analyze the effect of different ASMDL levels on the yield of onion and water productivity.

As the 2013 data analysis indicates, yield and plant height showed that there was no significant difference among the treatments. But, crop water productivity (CWP) showed a significant difference at available soil moisture depletion level (ASMDL).

The 2014 year data analysis of plant height and yield of onion also showed no significant difference among the treatments. But, the crop water productivity (CWP) showed significant difference among the treatments as indicated in Table 5. The 100% ASMDL showed a significantly highest CWP of 10.34kg/m^3. As the result indicate the yield and plant height is not significantly affected by the treatments so we can use the five soil moisture depletion levels without significance yield reduction or considering the water productivity of the treatments.

Crop water productivity

Crop water productivity is the ratio of actual yield (kg/ha) to the total water use (m^3/ha). It was calculated for each treatment during the experiment. The results of the crop water productivity (Table 5) showed that T3 recorded the highest crop water productivity of (8.61 kg/m^3) followed by T1 (8.122 kg/m^3), T4 (6.056 kg/m^3) and the water application of treatment 2 recorded the least crop water productivity of 5.636 kg/m^3. The results suggest that T3 and T1 are economically productive to adopt by onion farmers. According to the water utilization efficiency for harvested yield for bulbs containing 85 to 90% moisture is 8 to 10 kg/m^3 (Doorenbos et.al, 1986). The results obtained from this experiment are within the recommended range of FAO 33.

The over year analysis of the data showed no significant difference among the treatments on yield and plant height. However, WUE result showed there is significance difference ($P<0.05$). Among all treatments Treatment 3(100% ASMDL) performed high water productivity. As there is no significance yield reduction between the treatments, it is better to select the efficient water saving application in order to improve water productivity and water use efficiency. Therefore, 100% ASMDL is the best water productivity application without significant yield reduction of other treatment having 8.61% CWP.

Few studies have attempted to compare the impact of different irrigation scheduling strategies for onion production by size and onion quality. Kruse et al. (1987) evaluated yield and water used while scheduling irrigation with Bellani atmometers and estimated evaporation with meteorological data. Mermoud et al. (2005) compared empirical farmer practices with water balance techniques using different irrigation frequencies. They obtained increased yields and better irrigation efficiency when field water balance irrigation was used in combination with an irrigation frequency of twice per week. Another study showed that yields were not affected when water applications were reduced from 100% to 75% ETc and from 20 to 30 kPa. There were no differences between the 100% ETc, 75% ETc, 20 kPa and 30 kPa treatments probably because similar water levels were maintained during most of the season in the two years of the study (Juan et.al, 2008).

Table5. Statistical analysis of plant height and yield of onion for 2013 and 2014

Irrigation	2013			2014			Over year		
	Plant height (cm)	Yield (t/ha)	CWP (kg/m^3)	Plant height (cm)	Yield (t/ha)	CWP (kg/m^3)	Plant height (cm)t	Yield (t/ha)	CWP (kg/m^3)
60 % of ASMDL	38.33	25.5	6.05b	61	26.83	7.39b	47.4	29.07	8.122ab
80 % of ASMDL	39	26.17	4.66c	52.5	25	5.165c	44.4	25.7	5.636b
100% ASMDL	39	29.17	7.45a	54.5	34.4	10.34a	45.2	28.23	8.61a
120% of ASMDL	39.67	31.83	5.08bc	52	28.27	5.24c	44.6	30.41	6.056ab
140 % of ASMDL	38	26.67	5.10bc	50	23.27	5.17c	42.8	25.31	5.976ab
CV(%)	3.66	11.62	13.05	10.61	11.69	9.76	7.8	11.49	13.03
LSD0.05	NS	NS	1.39	NS	NS	1.8	NS	NS	2.96

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Optimal Irrigation Scheduling for Maize (*Zea mays)* at Tepi

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Introduction

In the study area, little concern has been given to the necessity and extension of irrigation technologies due to the presence of sufficient rainfall. However, recently, the occurrence of erratic rainfall or impact of climate change drastically reduced crop production. Consequently, traditional irrigation practices are being used for cultivating vegetables in different areas.

For effective use of available water resource, it is relevant to determine the actual crop water need and the right time of water application (irrigation scheduling).Hence, this study was conducted to determine the optimum irrigation scheduling based on the soil moisture depletion levels for hybrid maize (BH-140) at Tepi. The identified information is important for increased crop production and productivity, improved irrigation water management, and conservation of the environment.

Materials and Methods

Description of the study area

The experiment was conducted at Tepi National Spice Research Center, on station. It is found in Southwest of Ethiopia which is 611Km far from Addis Ababa. It is located at 7.18^0 N latitude and 35.42^0longitudes E with an altitude of 1200masl. The mean maximum and minimum monthly temperature is 29.85^0C to 18.01^0C. The area is categorized as hot to warm humid/sub-humid low lands with an annual rainfall of 1563.24mm. The soil has deep clay loam texture, and 7.3 mm/hr intake rate. The source of irrigation water is Shay River which is suitable for irrigation purpose.

Experimental design

The experiment was arranged in randomize complete block design with three replications. The treatment was rated for five levels of soil moisture depletion (SMD). The recommended allowable soil moisture depletion for maize is 55% (Allen *et al*., 1998) of the total available soil moisture that was used as 100% of SMD i.e. readily available soil moisture. The rates were 60%, 80%, 100%, 120%, and 140% of SMD. The total number of plots was fifteen where the size of each plot was $4m^2$. Hybrid maize variety (BH-140) was sown at the seed rate of the area (25kg/ha) and all the recommended practices for the area were applied during the growing season.

Climatic and soil data collection

Climatic data and reference evapotranspiration

Long-term (20years) monthly climatic data of Tepi area was collected from National Meteorological Agency of Ethiopia. The parameters included are rainfall, maximum and minimum temperature, relative humidity, wind speed, and sunshine hours. The monthly reference evapotranspiration of Tepi area was estimated by using FAO CROPWAT 8 program using long-term climatic data (Table 1).

Table1. Monthly reference evapotranspiration of Tepi

Month	Jan	Feb	Mar	April	May	June	Average
ETo(mm/day)	5.3	5.9	5.9	5.3	4.9	4.7	
Month	July	Aug	Sep	Oct	Nov	Dec	5.1
ETo(mm/day)	4.4	4.6	5.1	5.2	5.3	5.0	

Crop water requirement

For research purpose, the crop water requirement was determined by summing the net depth of water required (d_{net}) at each irrigation event throughout the crop growing season. The amount of water applied to the crop root zone was applied based on the soil moisture depletion level at each growth stage. The net irrigation requirement was calculated using the water balance formula (USDA, 1997).

$$NIR = d_{net} - Pe - GW - \Delta SW \text{............(1)}$$

Where

NIR = Net irrigation requirement, mm

d_{net} = Net depth of water required, mm

Pe = Effective precipitation, mm

GW = Ground water recharge, mm

ΔSW = Change in soil water content, mm

Water table of the experiment site is deep enough and vertical towards the crop root zone was assumed as negligible. Hence, the ground water recharge is negligible.

The net depth of water required (dnet) was determined by the equation provided by [6].

$$d_{net} = TAW \times Zr \times P \text{ ....(2)}$$

Where

d_{net} = Net depth of water required (mm)

P = Allowable soil moisture depletion by the crop (0.55).

TAW = Total available soil moisture (mm/m).

$$TAW = 10 \times (\theta_{FC} - \theta_{PWP}) \text{ .... (3)}$$

Where

TAW = Total available soil moisture,mm/m

θ_{FC}= Volume moisture content held at field capacity, %

θ_{PWP}= Volume moisture content held at wilting point, %

Effective Rainfall was computed using the [8] method and it is described in the following equations. $Pe = [P \times (125 - 0.2 \times 3 \times P)]/125$; for $P < 250/3$ ……(4)

$Pe = 125 / 3 + 0.1P$; for $P > 250/3$ ……...(5)

Where : Pe = Effective precipitation determined in mm/decade.

P = Total precipitation occurred in the crop growing season in the area, in mm/decade.

Gross irrigation requirement (GIR)

GIR is determined using the following formula developed by [6].

$$GIR = \frac{NIR}{(1-LR) \times Ea} \times 100 \qquad (6)$$

Where

GIR = Gross irrigation requirement (mm)
NIR = Net irrigation requirement (mm)
LR = Leaching requirement (fraction)
Ea = Application efficiency (%)

Irrigation scheduling

Irrigation frequency

The number of days between two subsequent irrigations, irrigation frequency, was determined by using equation (7).

$$IF = d_{net} / ETc \qquad (7)$$

Where

IF = Irrigation frequency (days)
d_{net}= Net depth of water required (mm)
ETc = Crop evapotranspiration (mm/day)

The crop evapotranspiration used in irrigation frequency determination was estimated by multiplying crop coefficient with reference crop evapotranspiration [5].

Yield and water use efficiency

The fresh maize grain yield and water use efficiency were selected as dependent variable. CWUE is the quantity of crop yield (Kg/ha) produced per unit depth (mm) of water used [7].

$$CWUE = \frac{Y}{ETc} \qquad (8)$$

Where

CWUE = Crop water use efficiency, kg/ha-mm
Y = Yield of crop, kg/ha
ETc= Cropwater requirement, mm

Data collection and analysis

From three consecutive years, data on grain yield and water use efficiency of maize were recorded. The results of yield and water use efficiency were subjected to Analysis of Variance test using the general linear model (GLM) in SAS 9.2 program. The least significant difference (LSD) test at 5% of probability was employed to distinguish among the treatment means.

Results and Discussion

Crop water requirement

The maize, BH-140 variety, was planted on February 26, 2013-2015.As shown detail in Table3, ten irrigation events with 390.66mm total irrigation water supplied in the entire crop-growing period. The amount of rainfall occurred during cultivation time was very small and the presence of irrigation water could show its importance.

Table3. Crop water requirement and irrigation scheduling for (120% MAD)

Irrigation event	CWR (mm)	Pe (mm)	NIR (mm)	GIR (mm)
1	7.12	0	7.12	10.17
2	8.90	0	8.90	12.71
3	14.24	3.05	11.19	15.98
4	32.04	6.2	25.84	36.91
5	64.04	10.06	53.98	77.11
6	101.99	16.28	85.71	122.44
7	103.22	0	103.22	147.45
8	103.30	10.24	93.06	132.94
9	100.77	19.12	81.65	116.65
Total	535.60	64.95	470.65	672.36

Note: CWR= Crop water requirement; Pe = Effective rainfall; NIR = Net irrigation requirement; GIR = Gross irrigation requirement

Maize grain yield

The results of pooled mean from the three consecutive years showed that the use of different soil moisture depletion levels were significantly effective ($P \leq 0.05$) in maize production. As described in Table4, the mean maize grain yield was gained as 10.4 ton/ha. The maximum yield was obtained when the soil moisture depletion level was reached 120% (SMD4) of the recommended level (55%). However, the yield has declined by 12.7% when the soil moisture depletion level was reduced from the recommended by 40%.The least grain yield was obtained from SMD1 which was practiced with frequent irrigation application or increased number of irrigation event that has the most payments for labors.

Table 4. Response of maize (BH140) for different irrigation regimes

Treatment	GY Ton/ha	CWUE Kg/ha-mm
SMD1(60%)	9.567[b]	17.833[b]
SMD2(80%)	10.32[ab]	19.267[ab]
SMD3(100%)	10.97[ab]	20.456[ab]
SMD4(120%)	11.078[a]	20.667[a]
SMD5(140%)	10.07[ab]	18.800[ab]
Mean	10.4	19.4046
LSD (5%)	1.44	2.7118
CV (%)	14.38	14.47

Note: GY = Grain yield of Maize,
CWUE = Crop water use efficiency,

Maize water use efficiency

The effect of different management allowable depletion levels were significant ($P \leq 0.05$) on maize water use efficiency. As described in Table4, the efficiency of an individual crop to convert irrigation water to maize grain was high in treatment SMD4 which has given 24.3kg/ha-mm. (20.67kg/ha-mm) check your result The minimum crop WUE was21.01kg/ha-mm check as (17.83kg/ha-mm) that has showed the least effectiveness of using water for making maize grain at SMD1. It is because of too much water frequently irrigated water and low yield.

Optimal Irrigation Scheduling for Potato (*Solanum tuberosum*) at Holetta

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Introduction

Potato yield is reduced by both over- and under-irrigation. A mere 10 percent deviation from optimum water application for the growing season may begin to decrease yield. Yield reductions due to over irrigation can be attributed to poor soil aeration, increased disease problems, and leaching of nitrogen from the shallow crop-root zone.

Crops that are kept within acceptable stress limits during their growth cycle have the potential to produce optimum yields of high quality. The aim of irrigation scheduling is to keep soil moisture within a desired range, usually between field capacity (full point) and a predetermined refill point for optimal growth. In order for an irrigation schedule to be effective, it has to tell us when to water and how much to apply. Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas.

Yield and quality of potatoes suffer due to insufficient water supply and improper scheduling of irrigation. Available irrigation water has to be utilized in a manner that matches the water need of the crop. The knowledge of crop water requirement is an important practical consideration to improve water use efficiency in irrigated agriculture. Water use efficiency can be improved by proper irrigation scheduling, which is essentially governed by crop evapotranspiration (ETc).Therefore, this activity is aimed to evaluate the responses of potato to irrigation regime (when and how much) and to identify WP under optimal irrigation regime.

Materials and Methods

Experimental site

The field experiment was conducted for two consecutive years from 2013 to 2014 at Holetta Agricultural Research Center (09^{0}03'N and 38^{0}30'E, 2400m above sea level with mean annual rainfall of 1044 mm). The mean maximum and minimum temperatures were 22.0^{0}C and 6.1^{0}C, respectively with a mean relative humidity of 60.6%. The main rainy season is from June to September when it receives 70% of the annual rainfall. The experimental site has a Nitisols with a pH of 5.24 and an average organic matter content of 1.8%. The soil contained 0.17% nitrogen, 4.55 ppm phosphorus and 1.12 potassium Meq/100 g soil (HARC, 2001).

Treatments and experimental design

Randomized complete block design with three replications was used. The experiment included 5 treatments randomized in plots as follows: treatment 1 is -40% of available soil moisture depletion level (ASMDL), treatment 2 is -20% of available soil moisture depletion level (ASMDL), treatment 3is available soil moisture depletion level (ASMDL), treatment 4 is +20% of available soil moisture depletion level (ASMDL) and treatment 5 is +40% of available soil moisture depletion level (ASMDL).

Experimental procedure and management practice

Belete variety was planted on 17^{th} and 24^{th} of January 2013 and 2014, respectively. Planting was performed by hand. Plot size was 4.5 m wide and 5 m long. The distances between rows and plants were 0.75 m and 0.3 m and the distance between plots and between replications were 1 m and 1.5 m respectively. Potato plots were fertilized with 46kg/h P as DAP and 23kg/ha N as Urea during sowing and, additional 23kg/ha N was applied in flowering stage. Plants were initially well watered to have suitable germination and favorable plant stand. Furrow irrigation method was used, and the amount of water applied was measured using Parshall flume. Irrigation scheduling was done based on soil water depletion replenishments using the CROPWAT program. Crop water requirement was calculated using CROPWAT program based on the FAO Penman-Monteith method. Soil water level was monitored using the gravimetric soil moisture content determination method. Soil sample was taken from well-irrigated plots just before irrigation to check the moisture content at management allowable depilation level and two days after irrigation to check the moisture content to field capacity level. The regular tillage and agricultural operations of growing potato of the location were followed. All other agronomic practices were kept normal and uniform for all the treatments including pre-irrigation and one irrigation after germination.

Data collection

Representative three rows potato plant samples were harvested after plant height recorded and collected per plot. Data on potato yield and yield parameter like plant height, tuber yield was collected.

Calculation of water productivity (WP)

Water productivity was estimated as a ratio of aboveground dry matter at maturity or grain yield to the total Etc through the growing season and it was calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$CWP = (Y/ET)$$

Where, CWP is crop water productivity (kg/m^3), Y crop yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Data analysis

The collected data were statistically analyzed using statistical analysis system (SAS) software version 9.0 using the general linear programming procedure (GLM). Mean separation using least significant difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

Results and Discussion

Effect of Soil Moisture Depletion on Potato Height, Yield, and Water Productivity

In order to evaluate the effect of soil moisture depletion levels on plant height, the plant height from ground level to apex stem were measured and the results are presented in Table 5.The two years and the over year analysis of variance showed that the effect of Allowable soil moisture depletion level on plant height was not significantly different. Though Aklilu (2009) who concluded that a 50% Etc resulted in 43.5 cm height of pepper whereas has reported findings, a 75 and 100% ETc resulted in 56.8 and 60.7cm height, respectively.

The effect of soil moisture depletion level on potato tuber yield is presented in Table 4.The analysis result has indicated that in 2013, there is no significant difference among the treatments regarding tuber yield of potato though the highest yield is registered on treatment 1(-40% ASMDL). In 2014, there is also no significant difference among the treatments, treatment 5 (+40% ASMDL) gave the highest yield which is 39 t/ha. No significant difference has been observed under the over year analysis too. Similarly, treatment 5 gave the highest yield which is 38 t/ha.

Water productivity of potato tuber yield as a function of the amount of applied water is presented in Table 1. The highest water productivity (14.62 kg/m^3) of yield was obtained under -40% ASMDL whereas the lowest water productivity (0.24 kg/m^3) of potato yield was obtained under +40 ASMDL. This results has similarity with results elaborated at applying 75% of crop water requirement throughout the growing season of potato has better water use efficiency than applying optimal irrigation with (100%) crop water requirement (Mulubrehan and Gebretsadikan, 2016).

Erdem et al. also reported that water productivity increased from 4.7 to 6.6 kg/ m^3 for furrow irrigated treatments and from 5.2 to 9.5 kg/ m^3 for drip irrigation. Kang et al. and Onder et al. also registered similar WUE values for potato. So the results found on this experiment are under the range of the values indicated above.

Table 1. Potato height, yield, and water productivity as affected by irrigation levels

Treatment	2013			2014			Over Year		
	Plant height (cm)	Yield (t/ha)	WP (kg/m^3)	Plant height (cm)	Yield (t/ha)	WP (kg/m^3)	Plant height (cm)	Yield (t/ha)	WP (kg/m^3)
-40 % ASMDL	91.33	38.08	15.36^a	58.67	34.33	13.87^a	75	36.21	14.62^a
-20 % ASMDL	93.00	33.48	10.13^b	55.33	26.33	8.03^b	74.17	29.91	9.08^b
ASMDL	92.33	33.77	8.18^c	61.33	36.67	8.86^{bc}	76.83	35.22	8.52^{bc}
+20% ASMDL	92.67	37.04	7.47^{cd}	64	32.23	6.52^c	78.33	34.69	6.99^a
+40 % ASMDL	92.00	37.48	6.48^d	54.67	39	6.74^c	73.33	38.24	6.61^c
CV (%)	3.62	8.46	8.4	14.65	13.11	12.24	8.65	10.89	10.35
$LSD_{0.05}$	NS	NS	1.39	NS	NS	1.8	NS	NS	2.3

**Means followed by different superscripts are statistically different*

The trend of WP in this experiment is in agreement with the findings of Yuan *et al.* (2004) who reported that the trends WP for the production of total fresh berry yields. The authors concluded that the lower the amount of irrigation water received, the higher the water productivity obtained for the drier plant biomass and berry yields. Mao *et al*. (2003) reported that highest WP of cucumber yield was obtained in treatment groups with minimal irrigation levels. Similarly, Sezen *et al*. (2005) reported that higher WP was obtained with lowest irrigation level in field-grown beans. However, lower irrigation level resulted in lower total yield. Water productivity probably will become more important as access to water become more limited (Shadeed, 2001).

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Response of Maize (*Zea mays*) for Moisture Stress at Different Growth Stages

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Introduction

Depriving irrigation in some growth stages of a crop leads to higher water use efficiency and economical cost of crop production. Many studies have shown that there is a significant yield and yield component reduction occurs when maize stressed at different growth stages. This makes an increase in water use efficiency when moisture stress happens in some non-sensitive stages (Yenesew and Tilahun 2009). Different crops response for moisture stress differently. Crops less sensitive to stress such as cotton, maize, groundnut, wheat, sunflower and sugar beet can adapt well to deficit irrigation practices provided good management practices can be secured (FAO 2002). Moreover, maize is one of the major food crops in Ethiopia. According to Central Statistic Authority (CSA) 2011/12 *Meher* season post harvest crop production survey, next to tef, maize was higher (17%) in area coverage which is about 2,054,723.69hectar and the highest in grain yield engaging the highest number of householders (9,154,883) among all crop types (CSA, 2012).

Different works have been done on maize moisture stress at different growth stage based on decreasing the amount of irrigation water given on few combinations of growth stage especially on seed formation and initial stage. However, much work has not been done on effect of moisture stress at different maize growth stages like initial, development, mid-season and late-season stages and their combinations with fully missing irrigation. Therefore, these field experiments were conducted to identify the most sensitive stage of maize crop, to avoid the risk of crop yield reduction and maximizing the efficiency of water used for irrigation.

Materials and Methods

The experimental area

Field experiments were carried out for two consecutive years on dry season of 2011/12 and 2012/13 at Koka Research Station of Wondo Genet Agricultural Research Center. The farm is located in Ethiopia 8°26' N latitude, 39°2' E longitude and 1602m above sea level altitude. Climate of the area is semiarid with total annual precipitation of 831.1mm and 132.0mm of rainfall expected in the dry season from October to March (Table 1). The soil type of the experimental area was clay in texture and the available water holding capacity per unit meter of the soil profile is 170 mm. Some physical characteristics of soil, such as field capacity, wilting point and total available water holding capacity of the experimental site are presented in Table 2.

Table1. Long-term monthly climatic data of the experimental area

Month	T_{max} (^{O}C)	T_{min} (^{O}C)	RH (kpa)	U (m/s)	N (%)	RF (mm)
January	27.4	11.3	1.34	4.04	75	13.5
February	28.3	12.6	1.39	4.08	76	26.1
March	30.0	14.4	1.50	4.64	74	51.5
April	30.3	15.2	1.64	3.80	71	58.5
May	30.9	15.1	1.63	3.98	68	48.5
June	30.0	15.5	1.70	4.91	65	72.7
July	26.7	15.0	1.74	4.30	54	212.7
August	26.3	15.1	1.75	3.15	53	202.4
September	27.8	14.9	1.79	2.30	57	104.3
October	28.3	12.7	1.48	3.50	73	21.1
November	27.4	11.3	1.30	4.09	83	9.9
December	26.1	11.0	1.26	4.19	76	9.9

Source: FAO. 2005. New-LocClim, Local Climate Estimator.

Table2. Physical characteristics of soil at the experimental site

Soil texture	Bulk density (g/cm3)	Field capacity (%)	Wilting point (%)	Available water holding capacity (mm)
Clay	1.17	34.5	17.5	170

Treatment and experimental design

Randomized complete block design with three replications were used following the procedure of Gomez and Gomez (1984). The experiment included 15 treatments (factorial of depriving irrigation on four growth stages) randomized in plots as follows: 1) irrigated all stages as control (no stress), 2) depriving irrigation at initial stage only (I), 3) depriving irrigation at development stage only (D), 4) depriving irrigation at mid-season stage only (M), 5) depriving irrigation at late season stage only (L), 6) depriving irrigation at initial and development stages (ID), 7) depriving irrigation at initial and midseason stages (IM), 8) depriving irrigation at initial and late season stages (IL), 9) depriving irrigation at development and midseason stages (DM), 10) depriving irrigation at development and late-season stages (DL), 11) depriving irrigation at mid-season and late season stages (ML), 12) depriving irrigation at initial, development and midseason stages (IDM), 13) depriving irrigation at initial, development and late season stages (IDL), 14) depriving irrigation at initial, midseason and late season stages (IML) and 15) depriving irrigation at development, midseason and late seasons (DML).

Experimental procedure and management practice

Grains of maize variety Melkassa-II was sown during the first week of November in 2011 and last week of October in 2012 of each experimental year. A row spacing of 0.75m and within-row spacing of 0.30m were used. Maize plots were fertilized with 46kg/h P as DAP and 23kg/ha N as Urea before sowing and, additional 23kg/ha N was applied as Urea when maize plant at knee height. The plot size used was 3.00m x 3.00 m. Furrow irrigation method was used, and the amount of water applied was measured using 2 inch Parshal flume. Irrigation scheduling was done based on soil water depletion replenishments using the CROPWAT program and adopting ten day irrigation interval. Crop water requirement was calculated using CROPWAT program based on the FAO Penman-Monteith method. Soil water level was monitored by using the gravimetric soil moisture content determination method. Soil sample was taken from well-irrigated plots just before irrigation to check the moisture content at management allowable depilation level and two day after irrigation to check the moisture content to field capacity level. The regular tillage and agricultural operations of growing maize of the location were followed. All other agronomic practices were kept normal and uniform for all the treatments including pre-irrigation and one irrigation after germination.

Data collection

Representative five maize plant samples were cut at ground level after plant height recorded and collected per plot from the center 150 days from sowing after physiologically matured. Aboveground biomass weight recorded after the maize harvested with cob. Data on maize yield and yield parameters like plant height, total biomass, cob length, cob diameter, grain yield and 1000 seed weight was collected.

Data analysis

The collected data were statistically analyzed using statistical analysis system (SAS) software version 9.0 using the general linear programming procedure (GLM). Mean separation using least significant difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

Results and Discussion

Plant height

Table 3 indicated that there was highly significant variation on Plant height among experimental treatments at 1% level of significance. Plant height was significantly influenced ($p<0.001$) due to moisture stress at different growth stages. The maximum plant height of 169cm was obtained during 2011/12 by irrigation at all stages treatment or no stress and 194.6cm by stressing only at mid season during 2012/13 experiment year (Table 3 and Table 5 respectively). The minimum plant height of 76.3cm and 114.5cm were observed during the first and second year, respectively due to stress at three stages (initial, development and mid season). The data indicated plant height for treatments stressed at development seasons with any combination are inferior to other treatments. This confirms that plant height associated with the water applied at development stage.

Cob diameter and cob length

Moisture stress at different growth stages of Maize had a significant influence ($p<0.05$ and $p<0.01$) on cob diameter and cob length during the first year and affect significantly ($p<0.001$) during the second year. Treatment that moisture stress occurs only at initial stage was superior during the first season scoring 4.80cm and 18.7cm on cob diameter and cob length respectively. During the second season, treatment, which only stressed at late season, was superior on both cob diameter and cob length of 4.85cm and 17.8cm respectively. However, in both years the two treatments were statistically the same on both parameters. The minimum cob diameter of 1.99cm and cob length 6.4cm was scored by treatment that stressed three stages (development, mid season and late season) during the first season. In the second season, minimum cob diameter of 3.64cm was due to treatment that stressed at development, midseason and late season stage and cob length of 10.6cm due to treatment stressed at initial, development and midseason stages. Generally treatments of DM, IDM and DML scored the minimum cob diameter and cob length.

Table3. Effects of moisture stress at different growth stage on maize yield components 2011/2012

Stages of Moisture stress	Plant height (cm)***	Cob diameter (cm)*	Cob length (cm)**	1000 seed weight (g)***
no stress	169[a]	4.63[ab]	18.3[ab]	492.3[a]
I	163.7[a]	4.80[a]	18.7[a]	494.7[a]
D	120.1[de]	4.11[ab]	14.6[abcd]	382.1[bc]
M	157[ab]	4.20[ab]	16.5[abc]	470.3[ab]
L	167[a]	4.67[ab]	17.9[ab]	435.7[ab]
ID	92.9[fg]	3.74[abc]	14.5[abcd]	428.9[abc]
IM	134.3[bcd]	3.78[abc]	15abcd	401.1[abc]
IL	137.3[bcd]	4.46[ab]	16.9[ab]	396.9[bc]
DM	102.2[ef]	3.17[abcd]	10.5[cde]	409.4[abc]
DL	126.3[cde]	4.32[ab]	17.3[ab]	437.5[ab]
ML	146.7[abc]	3.06[bcd]	12.2[bcde]	336.0[cd]
IDM	76.3[g]	2.41[cd]	8.9[de]	274.7[d]
IDL	93.2[fg]	3.79[abc]	15.8[abc]	408.1[abc]
IML	133.7[bcd]	3.66[abc]	14.8[abcd]	424.9[abc]
DML	94.1[fg]	1.99[d]	6.4[e]	263.7[d]
CV (%)	11.8	26.1	26.1	14.0
LSD0.05	25.3	1.66	6.2	94.6

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. *Significant at $p<0.05$, **significant at $p<0.01$ and *** significant at $p<0.001$.

Thousand seed weight

Moisture stress at different maize growth stage had a significant influence ($p<0.001$) on 1000 seed weight both season. Treatment moisture stress happen only at initial stage was superior (494.7g) during the first year. During the second year, treatment moisture stress happen only at late season stage was the highest scoring 528.1g. The least thousand seed weight of 263.7g was obtained due to treatment at which moisture stress happen at development, mid season and late season stage during first year and 340.1g by stressing at initial, development and mid-season stages during the second year. The data revealed that, minimum 1000seed weight associated with combined moisture stress at development and mid-season stages.

Table 4. Effects of moisture stress at different growth stage on maize biomass, grain yield, water use efficiency and harvesting index 2011/2012

stage of moisture stress	Biomass (kg/ha)***	Grain yield (kg/ha)***	Water use efficiency (kg/mm)***	Harvesting index (%)**
no stress	34668^{a}	7098^{ab}	10.8^{abc}	20.2cde
I	33740^{a}	9253^{a}	15.1^{a}	27.2abc
D	16062^{b}	5301^{bcd}	8.3^{bcd}	31.9ab
M	29653^{a}	4710bcde	12.9^{ab}	15.3e
L	27222^{a}	6147^{bc}	11.3^{ab}	22.9bcde
ID	14596^{bc}	3623^{cde}	8.5bcd	25.0bcd
IM	17972^{b}	2448^{efg}	6.2^{cde}	13.6e
IL	18983^{b}	4934bcde	9.9^{bc}	25.9abcd
DM	11695^{bcd}	2727^{defg}	10.5^{abc}	22.6bcde
DL	17675^{b}	4580^{bcde}	12.6^{ab}	21.1cde
ML	18954^{b}	3175^{def}	9.6^{bc}	16.9de
IDM	6855^{d}	840^{fg}	4.0^{de}	14.3e
IDL	11567^{bcd}	4676^{bcde}	14.9^{a}	34.8a
IML	16693^{b}	2976^{def}	10.6^{abc}	18.2cde
DML	7190^{cd}	257^{g}	1.8^{e}	3.7f
CV (%)	24.3	37.4	28.4	26.7
LSD0.05	7669.9	2614.8	4.6	9.3

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. * Significant at $p<0.05$, **significant at $p<0.01$ and *** significant at $p<0.001$.

Aboveground biomass yield

Moisture stress at different growth stage had a significant influence ($p<0.001$) on maize biomass production. Maximum biomass yield of 34668kg/ha and 37889kg/ha were obtained in the first and second cropping season due to no stress treatment and moisture stress only at late season treatment, respectively. The two treatments were statistically the same during both years (Table 4 and Table 6). During the first year minimum above ground biomass of 6855kg/ha was obtained due to moisture stress at initial, development and mid-season stages. Whereas in the second year minimum above ground biomass of 10128 kg /ha was collected from treatment with moisture, stress happened on three growth stages (development, mid season and late season). Both treatments were statistically the same both years. The trend of biomass production shows decreasing with increasing of moisture stress indicating well irrigated maize yields higher biomass production. This is in agreement with former reports of Ersel *et al*. (2010) on maize.

Table 5. Effects of moisture stress at different growth stage on maize yield components 2012/2013

Stages of moisture stress	Plant height (cm)***	Cob diameter (cm)***	Cob length (cm)***	1000 seed weight (g)***
no stress	177.8[abc]	4.41[bc]	16.4[ab]	456.9[abc]
I	188.3[ab]	4.65[ab]	16.5[ab]	471.5[ab]
D	146.2[de]	4.53[ab]	15.7[abc]	445.7[abcd]
M	194.6[a]	4.43[bc]	14.7[bc]	428.0[bcd]
L	178.1[abc]	4.85[a]	17.8[a]	528.1[a]
ID	144.5[def]	4.12[cd]	14.1[c]	431.6[bcd]
IM	178.6[abc]	4.12[cd]	15.3[bc]	431.3[bcd]
IL	161.4[bcd]	4.42[bc]	16.3[abc]	412.4[bcde]
DM	142.5[efg]	4.06[cd]	11.7[d]	380.7[cde]
DL	149.7[cde]	4.38[bc]	15.4[bc]	486.8[ab]
ML	178.8[abc]	4.26[bcd]	14.9[bc]	421.3[bcde]
IDM	114.5[f]	3.96[de]	10.6[d]	340.1[e]
IDL	135.9[def]	4.43[bc]	15.6[abc]	405.6[bcde]
IML	189.3[ab]	4.30[bcd]	15.7[abc]	440.1[bcd]
DML	122.7[ef]	3.64[e]	11.3[d]	363.6[de]
CV (%)	11.3	5.5	9.2	12.2
LSD0.05	30.4	0.4	2.3	87.7

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. * Significant at $p<0.05$, **significant at $p<0.01$ and *** significant at $p<0.001$.

Harvesting index (HI)

Moisture stress at different growth stages had significantly ($p<0.01$ and $p<0.05$) influence on maize harvesting index during the first and the second year, respectively. Maximum HI of 34.8% was obtained due to moisture stress at initial, development, and late season stages during the first year and 40.8% due to moisture stress at initial and late season growth stages during the second year. Whereas the minimum HI of 3.7% was due to DML treatment and 25.2% due to DM treatment during the first and the second years, respectively. The study showed that combined moisture stress during initial and late season maximize the harvesting of maize. This is due to the moisture stress happen at combined stages of initial and late season affect the biomass than grain yield when compared with other treatments. However, combined moisture stress at development and mid-season growth stages significantly reduce harvesting index. This revealed that moisture stress happen at combined development and mid-season growth stage affect the grain yield than the biomass when compared with other treatments.

Grain yield production

The result of both year and pooled mean indicated moisture stress happened at different maize growth stages had a significant effect ($p<0.001$) on grain yield per hectare. The pooled mean indicated that maximum grain yield of 10500kg/ha was obtained when moisture stress applied at initial stage only, which decrease with different moisture stress happen at different maize growth stage reaching minimum of 2053kg/ha due to moisture stress happen at development, mid-season and late season stages. Both year maximum grain yield of 9253kg/ha during the first year and 11748kg/ha during the second year was obtained due to treatment stress only at initial stage (Table 4, Table 6 and Table 7). This may be due to stressing moisture at initial stage after establishment enhances root development and which further enhance the capacity of the crop to up take both nutrient and moisture after growth. The minimum grain yield of 257kg/ha was obtained by moisture stress at three stages (development, mid-season and late season) treatment during the first year and 3330kg/ha due to treatment of moisture stress occurs at three stages (initial, development and mid season) during the second year. But as most parameters, grain yield was also statistically the same in the poor performed treatments of stress happen at initial, development and mid season stages treatment and stress happen at development, mid-season and late season treatment and scoring average of 2085kg/ha and 2053kg/ha, respectively .

Table 6. Effects of moisture stress at different growth stage on maize yield, water use efficiency, and harvesting index during 2012/2013 growing season

stage of moisture stress	Biomass (kg/ha)***	Grain yield (kg/ha)***	Water use efficiency (kg/mm)***	Harvesting index (%)*
no stress	36209^{a}	11408^{a}	9.09^{efg}	33.1^{abc}
I	33988^{ab}	11748^{a}	9.81defg	34.9^{abc}
D	27122^{abcd}	8413^{b}	8.40^{efg}	31.0^{bcd}
M	28291^{abc}	7623^{b}	9.68defg	27.8^{cd}
L	37889^{a}	11734^{a}	12.94^{cde}	31.2^{bcd}
ID	18096^{cdef}	6474^{bc}	6.85^{g}	35.5^{abc}
IM	22796^{bcd}	6957^{b}	9.52^{defg}	31.2^{bcd}
IL	24296^{bcd}	8684^{b}	10.22^{defg}	40.8^{a}
DM	16913^{def}	4231^{cd}	7.90^{fg}	25.2^{d}
DL	22665^{cd}	8074^{b}	12.33^{cdef}	36.1^{ab}
ML	18679^{cdef}	6799^{bc}	15.45^{bc}	36.1^{ab}
IDM	10961^{ef}	3330^{d}	6.96^{g}	30.8^{bcd}
IDL	22104^{cde}	8378^{b}	14.02^{cd}	39.6^{a}
IML	20890^{cdef}	7303^{b}	19.07^{ab}	35.8^{ab}
DML	10128^{f}	3850^{d}	20.50^{a}	37.3^{ab}
CV (%)	28.8	20.2	23.7	14
LSD0.05	11266	2594	4.56	7.9

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. *Significant at $p<0.05$, **significant at $p<0.01$ and *** significant at $p<0.001$.

These two treatments were performed poor both seasons in most of the parameters. The study revealed that when moisture stress happens both at development and mid season stage in combination, yield and yield parameter influenced extremely. Fairly higher grain yield associated with higher irrigation water applied treatments even though the variation exist due to moisture stress happen at different growth stages. Former report by Farshad *et al*. (2008) also shows lowest grain yield was obtained by applying water stress at silking growth stage which is equivalent with the mid season stage. Moreover, different stress level at different stages affect the yield of maize and even different cultivars have different tolerance level for moisture stress leads to a decrease of chlorophyll content which will reduce the amount of food produced in the plant (Adel et al., 2013). Another report by Ersel *et al*. (2010) also shows moisture stress occurring during vegetative and tasseling stage reduce grain yield significantly. A research conducted on tomato also shows moisture stress at vegetative and flowering stage significantly reduce the yield (Vijtha and Mahendra, 2010). This revealed that moisture stress occurs at mid-season especially when combined with development stage, the yield significantly reduced.

Table 7. Effects of moisture stress at different growth stage on average maize grain yield and water use efficiency (WUE) during 2011/2012 and 2012/2013 growing season

Treatment	Grain yield (kg/ha)***	WUE (kg/mm)***
no stress	9253^{a}	9.9cde
I	10500^{a}	12.5^{abc}
D	6857^{bc}	8.4^{def}
M	6167^{c}	11.3^{bcd}
L	8940^{ab}	12.1^{abc}
ID	5049^{cd}	7.7^{ef}
IM	4703^{cd}	7.9def
IL	6809^{bc}	10.1^{cde}
DM	3479de	9.2^{cde}
DL	6327^{c}	12.5^{abc}
ML	4987^{cd}	12.5^{abc}
IDM	2085^{e}	5.5^{f}
IDL	6527^{c}	14.5^{ab}
IML	5140^{cd}	14.8^{a}
DML	2053^{e}	11.1^{bcde}
CV (%)	22.2	19.6
LSD0.05	2198.4	3.5

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. * Significant at $p<0.05$, **significant at $p<0.01$ and *** significant at $p<0.001$.

Water use efficiency

Moisture stress at different growth stages had a significant ($p<0.001$) influence during both years. Water use efficiency was higher for moisture stress only at initial stage scoring15.1kg/mm during 2011/12 and 20.5kg/mm due to moisture stress happen at development mid-season and late season stages during 2012/13. The minimum water use efficiency was due to moisture stress happen at development, mid-season and late season stage scoring 1.8kg/mm during 2011/12 and moisture stress happen at initial and development stage scoring 6.85kg/ha during 2012/13 season. The study revealed that pooled mean of WUE of maize was maximized when moisture stress happen at three growth stages due to minimum water applied. However, when moisture stress happen in combined initial, development and mid-season growth stages, WUE was affected highly scoring only 5.5kg/mm.

The pooled mean showed that maximum WUE of 14.8kg/mm was obtained due to moisture stress happen at initial, mid-season, and late season growth stages. Generally higher water use efficiency was associated with lower water application showing moisture stress at different growth stage enhance water productivity. This is in agreement with former reports FAO (2002) on wheat, cotton and other crops, Ismail (2010) on bird pepper (*Capsicum annuum* L.) production, Romulus *et al*., (2009) on spearmint and R.

Huang (2006) on maize production. Better water use efficiency without significantly reducing the grain yield was obtained due to treatments in which moisture stress happen only at initial stage and treatment in which moisture stress happen only at late season stage.

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Determination of Optimal Soil Moisture Depletion Level for Lemongrass

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Introduction

The optimization of irrigation for the production of fresh herbs and essential oils is important, since water is a major component of the fresh produce and affects both mass and quality (Jonesand Tardien, 1998). Study of soil moisture contents and the patterns of moisture depletion as the crop grows could help to sort out a suitable irrigation schedule for this objective. Although different studies has been conducted to evaluate different crops yield and yield component under different soil moisture depletion levels, little work was reported for aromatic and medicinal crops in general and for lemongrass in particular. For production of lemongrass under irrigated conditions, determination of the optimum soil moisture depletion level is crucial to recommend when and how much irrigation water to be applied under specified agro-ecology and soil type. Therefore, this field experiment was initiated due to unavailability of information regarding soil moisture depletion level, and irrigation scheduling for lemongrass, based on the objective to determine optimum soil moisture depletion level for lemongrass (*Cymbopogon citratus* L.) at Wondo Genet area.

Materials and Methods

Description of the experimental site

A Field experiment was carried out at Wondo Genet Agricultural Research Center, Ethiopia latitude 8^{O}25'59", longitude 39^{O}01'44" and altitude of 1800 m during 2013/14 and 2014/15 dry season to determine optimum soil moisture depletion level for the production of lemongrass. The soil texture in the experimental site was clay loam with moisture content at field capacity and permanent wilting point of 30.8% and 19.0%, respectively. The bulk density of the soil was 1.1 g/cm^3 and hence, the available water holding capacity per unit meter of the soil profile in the root zone is 130 mm. The area gets total annual rainfall of 1121.80mm. From this, 72.3% of the rainfall falls in the main rainy season (April to September).

Experimental design and procedure

The field experiment was carried out using randomized complete block design with three replications following the procedure of Gomez and Gomez (1984). The plot size used was 3.00m X 3.00 m with spacing of 1.50 m between plots and 3.00 m between blocks. Six treatments of different soil moisture depletion levels (20, 30, 40, 50, 60 and 100% TAW) were randomly assigned for each plot in each block.

Lemongrass stem from one-year-old matured plant was taken and planted. Three tiller split was planted at a point with spacing of 60cm both between raw and between plant/hill. The regular tillage and agricultural operations for lemongrass in the study area were followed during the experimentation. All other agronomic practices were kept normal and uniform for all plots regardless of the treatment variation. Irrigation water was applied based on the treatments, soil moisture depletion levels to bring the soil to field capacity. The calculated gross irrigation depth was applied for each plot measuring the irrigation water using 2-inch Parshall flume. Soil sample before and after irrigation was taken to determine the moisture content of the soil until the soil moisture depletion level approached treatment level for all harvesting cycle.

Data collection

Five plant hills were randomly selected for sample from the central part of the plot excluding the border for data collection on growth, yield and yield components of lemongrass. Data on number of tiller per hill, number of leaves per hill and number of leaves per tiller was counted at field. The selected five samples were harvested 120 days after planting for the first harvest and 60 days after the first harvest, the second harvest for both seasons were made. Fresh biomass of lemongrass (30cm above the ground at the edge of the leaf) was harvested manually using sickle. Data on moisture content and essential oil content was collected after the sample was extracted at Wondo Genet Agricultural Research Center, Natural Product Laboratory using hydro distillation method. Based on the oil content and moisture content, essential oil content and dry biomass yield was calculated. Moreover, based on the obtained yields and amount of irrigation used, water use efficiency was calculated using the following formula.

$$WUE = \frac{EOY}{TW}$$

Where: WUE is water use efficiency (kg/m^3); EOY: is the essential oil yield (kg/ha); TW: is the seasonal total water use (m^3/ha)

Data analysis

The data collected were statistically analyzed using statistical analysis system (SAS) software version 9.0 using the general linear programming procedure (GLM). Mean comparison was carried out using least significant difference (LSD) at 5% probability level to compare the differences among the treatments mean.

Result and Discussion

Different levels of soil moisture depletion levels significantly affected all recorded yield and yield components except number of tillers per hill and essential oil content. Significantly, highest number of leaf per hill, aboveground fresh and dry biomass, essential oil yield and water use efficiency yield were obtained as lemongrass irrigated when 60% of the total available water in the soil was depleted.

Number of tiller and leaf per hill

As shown in Table 2, the number of tillers per hill of lemongrass was not significantly ($p>0.05$) affected by different levels of soil moisture depletion level. However, the value ranges between 72.7 and 61.8 tillers per hill. On the other hand, different levels of soil moisture depletion level on lemongrass had a highly significant ($p<0.01$) effect on number of leaf per hill.

The combined analysis revealed that maximum number of leaf per hill of 344.7 was obtained as lemongrass irrigated when 60% of the total available water in the soil depleted. However, the maximum leaf per hill recorded at 60% TAW treatment was statistically similar with 30 and 40% TAW treatments. On the other hand, the minimum leaf per hill of 278.4 was obtained when lemongrass irrigated when 20% of the total available water in the soil depleted. The minimum leaf per hill recorded at 20% TAW was not statistically different from 40, 50 and 60% TAW treatments (Table 2).The study showed that as soil moisture depletion level increased and decreased from 60%, number of leaf per hill was reduced. The maximum number of leaf per hill obtained at 60% TAW treatment was 23.8% higher than the least leaf per hill recorded at 20% TAW treatment.

Different studies revealed that different levels of soil moisture depletion significantly affect growth, yield and yield components of different crops. This study revealed that the maximum yield component leaf per hill was recorded when lemongrass irrigated after 60% of total available water in the soil depleted. The finding is in line with FAO (1998) recommendation of 60% depletion level for production of grass species. This might be due to the required optimum depletion level of lemongrass required, as 60% of TAW both for optimum water and air circulation in the root depth. This could be as soil gets dried beyond 60% of the crop experience stress in the growing season which leads to reduction in growth and yield components of the specified plant. Different studies revealed that moisture stress due to depletion to higher amount leads to reduction of growth parameters. Razmjoo *et.al* (2008) reported that drought stress in chamomile reduced some growth parameters.

Table 2. Yield components of lemongrass as influenced by different soil moisture depletion levels at Wondo Genet during 2013/14 and 2014/2015 dry season (two harvests)

Treatment	Tiller per hill	Leaf per hill	Aboveground fresh biomass (kg/ha)			Aboveground dry biomass (kg/ha)		
	(Pooled)^{ns}	(Pooled)**	(2013/14) *	(2014/15)*	(Pooled)**	(2013/14) *	(2014/15)**	(Pooled)**
20% TAW	61.8	278.4^{c}	9468^{ab}	13727^{bc}	11597^{b}	2617^{ab}	3984^{b}	3301^{b}
30% TAW	66.7	315.8^{ab}	10165^{a}	15673^{ab}	12919^{ab}	2666^{a}	4299^{ab}	3482^{ab}
40% TAW	69.0	310.6^{abc}	10350^{a}	16181^{ab}	13266^{ab}	2757^{a}	4434^{ab}	3596^{ab}
50% TAW	66.9	301.8^{bc}	10365^{a}	15877^{ab}	13121^{ab}	2885^{a}	4474^{ab}	3679^{ab}
60% TAW	72.7	344.7^{a}	11164^{a}	18160^{a}	14662^{a}	3037^{a}	5047^{a}	4042^{a}
100% TAW	64.1	293.5^{bc}	7613^{b}	10059^{c}	8836^{c}	2130^{b}	2800^{c}	2465^{c}
$LSD_{0.05}$	ns	37.3	2151.5	3926.8	2311.6	510.9	913.1	570.7
CV (%)	12.9	11.9	14.5	17.4	14.4	12.6	14.5	11.0

Means followed by the same letters with in columns does not differ significantly at $p< 0.05$ probability level. *significant at $p<0.05$, ** significant at $p<0.01$

Aboveground fresh and dry biomass

Different levels of soil moisture depletion had a significant ($p<0.05$) effect on aboveground fresh biomass during both the first the second (2013/14 and 2014/15) years experimentation. Whereas, the combined analysis (pooled mean) revealed that, different levels of soil moisture depletion had a highly significant ($p<0.01$) effect on aboveground fresh biomass of lemongrass. On the other hand, aboveground dry biomass was significantly ($p<0.05$) influenced due to different soil moisture depletion levels during the first experimental year (2013/14). However, during the second experimental year (2014/15) and the combined analysis revealed that aboveground dry biomass was highly significant ($p<0.01$) effect due to different soil moisture depletion levels.

The pooled mean revealed that maximum aboveground fresh and dry biomass of 14662 and 4042 kg/ha were recorded when lemongrass irrigated at 60% of the total available water in the soil is depleted, respectively (Table 2). However, the maximum aboveground fresh and dry biomass obtained at 60% TAW treatment was statistically similar with 50, 40 and 30% TAW treatments. On the other hand, the minimum aboveground fresh biomass was obtained at 100% TAW treatment. Moreover, the minimum aboveground fresh and dry biomass was recorded at 100% TAW which was statistically inferior to all other treatments in both parameters. The study showed that as soil moisture depletion level increased and decreased from 60% TAW, aboveground biomass was reduced. The maximum aboveground fresh and dry biomass obtained at 60% TAW treatment were65.9 and 64.0% higher than the least yield recorded at 100% TAW treatment, respectively.

Different studies revealed that different level of soil moisture depletion significantly affect yield and yield components of different crops. For example; Narang *etal*. (2000) found that yield of all wheat cultivars studied decreased with increasing levels of soil moisture depletion level. As the depletion level increased, the fresh biomass also increased; on the contrary, drought stress caused significant decrease in fresh and dry biomass, nutrient content and essential oil production of basil (Simon *et.al*., 1992).According to Singh (1999) a field experiment conducted on lemongrass (*Cymbopogonflexuosus*) soil moisture regime maintained at 0.75 irrigation water to cumulative pan evaporation ratio (IW:CPE) significantly increased herb yield compared with those having 0·25 and 0·50 IW:CPE ratios.

This study revealed that the maximum aboveground fresh and dry biomass yield was obtained when lemongrass irrigated after 60% of total available water in the soil depleted. This is in line with the findings of Singh *et.al*. (2000) who reported maximum herb yield of lemongrass (*Cymbopogonflexuosus*) recorded around mid of the tested irrigation water levels (from 0.1 to 1.5 times cumulative pan evaporation) at 0.7 IW: CPE ratio on deep sandy soils. Similar research on rosemary plant showed that the herb growth was influenced by different levels of irrigation intervals which lead to different soil moisture depletion level (Soha and Ashraf, 2015).

Essential oil content and yield

Table 3 revealed that different levels of soil moisture depletion level on lemongrass had no significant ($p>0.05$) impact on essential oil content. However, the value (weight in wet base) ranges between 0.63 to 0.66%. On the other hand, different soil moisture depletion levels significantly ($p<0.05$) influenced essential oil yield of lemongrass during both experimental years. Moreover, the pooled mean analysis revealed that different levels of soil moisture depletion levels significantly ($p<0.01$) influenced essential oil yield production of lemongrass.

Maximum essential oil yield of 93.1 kg/ha was obtained at 60% of TAW treatment. However, the maximum essential oil yield recorded at 60% TAW was statistically similar with oil yield obtained at 50, 40 and 30% TAW treatments (Table 3). On the other hand, the minimum essential oil yield of 54.8 kg/ha was obtained when lemongrass irrigated after the total available water in the soil depleted to100%. The minimum essential oil yield obtained at 100% TAW was significantly inferior to all other treatments. The maximum essential oil yield obtained at 60% TAW improves essential oil yield by 69.9% than that obtained at 100% TAW treatment. The study showed that when the soil moisture depletion level increased and decreased from 60% TAW, essential oil yield of lemongrass decreased. This is in line with the findings of Singh *et.al*. (2000) who reported maximum essential oil yield of lemongrass recorded around mid of the tested irrigation water levels (from 0.1 to 1.5 times cumulative pan evaporation) at 0.7 IW: CPE ratio on deep sandy soils.

According to Singh (1999) soil moisture regime maintained at 0.75 irrigation water to cumulative pan evaporation ratio (IW: CPE) significantly increases lemongrass essential oil yields. The current finding is in line with the findings of Soha and Ashraf (2015) on rosemary plant who reported essential oil yield influenced by different levels of irrigation intervals based on different soil moisture depletion levels. Different reports also revealed that lemongrass responds differently under mild and moderate stress conditions and responses varied depending upon the level and duration of moisture stress (Singh-Sangwan *et.al*., 1994). Under water stressed conditions, total essential oil yield of lemongrass remained the same in different varieties with increased levels of geraniol and citral content. The same author reported that mild and moderate moisture stress substantially increases major oil constituents like geraniol and citral in different lemongrass species. This could be a possible relevance for lemongrass as drought stress adaptability for moisture stressed area.

Increasing soil moisture depletion means that reducing the frequency of irrigation and subjecting a little bit to stress. However, different studies on aromatic plants showed drought stress due to different irrigation regimes to enhance some of yield and yield components. For example, essential oil and proline contents of sweet basil increased in response to water stress by subjecting basil plant towards water stress just before harvesting by increasing soil moisture depletion level (Baeck *et.al*., 2001). On the other hand some reported that as the depletion level increased, drought stress initiated significant decrease in essential oil production in basil plant (Simon *et al*., 1992).

Moreover, Razmjoo *et al*., (2008) reported that drought stress in chamomile reduced essential oil yield.

Water use efficiency

The different soil moisture depletion levels significantly ($p<0.05$) influenced water use efficiency of lemongrass during both experimental years. Moreover, the pooled mean of two year analysis revealed that water use efficiency was significantly ($p<0.01$) influenced due to different levels of soil moisture depletion levels on lemongrass based on its essential oil yield per irrigation water used.

Maximum water use efficiency of $19.7*10^{-3}$ kg/m^3 was observed when lemongrass irrigated after 60% of the total available water in the soil was depleted (Table 3). However, the maximum water use efficiency recorded at 60% TAW treatment was not statistically different with that of 50, 40 and 30% TAW treatments. Contrary to this, the minimum water use efficiency of $12.4*10^{-3}$ kg/m^3 was recorded when lemongrass irrigated after 100% of the available water depleted. The minimum water use efficiency obtained at 100% TAW was statistically similar with that of 20% TAW. The study showed that irrigating lemongrass at 60% TAW improved water use efficiency by 58.9% than the 100% TAW treatment. Improving water use efficiency is an increasing concern through different irrigation practice to enhance yield of crop per irrigation water used. Different studies on different crops revealed that water use efficiency improved based on different irrigation practice like determining the optimum soil moisture depletion level before irrigation for specific crop, variety and agro ecology. The current finding is in line with the findings of Singh *etal*. (2000) who reported maximum water use efficiency of lemongrass recorded around mid of the tested irrigation water levels (from 0.1 to 1.5 times cumulative pan evaporation) at 0.7 IW: CPE ratio on deep sandy soils.

Table 3.Yield and water use efficiency of lemongrass as influenced by different soil moisture depletion levels at Wondo Genet during 2013/14 and 2014/2015 dry season (two harvests)

Treatment	Essential oil content (%) (Pooled)^{ns}	Essential oil yield (kg/ha)			Water use efficiency x10^3 (kg/m^3)		
		(2013/14) *	(2014/15)*	(Pooled)**	(2013/14) *	(2014/15)*	(Pooled)**
20% TAW	0.64	53.7^{bc}	95.5^{a}	74.6^{b}	10.8^{b}	19.8^{a}	15.3^{bc}
30% TAW	0.64	61.2^{abc}	103.8^{a}	82.5^{ab}	12.6^{ab}	21.7^{a}	17.2^{ab}
40% TAW	0.66	67.8^{a}	104.7^{a}	86.2^{ab}	15.0^{a}	21.7^{a}	18.4^{ab}
50% TAW	0.64	65.2^{ab}	102.8^{a}	84.0^{ab}	14.6^{a}	21.0^{a}	17.8^{ab}
60% TAW	0.64	70.6^{a}	115.6^{a}	93.1^{a}	15.4^{a}	24.0^{a}	19.7^{a}
100% TAW	0.63	49.3^{c}	60.3^{b}	54.8^{c}	11.5^{b}	13.3^{b}	12.4^{c}
$LSD_{0.05}$	Ns	13.4	27.5	15.2	2.9	5.7	3.19
CV (%)	8.7	14.5	18.8	12.7	14.7	18.7	12.6

*Means followed by the same letters with in columns does not differ significantly at $p< 0.05$ probability level. *significant at $p<0.05$, ** significant at $p<0.01$*

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Agroforestry Practices in Addis-Zemen and Alemsaga Watersheds

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Introduction

In Ethiopia, governmental and non-governmental organizations have been implemented agroforestry practices as a major component of soil and water conservation activities to curve natural resources and land degradation. However, the types of agroforestry practices applied, tree species planted and farmer's perception on utilization of the practices have not been studied and documented so far. Besides, factors affecting the expansion of agroforestry practices are not well known and the inventory of tree species and diversity on farm lands and reasons for using and maintaining these species have not been clearly documented.

Therefore, this study aims to fill some of the gaps on the information's and knowledge of existing agroforestry practices with tree/shrubs used and their role in supporting natural resources conservation for effective livelihood and ecosystem services improvement in the watersheds.

Materials and Methods

Study area

The study was conducted in Addis Zemen and Alemsaga watersheds located in Libokemkem and Fogera districts Amhara regional state, respectively. The watersheds are near Lake Tana at the upper part of Blue Nile Basin. The geographical location of the Addis Zemen and Alem saga watersheds are found at an average elevation of 1815 meter above sea level with mean annual rainfall that ranges from 800 to 2000 mm; and with mean annual minimum and maximum temperatures of 13.5°C and 26.1°C, respectively.

Data collection

Field observations were held along a transect walk accordingly, plots were established by measuring 10 m ×10 m. Five plots were sampled for each agroforestry practices. In each plot, all woody species were identified by their local and/or scientific names and identities to produce a more complete list of the woody plants in the study area. The environmental variables, namely altitude and position of each plot were measured with GPS. Trees, shrubs, and grasses were counted. Diameters at breast height (DBH) for trees and shrubs that have diameters ≥2 cm were measured by using calliper. Key informant interview and discussion with farmers groups were also carried out in order to assess relevant farmers view regarding agroforestry and support field measurement data.

Data analysis

Structural arrangement of agroforestry practices in the target area like plantation in active enclosure, tree plantation in gulley, scattered trees on-farm land, farm boundary, taungya, home-garden, live-fence and scattered trees on pasture land were described. Data for tree height and diameter were arranged in classes. The total number of tree species in a community is referred to as species richness. Richness of each agroforestry practice types is calculated as the number of species observed in each plot. In addition to this, importance value index (IVI) was calculated to demonstrate the importance of individual tree species on farm land and to compare the ecological significance of the species. It was calculated with three components (Kent & Coker, 1992) as follows;

$$IVI = RF + RD + RDO$$

Where;

$$Relative\ frequency\ (RF) = \frac{Frequency\ of\ species}{Sum\ of\ frequency\ of\ all\ species} x100\%$$

$$Relative\ density\ (RD) = \frac{Number\ of\ individuals\ of\ species}{Total\ number\ of\ individual\ of\ all\ species} x100\%$$

$$Relative\ dominance\ (RDO) = \frac{Dominance\ of\ species}{Total\ dominance\ of\ all\ species} x100\%$$

The collected data were analysed in Excel and SPSS Version 20.

Results and Discussion

Agroforestry practices implemented

Tree plantation in active enclosure

A total of 11 woody species were recorded and of all the woody species three of them were trees and accounts 27% of the composition while shrubs were eight and accounts 73%. The practices of traditional agroforestry system undertaken in the study area are summarized in Appendix 1. The major trees/shrubs found on tree pplantation in active enclosure area which are deliberately planted by the community in the Addis zemen watershed include *Croton macrostachyus, Justicia schimperiana, Acacia saligna Dodonaea angustifolia, Rumex nervosus, Sesbania sesban, Euphorbia tirucalli, Maytenus arbutifolia and Acacia bussei* species. Trees are planted in different designs consisting of different species. Mixed indigenous tree species are considered as a suitable for rehabilitation purposes. According to Vikram (2015), conversion of degraded land through mixed tree plantation rather than monoculture plantation may be better for meeting the diverse products needs of local people and environmental amelioration

Farm boundary plantation

In both the watersheds most farmers plant trees and shrubs along the boundary of their farms to protect their crops and as a source of different wood products. Among the familiar trees planted on farm boundaries include *Cordia Africana, Eucalyptus camaldulensis, Albizia gummifera, Ficus ovata, Sesbabnia sesban, Vernonia amygdalina Ficus vasta, Grevillea robusta and Solanum giganteum* . Trees are planted in a single line or multiple rows consisting of a mixture of different species. The trees are regularly pollarded and farmers used the branches for fuel, fencing and source of income. Pruned materials/branches are used as mulch and fodder. In addition to these, it offers shade for animals. Trees in boundary plantings and intercropping systems, practiced deliberately planted and managed. This idea is similar to (Gessesse *et al.,* 2011; Gil L. *et al.,* 2010) that boundary plantation provides additional services as wind breaks, shelter belts and boundary demarcation.

Taungya

Taungya **s**ystem is a form of agroforestry system in which short term crops are grown in the early years of the plantation of a woody perennials species in order to utilize the land, control weeds, reduce establishment costs, generate early income and stimulate the development of the woody perennials species. Taungya farming involves the growing of annual or biennial agricultural crops along with the forest species during the early years of establishment of the forest plantation (Agera *et. al.,* 2010).

The planting of *Eucalyptus camaldulensis with* maize and green pepper at the early establishment of the eucalyptus is commonly practiced. Farmers care for the trees and at the same time grows crops for a year; then the woodlots take over the plots. According to V.K.Agyeman (2003) food crops, especially annuals were interplant with determined tree species. The food crops were normally cultivated for two years, after which the shade from the trees impeded further cultivation of the crops. Currently every household has planted *Eucalyptus camaldulensis* for the reason that it is the only resource used for construction of houses, making farm implements and considered as cash crop. Wood and food production is the ultimate objective in the taungya system and agricultural crops are planted with proper agronomic practices to utilize the land efficiently or to get some amount of crop products during establishment period.

Trees on pasture land

The following trees: Acacia abyssinica, Cordia africana, Ficus ovate and Sesbania sesban play an interactive role in animal production by providing shade and fodder. The fodder trees are left to grow sufficient wood so that they serve as live fence around grazing units and farmyards. The trees are lopped periodically for fodder and sometimes fruits and pods of standing trees/shrubs are consumed. The major livestock are cattle, goats, sheep, donkey, and mule. *Cordia africana* is an important feed source for cattle, sheep, and goat during dry season. *Acacia abyssinica* is also a liked by goats while *Sesbania sesban* is liked by cattle, goat and sheep. *Cattle, sheep, and goat eat ficus ovate*. *Ficus ovate* propagation is performed by cutting the branches. It commonly used as live fence around homestead and farm boundaries. Almost all of the respondents use trees/shrubs for feed during dry season. The most important parts of fodder species were found to be leaves and new shoots. *Ficus ovate, Cordia Africana* and *Sesbania sesban* are green in the dry season that helps as supplementary feed during dry months.

Home garden Agroforestry

In the home garden agroforestry category, 12 woody species were recorded and of all the species 5 (42%) were trees; 5 (42%) were trees/shrubs; whereas 2(16%) were fruit trees. In most cases, farmers in the study area posses' perennial crops, annual crops, poultry, sheep, goat, equines, cattle, and bees in their compound where tree-crop-animal interactions is clearly evidenced and support each other. Foliage biomass enhances soil fertility and improves crop yield. The higher soil fertility from animal manure also contributes to the higher performance of trees and shrub as well as annual crops around homesteads. The different parts of trees were used for livestock feed. The flowers of the trees and crops are also used for bee farming. Kanshie (2002) who reported that home gardens tree supports the idea and shrubs, apart from optimizing the yields of diverse crop/tree species, regularly replenish soil fertility and productivity through continuous supply of organic matter and through protection from erosion and leaching. Fruit trees such as *Rhamnus prinoides, papaya, and Psidium guajava* fruit trees are also found in the components of this agroforestry. Women prefer home garden AF trees (*Rhamnus prinoides)* to manage and control closely while men focus wood lot plantation anywhere. The intimate mix of diversified agricultural crops and multipurpose trees help to improve biodiversity and plays a significant role for income generation. The trees/shrubs *Eucalyptus camldunesis, Sesbania sesban and Rhamnus prinoides* dominates the area and the most appropriate niche for these species is found to be homesteads. Mulu (2009) reported that in tree inventory, the number of tree species in traditional agroforestry practices varies from place to place and trees and shrubs are found in different niches.

Importance value index (IVI)

Importance value index was calculated for those tree/shrub species with a (dbh) of ≥ 10 cm. On-farm tree inventory shows that the species with the highest IVI value were *Eucalyptus camaldulensis* (56%) from homegarden; *Dodonaea angustifolia L.* (47.9 %) from tree plantation on active enclosure; and *Nuxia congeta*(57.9 %) from gully rehabilitation plantation. The high IVI values for tree species were because of their high relative density and relative frequency. On the other hand, the high IVI values of the species were because of its high relative basal area though it had low relative density and relative frequency. According to (Zegeye *et al.*, 2011) IVI value is an important parameter that reveals the ecological significance of species in a given ecosystem. Some trees/shrubs with < 10 cm (dbh) were common and important to the farmers. The diameter class distributions exhibited different trends from species to species. Similarly, the height class distributions exhibited different trends from species to species within the watershed.

Conclusions

Different trees/shrubs which possess high biomass and leguminous rooted species are needed for the watershed in line with the improvement of soil fertility and conservation. Trees and shrubs which are planted in different soil and water conservation structures have got good acceptance by the community and the degraded area is rehabilitated and restored. This practice has also great role in soil fertility improvements, improving crop yield, forest product demand, income generation, fuel wood and livestock fodder production as well as for environmental amelioration. *Sesbania sesban, Croton macrostachyus, Cordia africana, Acacia abyssinica, Nuxia congeta, Justicia schimperiana and Eucalyptus camaldulensis* are widely planted and adopted in the area and eco-friendly for different ecosystems. Hence, agroforestry practice should be incorporated as an option package for livelihood improvement and climate change mitigation and in sustaining watershed management.

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The Impacts of Climate Change on Livestock Production and Productivity in Ethiopia

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Introduction

In Ethiopia, a significant change in climate has already occurred and this change affected the livestock production system in the country (Anne C. W., 2013). Mean annual rainfall shows large spatial and temporal variation. Data analyzed in selected stations indicated that temperature has been increasing by 0.37^0C every ten years (Kefyalew A. and Tegegn F., 2012). Climate change projection models also indicated that the mean annual temperature in Ethiopia expected to increase from 0.9 -1.1°C by 2030, 1.7 - 2.1°C by 2050 and 2.7-3.4°C by 2080 (Kefyalew A. and Tegegn F., 2012). Same authors also indicated that the ruminant livestock population in Ethiopia show increasing trend (reference. However, climate change has a negative impact on the population dynamics (Kefyalew A. and Tegegn F., 2012). According to Solomon (2001); Kgosikoma (2006); Angassa (2011), there are correlations between climate variability, particularly rainfall, and livestock population dynamics in Ethiopia.

Climate change impacts on livestock could be mainly exhibited through changes in the productivity of rainfed crops and forage, reduced water availability and more widespread water shortages, and changing severity and distribution of important livestock pest and diseases.

Despite a number of knowledge and information generated on impacts of climate change and adaptation options on livestock sector in Ethiopia, there is limited effort to review and synthesis the impacts of climate change on livestock and demonstrate the different adaptation options.

This review and synthesis work is also increasingly important to identify key knowledge/information on adaptation options, which could help to enhance understanding of policy makers for setting appropriate actions in place.

Methodology

The methods used to gather and synthesized all relevant documents related to vulnerability of livestock sector to climate change included a combination of various sources. It included gathering of primary 'indicator' data, review of climate data from the National Meteorological Agency (NMA), Secondary desk-based review of key documents including: UNDP's document entitled as climate change and country profile for Ethiopia, IPCC reports, Ethiopia's National Adaptation Program of Action (NAPA) and other relevant research reports. Various national research strategic documents, national and international journals, national livestock development strategies, policies and programs were also reviewed.

Livestock production systems

Ethiopia has a diversified climate types that ranging from semi-arid desert type in the lowlands to humid and warm (temperate) type (NMSA 2001). The size and diversity of major agro-ecological zones provide suitable support for large numbers and classes of livestock and different livestock production systems (Funk et al 2012). The system constitutes a large component of the Ethiopian agricultural sector and well integrated with the farming systems found in the highlands and provide the sole means of subsistence for the mobile pastoralist in the lowlands.

Pastoralism and agropastoralism as mode of production based on extensive and mobile livestock husbandry exists in all federal states but are predominant in dry lands agro-ecologies of Ethiopia. It is the dominant system in Afar, Somali and Oromia and parts of the Southern Nation Nationalities and Peoples region (SNNP), Gambela and Dire-Dawa administrative council (MoARD, 2004). About 29 ethnic groups are generally identified as Pastoral and agropastoral community (Biruke, 2003; MoARD, 2004).

In the mixed crop-livestock production of the highlands where 70% of cattle population exists, livestock production is an integral part of the farming system. Besides their direct economic importance in the provision of food (e.g. meat, milk) and raw materials for industry (e.g. skins), livestock play a number of other functions, including the provision of draft power and manure for crop production; saving and social display (Ayele et. al., 2003; Beyero et al., 2010). Over 70% of cattle and 80% of equines are found in the highlands of the country where over 90% of the farmers use oxen for crop production (Amede *et al*., 2005).

Climate change impact on livestock

Climate change impact on livestock are discussed in detail below under sub-sections of livestock dynamics, feed quantity and quality, water, livestock diseases, farm power in mixed crop-livestock production system and livestock biodiversity.

Livestock population dynamics

Studies had reported that there are correlations between rainfall variability and livestock population dynamics (Solomon, 2001; Kgosikoma, 2006; Angassa, 2011). According to Kefyalew A. and Tegegn F., (2012), sheep ($r = 0.535$, $P < 0.05$) and cattle ($r = 0.669$, $P < 0.001$) were negatively affected by climate change in Ethiopia. Whereas goats were having positive relationship ($r = 0.789$, $p < 0.001$) (Fig. 1).

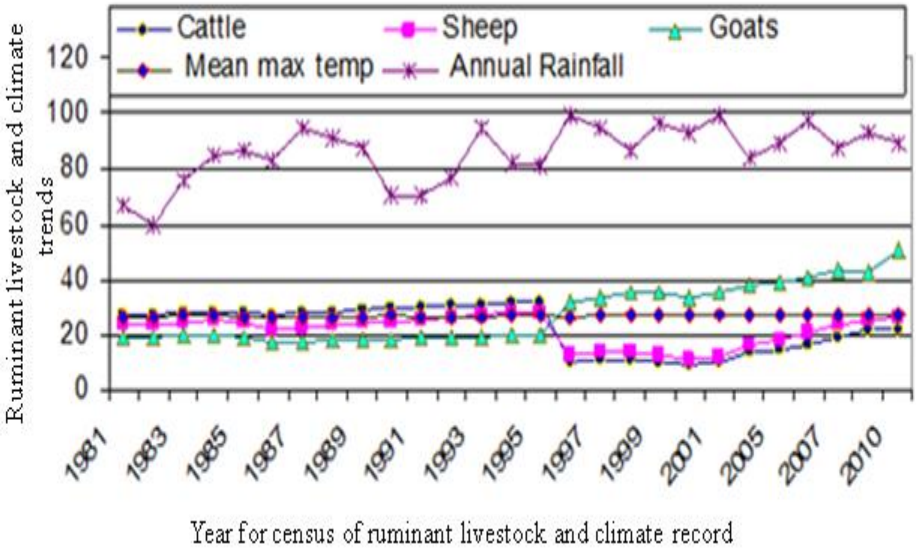

Figure 1. Trends of ruminant livestock dynamics and climate change (Source: Kefyalew A. and Tegegn F., 2012) (Annual rainfall is N x 10; Cattle, sheep and goats are N x 100000 and Mean max temp is N x 0. where N is ruminant livestock and climate trends)

Studies conducted in Borana, southern Ethiopia showed that, rainfall variability had a highly significant effect on the stability of herd dynamics (Angassa and Oba, 2007, Zelalem et. al., 2009; Angassa, 2011) (Fig. 2). The decline in herd size over years was attributed to the impact of drought (Angassa, 2011). The average cattle holding per household was declined by 54% between 1983 and 2003. Subsequent loss of cattle herd during the1983/84 droughts accounted on average 52 head of cattle per household. Overall, multiple droughts (1983/84, 1992/93 and1999/2000) resulted in a massive loss of cattle herd with an average loss of 49% under communal land use.

Another study in Borana, Ethiopia showed that rainfall variability greatly influenced herd dynamics under the communal and ranch management in terms of herd die-offs and lower birth rates, which also considerably affected milk production for household consumption. Droughts of the 1980s and 1990s caused 49% herd losses under the communal land use, while 57% of the cattle mortality under ranch management was attributed to droughts of the 1990s (Angassa and Oba 2007; Angassa 2011). A similar study by Zelelem et al. (2009) showed that, owing to the severe drought manifested in 2004/2005, a total of 36,127 cattle heads died only during three months (November 2004 to January 2005) in the Moyalle district. The number of cattle heads died in four peasant associations (Pas) accounted for about 35% (12,702 heads of cattle) from the total figure of the district.

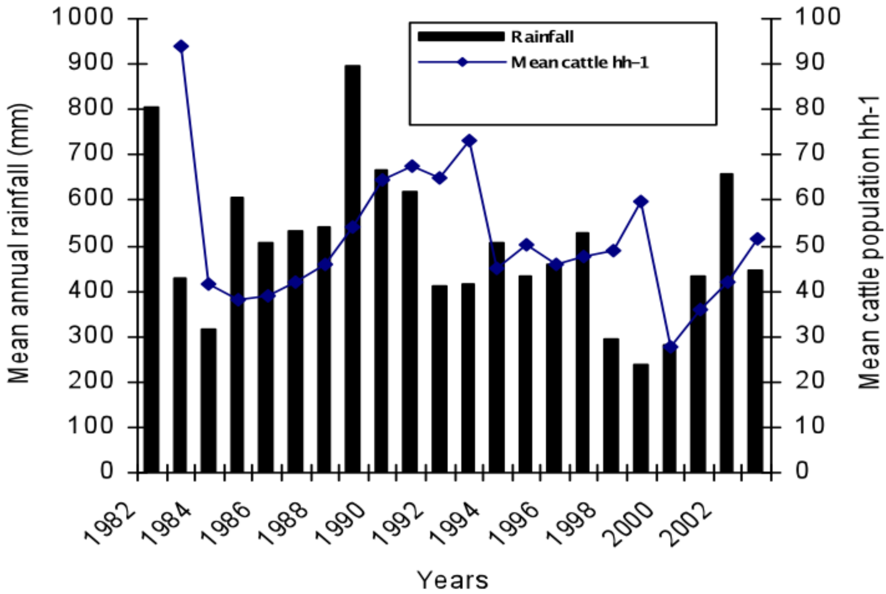

Fig. 2 Relationship between inter-annual rainfall variability and cattle herd dynamics (Source: Angassa and Oba, 2007)

Other reports also indicated steady decline of average cattle holding per household from as high as 90 head to less than 65 head during the period 1980 to 1997, with cumulative mortality loss of 140 head per household in the Borana pastoral areas (Solomon Desta, 1999; Zinash *et. al*., 2000 and Getachew *et. al*., 2003). Similarly, Cossins and Upton (1988) noted that climate change scenarios adversely impacted cattle herd dynamics in southern Ethiopia, which often seem to be a direct influence on forage productivity where herbivores have insignificant impact.

On the other hand, the livestock holding per a household among the Somali pastoralists in Shinile zone, in eastern Ethiopia have declined from 809 Tropical Livestock Unit(TLU) before 1974 to 483 TLU after 1974. During the 2001/3 drought, the Somali region alone lost more than 4.6 million livestock representing almost 25%of the total cattle, 70% of the total small ruminants and 5% of the total camel population of the region. This has left almost 40% of the pastoral households of the region food insecure and destitute (Amha, 2006).

Similarly, study reports by ICRA (1999) show decreasing trend in livestock number in Central Rift Valley of mixed crop-livestock production system. According to ICRA (1999), reduction of livestock number is perceived by farmers as to be due to extreme variability and near total change of climate. The great reduction in livestock numbers is also described by the farmers as due to crop failure that necessitated sell of livestock to purchase food. Livestock diseases including foot and mouth and anthrax and external and internal parasites are also contributed to the problem (ICRA, 1999).

Feed quantity and quality

The pastoral livestock production is totally dependent on range vegetation (MoARD, 2004), while in mixed crop-livestock system of agro-pastoral areas, the bulk of the biomass fed to livestock is obtained from residues of food crops, which are increasingly becoming a year-round forage supply (Sisay et al., 2002; Romney et al. 2003).

The effect of climate change on the range lands is remarkable. In many of the cases, the rangeland is changed into bare termite mound. In situations where some plants are seen, the general indication is that there is encroachment of unpalatable bushes (Zelalem et. al., 2009).The decrease in total amount of rainfall and associated increase in average temperature reduces the availability of feed and water to the pastoralists and the livestock in the Somali National Regional state (Devereux, 2006). Similarly, the western and southwestern lowlands generally produce higher amount of low quality grasses because of unfavorable climate for desirable, productive and high quality forage species (Workneh and Woudyalew, 2004). Climate change scenarios adversely impacted on livestock species compositions in which trends of camel and cattle population increased and decreased, respectively. in southern Ethiopia, which often seem to be a direct influence on forage productivity where herbivores have insignificant impact (Angassa 2011). As shown in figure 3, there was a significant decrease in annual primary productivity or forage productivity as the amount of rainfall declined; suggesting that rainfall variability could be much stronger in regulating availability of feed in such a way that increase in the amount of rainfall enhances annual primary productivity and a declined annual rainfall reduces it."

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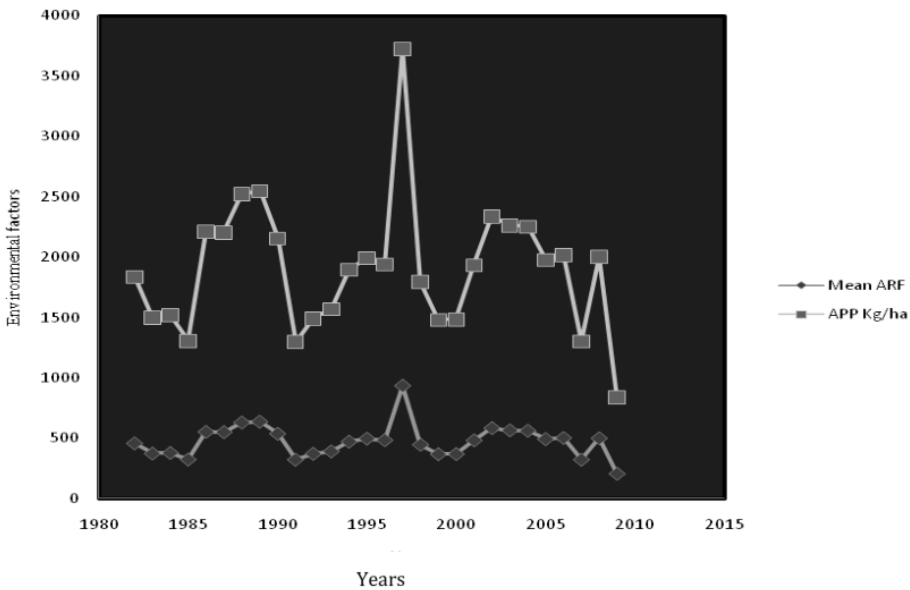

Fig. 3. Relationship between mean annual rainfall (ARF) and annual primary productivity (APP) (Source: Habtamu T., unpublished data in Angassa, 2011)

Major reduction in the quantity and nutritional quality of the vegetation available for grazing in Afar rangelands was reported by ANRS (2010) due to the decline in the amount of rainfall, the erratic nature of the rains and even the failure of the main or short rainy seasons, aggravated by high temperature. The replacement of the productive and highly valued grass species with low quality feed resources and unpalatable weeds have greatly reduced available consumable herbage accentuating the problem of poor pasture and feed scarcity. Feed scarcity is a serious threat as livestock malnutrition is causing high miscarriage rates and distress which reduced reproduction and production rates and mortality of weak livestock. Encroachment of unwanted plant species is resulting in deterioration of the rangelands in the pastoral areas. It has been indicated by FAO (2009) that woody species of both native and exotic origin pose the greatest threat to the rangelands of arid and semi-arid lowlands of Ethiopia.

At higher temperature, loss of moisture through evaporation and transpiration reduce growth and survival of plants. Desirable forage plant species are diminishing from grazing lands with reduced nutritional outputs of animals. Encroachment of unwanted plant species is resulting in deterioration of the rangelands in the pastoral areas. In Borena, encroachment of unwanted woody plant species (*Acacia drepanolobium)* have increased after the 1960s and worsened following a ban on the use of fire to control expansion of undesirable species and to increase productivity of the range land by adding organic matter into the soil (Zelalem et al., 2009). According to Coppock (1994), about 15 woody plant species are considered to be encroachers in the Borena rangeland. Even though there is no accurate information on the types and area coverage of unwanted plant species, rapid expansion of *Prosopis juliflora* in Afar region is a prime concern (ANRS, 2010). In the Somali region, the rapid expansion of *parthenium* commonly known as congress grass into the rangelands and crop farms is also alarming (Amha, 2006).

Livestock biodiversity

The dry land areas of Ethiopia are centers of diversity of animal species, breeds, strains, and their wild relatives that are of economic, scientific and cultural interest for food production purposes. Animal genetic diversity is fundamental natural resources for potential improvements in production and productivity of local agricultural systems particularly in areas where climatic limitations, disease challenges and water availability dictate the type of animal that can survive and produce to support livelihood needs (ESAP, 2003).

However, these important diverse animals' species are subjected to loss with frequent drought and death of breeding animals. As post drought restocking strategy, pastoralists are forced to introduce animals of different breed types that are not well adapted to the pastoral environment.

The changes brought about by climate have forced herders to look for new types of animals. Cattle and sheep, which were part of the Afar herds, are now decreasing in numbers, as more emphasis is put on goats and camels. Similarly, camels were rare in Borana pastoral areas, but are becoming very common (Alemayehu, 2003). In Borena, cattle in general are in danger of being replaced with camels and goats (Zelalem et. al., 2009). In Somali pastoralits, the species composition of livestock holding per household have also changed. The numbers of camels are increasing by 126.2%, goats by 73.7% and sheep by 47.1%, whereas the numbers of cattle and donkeys have declined by 77.5% and 48.6%, respectively (Amha, 2006).

According to Zelalem et. al. (2009) and Nigatu *et. al*. (2003), recurrent drought was the most severe reason for the genetic erosion of the Borana cattle. There are also emergency interventions involving restocking to the drought affected communities. After frequent droughts, the loss of Borana cattle is often compensated by other breeds that are readily available or cheaper. The genetic erosion for the Afar cattle in north eastern part of the country was estimated to be in the range of 45% to 73% (Belete, 1979) which was largely the result of the restocking programs conducted following the 1972-74 drought (Nigatu *et. al.,* 2003).

Another biodiversity loses observed due to climate change is replacement of key range vegetations by unwanted plant species. In Borena, desirable indigenous grass species have been lost due to the heavy grazing pressure induced by climate change (Zelalem et. al., 2009). A similar view has been shared by FAO (2009) indicating that *Crysopogon plulimosus*, *Cenchrus ciliaris* and *Themeda triandra* are remained desirable indigenous grass species in a state of continued decline. Similarly, in Somali region the decrease in a total amount of rainfall and associated increase in average temperature has brought change in range vegetation composition (Devereux, 2006). In Afar region, despite the pastoralists' indigenous mechanism of coping with the problems of feed and water shortage during the dry season and during drought years, the loss of specific feed varieties and their replacement by less palatable and hardy bush species has been reported (ANRS, 2010). According to Solomon M. (2009), erratic rainfall and excessive evapo-transpiration due to extended dry season caused drastic crop yield reductions, or crop failures, decreased herbage biomass yield and carrying capacity of grazing lands and loss of biodiversity.

In general, change in vegetation composition from grass land to woody and unpalatable plant species, has forced pastoralists to alter their livestock composition from grazing to browsing species. The implication is that, vulnerability of the livestock sector will be much higher as climate change unfolds.

Farm power

Animal power is a major farm power resource in Ethiopia to perform land preparation for growing crops, and transportation. According to Abegaz (2005), draft power ranks first among the objectives of keeping animals in the mixed crop-livestock production systems in Northern Ethiopia. Hence, owning draft oxen is the root base for the life of Ethiopian people. Tractors use is limited constrained by several factors such as economical and topographic factors. Moreover, long term tradition of use of draft animals for plowing coupled with favorable climates (e.g. absence of Tse-Tse flies) that also contributed to the high livestock population make animal power more attractive in Ethiopia.

According to CSA (2011), over 10 million oxen, which represent approximately 50% of all oxen in sub-Saharan Africa, 4 million donkeys that is the second largest population in the world, 347 thousand mules and 2 million camels are found in the country. Animal power can be broadly classified into two as traction animals which mainly used for plowing and pack animals which used for transportation purpose. Oxen are widely used for plowing while equines are used for transport. Crop and livestock production systems in the Ethiopian highland areas are highly integrated with increased yields of crops and crop residues combined with increased efficiency from draft power supporting the additional feed requirements of draft animals.

The vulnerability of farm power in Ethiopia to climate change stems from the fact that animals performance depends very much on the climate status particularly heat stress. Heat stress due to increased temperatures results less power outputs of both humans and animals. Rainfall variability has implications on feed and water availability. As a result of drought, biomass yield is reduced resulting in feed shortages especially during the dry season (Mulatu and Regassa, 1986). Primary tillage, which requires the highest power output of all agricultural operations, is carried out at the end of the dry season, during which feed shortage is at its worst. Therefore, any reduction in the annual biomass yields as a result of moisture stress causes severe reduction in power availability, which in turn has a negative effect on crop productivity or feed availability thus forming a vicious circle.

According to MoARD (2006), the number of draft animals available at house hold level is declining over time. As a result, over 29% of the farmers in the highlands are without an ox, while 34% have a single ox and 29% own a pair of ox with only 8% of the households having three oxen. The mule population is reportedly declined from 1.2 million to 0.35 million (MoARD, 2006) which has several implications on food production. Since oxen need to be paired traditionally to use them for work, more than 60% of the Ethiopian farmers in the highlands have either rent or borrow one or more oxen for cultivation. As a result, timely land preparation is not possible leading to substantial yield reduction.

Positive and linear correlations were reported between availability of draft animals and cereal production (Gryseels *et al.*, 1984; MoARD, 2006). In a similar study, farmers with one ox were found to plant an average of 32% more land with cereals each year than farmers with no oxen, while farmers owning two oxen could plant 60% more land to cereals than farmers with less than two oxen (ILCA, 1987; M0ARD, 2006).

Water availability and Disease epidemics

The erratic nature of the rains and even the failure of the main or short rainy seasons, aggravated by climate change, create a serious water shortage and stress particularly on pastoral and agro-pastoral households. As a result of the water stress, permanent water sources are now being over exploited (ANRS, 2010). In Borena also there is critical shortage of rainfall (unreliable, less intensity and duration), and hence ponds do not fill to their capacity and dry out fast, streams and rivers disappeared and boreholes dried out (Zelalem et. al., 2009). In most lowland pastoral areas livestock are driven 30 to 50 km in search of waterholes with longer watering interval of 3-4 days for cattle, 6-8 days for sheep and goats and 15-20 days for camel. The animals lose significant portion of body weight for long distance walk to watering points and back to the initial areas without getting feed en route (Mesfine, 2000).

There is a link between climate and epidemiological conditions of disease agents. Temperature, precipitation, humidity, and other climatic factors are known to affect the reproduction, development, behavior, and population dynamics of the helminthes, arthropod vectors, and the pathogen they carry. Climate change influences the emergence and proliferation of disease hosts or vectors and pathogens and their breeding, development and disease transmission (Reta D., 2009)

Heat stress

The response to heat stress and the level of tolerance vary with the species, body condition, size and production level of the animal as well as the degree and duration of occurrence of stress. Although accurate information are currently lacking on extent of loss in productivity under the pastoral herd management system, drought simulated feeding trial conducted on different species of Somali region animals in eastern Ethiopia showed 30% weight loss and 25 % death in cattle; 50% weight loss and 25% death in case of goats, and pronounced emaciation in case of sheep when subjected to 50% and 75% reduction of the daily dry matter intake for a period five to ten weeks (Amha, 2006). The rise in temperature above the cardinal optimal range disrupts the normal physiological and biochemical activity of animals. The feed intake, reproductive efficiency, growth, and milk production continue to decline with increased mortality of young animals (Thornton et. al., 2009).

Responses to climate change impacts

Because of high climatic variability, communities living in marginal environments of Ethiopia have developed strategies to cope with drought. The high vulnerability of people to climate variability is attributed to a large extent to their low adaptive capacity (IPCC, 2007). Improving adaptive capacity is important in order to reduce vulnerability to climate change (Elasha *et al*., 2006).

Despite the low adaptive capacity of Africa in general and Ethiopia in particular, people have developed traditional adaptation strategies to face the great climate inter-annual variability and extreme events. They have been trying, testing and adopting different types of coping strategies (Elasha *et al*., 2006). This reinforces the observation that local people have perceived, interacted with, and made use of their environment with its meager natural resources and changing climatic conditions. This practical coping mechanism is particularly true for the drought prone areas in Ethiopia and in the African Sahel region, which is susceptible to frequent climatic hazards (Elasha *et al*., 2006).

According to different sources (ECBP, 2007; Elasha *et al*., 2006; Admassie, 2007; Hellmuth *et al*., 2007), the most common climate variability and climate change adaptation strategies in Ethiopia are:

Changing livestock types or diversification of livestock

Livestock keepers seem to increasingly shift from vulnerable to more adapted species (Seo et al. 2009). Differences among livestock species in their tolerance to drought, heat stress, or water and feed shortages, offer livestock keepers the possibility of choosing species that are better adapted to changing environmental conditions (Seo et al. 2009). Shifts in the balance of species can occur as responses to climate variability and changes and pastoralists classically keep multispecies herds to take advantage of different ecological niches (Speranza 2010). Diversification of herd composition among the Borana herders is on the rise (Homann et al. 2008; Zander 2011).

Conservation of dry season grazing reserves and use of crop by products

One adaptation mechanism to cope with feed and water shortages is the use of dry season grazing reserves. During the rainy season when grazing and water is available, livestock are kept around villages' area. As pasture and water is depleted and the dry period advances, livestock are taken to dry season reserve areas. Transhumance is also practiced as coping mechanism based on traditional norms and resource management. In most area, duration of dry season ranges from3to 7 months depending on the onset of the rain and severity of the drought. However, transhumance to dry season areas is restricted because of rangeland resource shrinkage and degradation. As a result, some pastoralists and agro-pastoralists in Somali region have started fencing few grazing areas to conserve fodder for their own stock. According to Bruke (2003), agro-pastoral communities depend on crop residues to feed livestock in good rainy season. In bad seasons, they collect stalks of maize and sorghum, conserve and feed their livestock.

Minimizing watering frequency

Livestock watering frequency primarily depends on the season, type of livestock and distance from watering points. Reduced frequency of watering is a common coping mechanism in areas where watering points are far from bass village. Accordingly, cattle have access to water every 3 days, sheep and goats every 5 to 7 days and camels every 10 to 12 days. Pastoralists who are residing close to perennial rivers and water points provide water for their animals every day (Biruk, 2003).

Sale of livestock

The primary interest of pastoral family is maximization of herd for insurance and security purposes than sources of cash. In good years, pastoralists living close to towns do sell livestock products such as milk and butter. In addition, male sheep and goats are sold for the purchase of cereals and household food supplies and to cover expenses for medical care, payment of debt, taxes and social obligations. In addition, during post drought, male stocks are sold for the purchase of female breeding stock from the adjacent highlands. In pastoral area, sale of livestock is a major coping strategy in years of climatic crisis to balance the livestock number with available feed and water resources. However, sale of livestock in particular young and productive cattle has serious limitations because when young and productive animals are sold out, the system will become less productive and sustainable (Biruk, 2003).

Adaptation options to Challenges of climate change on farm power

Several options can be used to improve availability of farm power. These could be in the form of mitigating the effect of drought on animals and human beings such as shortage of drinking water and disease. Other options could be in the form of introduction of technologies to make better use of the available power or to look for alternative power sources.

Improving performances of draft animals

In order to improve the performances of the available draft power, measures could be taken in the form of availing animal feed technologies or improving the harnessing and tillage implements systems. Conservation and utilization of hay from natural pastures (hay making with local grasses) as well as feed supplements such as urea treatment applied. Improving harnessing systems such as the use of proper padding can increase the draft power output of animals. Cross breeding for draft power can enable farmers to use fewer animals to develop the same power output, which has got implications on efficient use of feed (Thornton et. al., 2009).

Introduction of improved implements

Improved tillage implements can increase efficiency of oxen by either reducing the draft force require for tillage operations or by increasing the work rate. Different types of implements such as the animal drawn moldboard plow, which reduces the number of times the land has to be plowed thereby reducing traction requirements can be used to make the available draft power more efficient. The sweep cultivator, which requires lower draft power and which operates wider than the traditional tillage implement, *Maresha*, can also be used to undertake secondary tillage operations thereby improving the work rate of draft animals. Other implements such as animal drawn row planters and tie ridgers can also be used to improve crop productivity, which in turn improves feed availability. Introduction of forage choppers can be useful to improve efficiency of feed. Weeding implements make labor more efficient for timely operations while use of draft animals for weeding with appropriate implements can alleviate the problem of labor shortage during weeding.

Wider use of mechanical threshers and shellers can reduce the need for oxen and other animals. This could be attractive to farmers who want to fatten their oxen after finishing tillage operations and sell them at higher prices thereby avoiding the need for keeping animals throughout the year just for the purpose of tillage. Farmers can then buy oxen again at the beginning of the rainy season, which will improve feed availability and household income.

Animal drawn carts improve the capacity of animals for transportation of products, inputs and people. In lowland areas with plain topography, the use of carts can be successfully introduced. In the rift valley of Ethiopia, donkey carts are being extensively used. Further improvement of the existing carts and introduction of animal drawn carts including oxen carts in other areas could improve power availability to rural people.

Conservation tillage

Conservation tillage generally aims at reducing the intensity of tillage. There are different forms of conservation tillage adapted to different regions of the world depending on the socio-economic and environmental conditions. Where sufficient rainfall and well drained soils are present, no tillage systems in which plowing is replaced by direct planting with appropriate equipment followed by use of herbicides for weed control can be applied. Zero tillage has been widely adopted in Southern American countries and in the US. Locally adapted conservation tillage systems have also been developed to suit the semi-arid areas of Ethiopia (Temesgen, 2007). Introduction of conservation tillage systems that suit local conditions can help reduce the need for draft power.

Use of alternative draft animals

Alternatives to the current draft animal use (i.e. a pair of oxen) for tillage, single animal operations that also need introduction of single animal harnesses and associated implements can be considered. V-shaped yokes have been developed by the Agricultural Implements Research and Improvement Center (AIRIC), which can be used to improve power out puts of single animal harnessing. Implements that require lower draft power are also available to match the power output of the single animal.

Following climate changes, in particular, increased temperature and feed shortage, the use of alternative power sources to oxen becomes necessary. The tradition of using animal power, which started in the highlands, mainly employs oxen for tillage operations while equines are mostly used as pack animals. However, with the introduction of improved harnessing and implements, horses and mules can be used for tillage. Moreover, through careful selection of working periods in relation to reproductive cycles, cows can be used for traction.

In low land areas, alternative power sources can be used including donkeys and camels. Field test results carried out at Melkassa Research Center have shown that a single camel can generate draft power equivalent to a pair of oxen (Melesse Temesgen, Unpublished data). Moreover, camels and donkeys can survive on low quality feed, which makes them appropriate for low land areas with deteriorating conditions of feed availability under changing climate. Harnesses and implements appropriate for use with camels and oxen have also been developed at Implements Research and Improvement Center (AIRIC). Introduction of these implements and harnesses together with training of animals is recommended.

Conclusions

The prime effect of climate change and variability is genetic erosion of indigenous breeds with declining reproduction and productivity of the animals. In some pastoral areas genetic loss of 45% to 73% has been reported. The change in climate and the associated variability also influenced the spatial and temporal availability of feed. Scarcity of water and distance to be covered in search of water has increased with declining precipitation. The pastoralists and the agropastoralists being there for centuries have developed their own traditional coping strategies. Among others mobility, herd diversification, feed conservation, conflict resolution, herd reduction etc. have tended to sustain the system. However, the increased encroachment of non pastoral systems and the steady change in climate undermined the value of traditional coping strategies. External institutional and organizational supports by and large neglected the impact of climate change and variability and were not sustainable and fruitful.

As observed in the present study there is great variability and also changes in climatic condition of the country. The changes have already resulted in unestimated amount of loss in livestock productivity and the environment. The impact is severing in the arid and semiarid pastoral and agropastoral areas that cover over 61% of the total geographic area of the country. Feed and food security, protection of the natural resource and improvement in the livelihood of the pastoral and agropastoral community can only be attained if we able to manage the risks **r**educe vulnerability and enhance productivity of the livestock under this changing and variable climate. Decisions, recommendations, mitigation strategies and development interventions need to base analyses of the past, present and prediction of the future climate of each locality.

Feed and water availability for livestock has greatly reduced, and livestock number has declined. This has already claimed lives of millions of financial and capital assets and threatens the livelihoods of great majority of marginalized pastoralists under threat. Due to climate change, human and livestock diseases as well as crop diseases and pests have shifted in geographic spread, and vector borne and water borne diseases are causing serious losses. Ecosystem is shifting in a pace difficult to cope with. Bio-diversity losses are quite phenomenal. Farmers (crop and livestock) in Northern, Central and Eastern part of Ethiopia have long recognized these changes. They have set out strategies to cope with variability taking different tacks. Their systems based on trial-and-error over long years of struggle for survival have in fact made significant contribution and have made possible production of food for the nation and for their family. The question is whether their adaptation strategies ranging from field level to livelihood levels will be adequate as climate change unfolds.

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Impacts of Climate Change on Water, Soil, and Forest Resources

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Introduction

As a major climate change properties, rising temperatures and/or increasing rainfall variability is already imposing significant challenges to Ethiopia (Jennie *et al.*, 2010; IPCC, 2007; Bekele, 2017). These challenges have been amplified by extreme events having social and economic impacts. In fact, regions with an arid and semi-arid climate could be sensitive to even significant changes in climatic characteristics (Boko, 2007).

Hydrologic cycle, forest resource composition and growth, soil properties and process were altered and will continue to alter by climate change and this exacerbates land degradation (Bekele 2017; Brevik, 2013; Jennie *et al.*, 2010; Lukac *et al.*, 2010). However, Pimentel (2006) and Brevik (2013; 2012) reported that climate change has positive and negative effect on the land resources. In order to embrace all round benefit and adversity of climate change critical review of current knowledge and research findings is important.

The aim of this paper is via critical review to highlight priority targets for upcoming research and to summarize the observed and projected impacts of climate change that provide information's. This information is not intended as a comprehensive review of climate change impacts on Ethiopian land resources, but instead is meant to illustrate some of its major features.

Climate change impacts: review and discussions

Trends of Climate Change

Globally, there will be average temperature increase of 2°C by 2100 (IPCC, 2007). Similarly, IPCC (2001) predictions showed that global temperature will increases by 1 to 3°C by the mid-21st century and by about 2 to 5°C by the late 21st century. Over both the last 140 years and 100 years, the best estimate is that the global average surface temperature has increased by 0.6 ± 0.2°C (Figure 1).

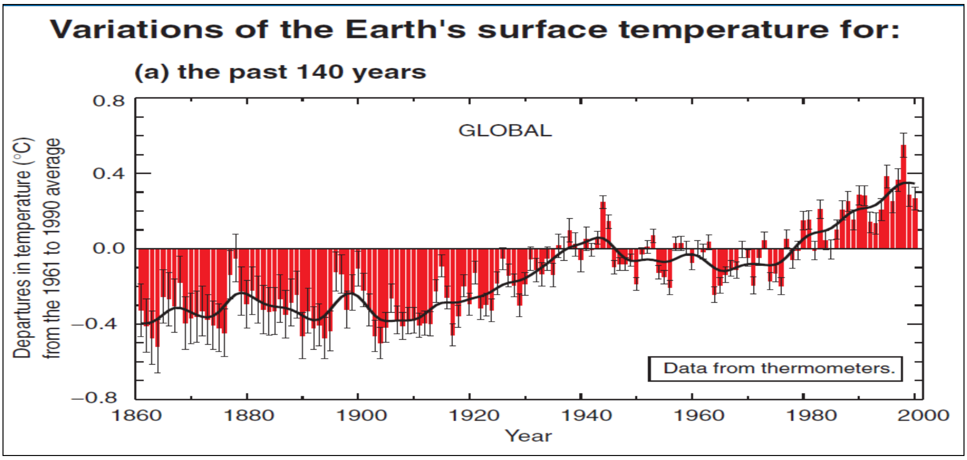

Figure 1: Variations of the Earth's surface temperature over the last 140 years and the last millennium (source: IPCC (2001)).

In Ethiopia an increment trend was observed for mean annual temperature by 0.37^{0}C per decade between 1951 and 2006 (NMA, 2006) and 1.3^{0}C increment between 1960 and 2006 (IPCC, 2007). The projected trend also shows that an increase of average temperature by 0.9 to 1.1^{0}C by the year 2030 as compared to the period 1961 to 1990 (NMA 2006). Temperature effects are often better understood than others climate parameters. However, precipitation has much larger spatial and temporal variability than temperature, and it is therefore more difficult to identify the impact it has on changes in many systems (IPCC, 2007). Precipitation on the other hand remained fairly stable over the last 50 years when averaged over the country. However, the spatial and temporal variability of precipitation is high (Figure 2). According to NMA (2006) report, the expected variation for annual precipitation will be 0.6 to 4.9% by 2030. Mekonen et al. (2017) also reported that there is a considerable inter-annual variability and increments of rainfall. Potential evapotranspiration also varies considerably and, like rainfall, it is highly correlated with altitude (reference). Unpredictable flood and drought is considered as an indicator and posed by climate change (reference).

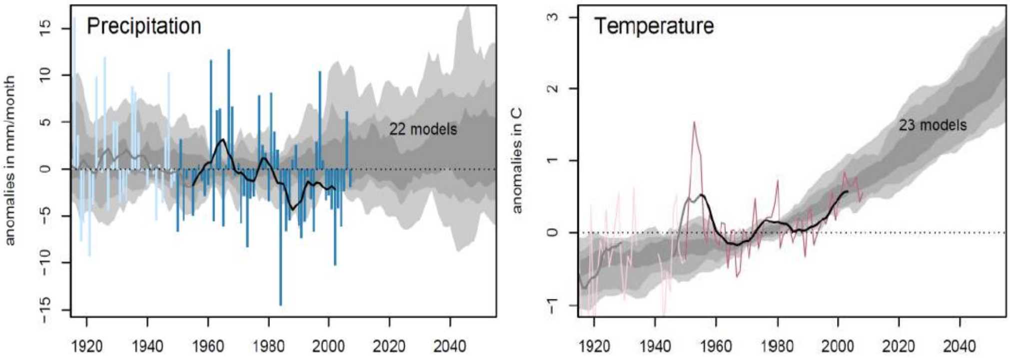

Figure 2: Observed precipitation and temperature changes in Ethiopia (source: Keller (2009))

Impact of climate change on water resources

Climate change is increasing the number of people living in water stressed regions globally (Bates *et al*., 2008). According to IPCC (2007), the population at risk of increased water stress in Africa is projected to be between 75 and 250 million and 350 and600 million by 2020s and 2050s, respectively. Moreover, yields from rain-fed agriculture could be reduced by up to 50% in countries that depend mainly on rain-fed agriculture. The progressively changing land use and land cover pattern along with climate variability result in food insecurity and declining water availability, and cause erratic rainfall over the country finally leading to poverty and environmental damage (Abebe, 2007).

Though, Ethiopia is known to be the water tower of east Africa, the impact of climate change has been affecting the spatial distribution of the resources. Climate based studies showed that there is a dramatically decreasing trend on water resources of the country due to climate change. The disappearance of Lake Haramaya is one of the recent phenomena in Ethiopia (Zeray *et al*., 2007; Wakgari, 2005). According to a study by McCartney (2012) shows that changes in climate affect both water availability and demand of Blue Nile River. The flow of Nile is predicted to decrease by about 40% by year 2025. Moreover, shrinkage of Zeway Lake is evidence to impact of climate change (Zeray*et al*., 2007). Runoff from the watershed is likely to decrease as observed from analysis of projected climate scenarios. Thus, a projected drop in the lake level up to two third of a meter and water surface area shrinkage to 25 km^2 which is about 6% of the base period is expected in the third quarter of the century (Zeray*et al*., 2007).

Water balance study result for Lake Tana shows that increasing temperature due to climate change results in increasing lake evaporation consequently decreasing in depth of the lake (Zemede, 2013). Another study by Taye *et al.* (2011) confirmed that as a result of climate change and variability, the water level in the lake fluctuates and also quantified the impact. Hailemariam (1999) indicated that Awash River is highly vulnerable to climate change. Accordingly, a decrease in rainfall by 20% coupled with an increase in temperature by 2°C would result in a 41% decrease in the annual runoff in the basin. Even a temperature increase of 2°C without precipitation change would result in a 9% decrease in annual runoff. In general, climate change results in a substantial decrease in annual runoff over the Awash River Basin (Hailemariam, 1999).

Climate change and fluctuations also affect the use of agricultural land associated with irrigation; complicate the design, operation, and management of water-use systems. This in turn has the potential to disrupt livelihoods, increase poverty and cause marginalization of poor and escalate inequality (reference). Many concerns and issues related to water resources are increasingly linked to climate change. Given the economic role of the water resources, climate risk will be too costly to be tolerated and urgent measures should be taken to mitigate the impacts through adopting feasible strategies which include storage, increasing water productivity and use of efficient technologies. Moreover, relevant and practical research inputs are highly important to overcome gaps and deal with challenges in the process of managing the water resources.

Impact of climate change on soils

Climate change has effects on soil properties and processes (Pimentel, 2006; Brevik and Homburg, 2004). Soils are integral parts of several global nutrient cycles through the Carbon (C), Nitrogen (N), and hydrologic cycles. Carbon and Nitrogen are important components of soil organic matter, carbon dioxide (CO_2), and nitrous oxide (N_2O) which are the most important of the long-lived greenhouse gases (Hansen *et al.,* 2007; Brady, 2008). Soils naturally sequester C through the soil-plant system while plants photosynthesize and then add dead tissues to the soil (Bervik and Honburg, 2004). Carbon is also naturally emitted from soils as CO_2, and methane (CH_4) gases due to microbial respiration, with the form of the C gas. Human management and climate change, in turn, is expected to influence soil erosion and nutrient cycle in the soil (Brevik, 2012). The interaction between soils and temperature believed to be changed along the time. This might have direct impact on the services provision from soil ecosystem. As shows in (Figure 3) different tillage practices have an influence on soil organic C along the time. In addition, changes in organic carbon content are rapid, immediately following tillage changes and stop as the soil reaches carbon equilibrium (Figure 3). Similarly, several studies have reported the increment of organic C due to tillage and soil management practices in Ethiopia (Assefa 2007; Damene *et al.,* 2012; Demelas and Stahr 2010; Gebreselassie and Belay 2013). Soil organic matter and climate change have mutual interaction via C and N cycles (Brevik, 2012). The change occurring on organic matter alone in the soils would have strong influences on others soil properties. It was also found that the increased atmospheric CO_2 has effect on the CO_2 fertilization and soil-plant system (Coughenour and Chen 1997). However, recent studies indicate that the CO_2 fertilization effect may not be as large as originally thought (Poorter and Navas 2003; Zaehle *et al;* 2010). Therefore, elevated CO_2 levels will not necessarily lead to increased soil C sequestration, but may instead result in more C turnover (Eglin *et al;* 2011). This turnover affects plant growth and influence N mineralization (Zaehle *et al;* 2010). CO_2 enrichment increases the soil C: N ratio and leads decomposing organisms in the soil in turn which need more N and which could reduce N mineralization which ultimately could leads to plant productivity reduction (Hungate, *et al*; 2003; Gill, *et al*; 2002; Reich, 2006).

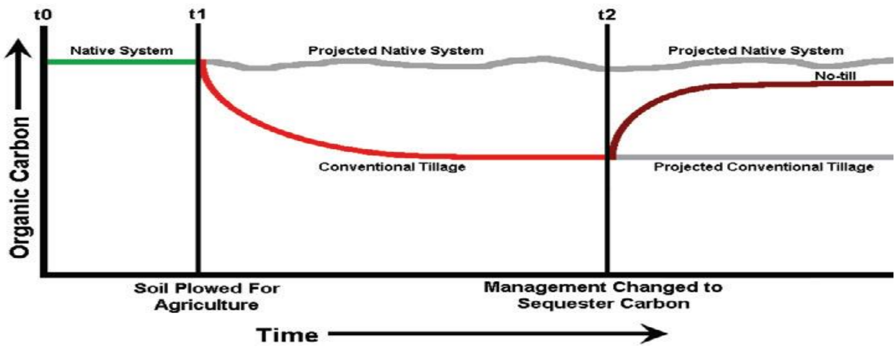

Figure 3: Soil organic C change with time under different soil management (Source, Brevik (2012)).

Carbon allocation to the soil is affected by temperature increment and leads to reductions in soil organic C (Gorissen *et al;* 2004; Wan, 2011). Modeling of C responses to climate change predicted small increases in aboveground biomass in forest and large decreases in soil, but showed an overall increase in atmospheric C (Price *et al;* 1999). Soil organic C decreased from 2.0% to 11.5% by 2100 as compared to 1990 C values (Price *et al;* 1999). Therefore, there are strong correlations between climate change with soil and adverse impacts on soil properties. Brevik (2009) also reported that the important soil properties such as aggregate stability, bulk density, water holding capacity, pH, organic matter, total N, and soluble P in the soil under the influences of climate change. Consequently, climate change has the potential to exacerbate food security issues through its potential effects on soil health. Healthy soils are important because it supply nutrients to the crops grown in those soils. However, if the nutrient is not present in the soil, or if it is not available due to being tied up in the soil or through antagonistic effects from other ions, plants cannot access the nutrient and pass it to the food chain. Unhealthy soils tend to have a lower overall nutrient status.

Impact of climate change on forest

In many tropical countries like Ethiopia, information of the impacts of climate change on forest resources (type, quality, extent, values and changes) is deficient and sometimes non-existent (FAO, 2012). Species diversity, composition and abundance patterns of trees and shrubs are an indicator for forest ecosystem status. Temperature and precipitation are believed to have an influence on these forest ecosystem components. The response of plant species is different to temperature and CO_2 (Collatz., *et al* 1992) and in photosynthetic CO_2 fixation (Cerling *et al.,* 1993; Ehleringer and Bjorkman, 1977). The rate of leaf photosynthesis increases as leaf temperature increases to an optimum, and then decreases as temperature rises further (Figure 4).

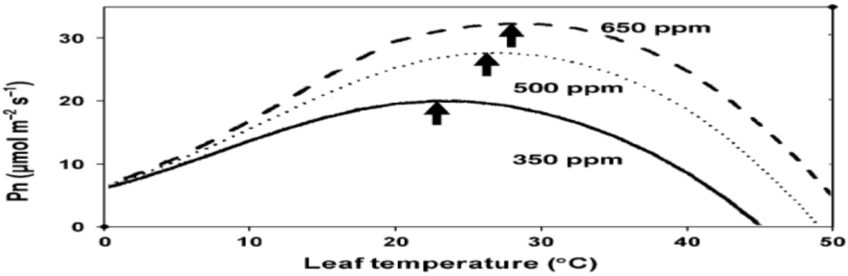

Figure 4: The response of light-saturated net photosynthesis to changes in leaf temperature at different atmospheric CO_2 concentrations. Arrows indicate the shift in optimum temperature with increasing CO_2 concentration (Source: Norby and Luo (2004)).

The plant physiology nature determines their efficiency and physiological processes. For instance, C_3 and C_4 plants have different efficiency under different and changing climatic conditions. The reason that C_4 plants in subtropics and C_3 plants commonly grow in cool climate is related to their efficiency to different climate conditions (Hatch, 1987; Reddy and Hodges, 2000). This may also directly related to the physiology nature of the plants. Barley, rice, wheat, soybeans, cassava, potatoes, legumes and most of trees are categorized under C_3 plants. Maize, sorghum, sugarcane, and teff are few of among C_4 plants category. Ehleringer and Bjorkman (1977) explain that the assimilation of solar energy into carbohydrates decreases while temperature decreases in C_3 plants.

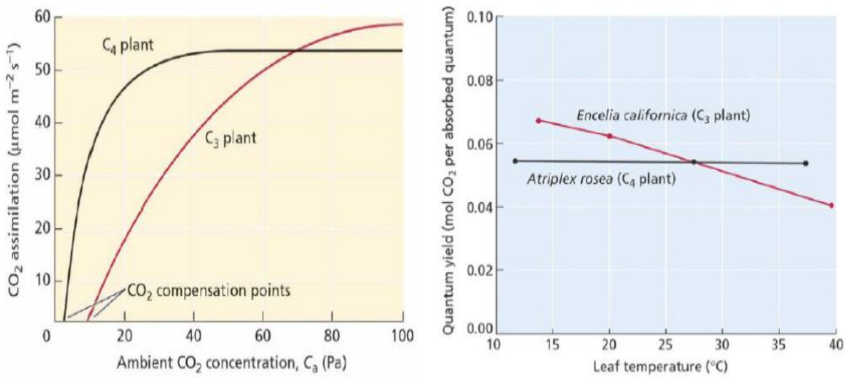

Figure 5: Responses of C_3 and C_4 plants of CO_2 (left) and temperature (right) (source: Collatz *et al.* (1992); Ehleringer and Bjorkman (1977))

Increase in CO_2 has a positive and negative effect on plants. The double increment of CO_2 is increases photosynthesis in C_3 plant via reducing stomata opening process (Sievänen *et al.*, 2013). As a result plant water and nutrient use efficiency, growth and nutrient availability would be enhanced. However, CO_2 could also increase global warming and aggravate related problems. Extreme temperature and water limitation due to the effects CO_2 on the atmosphere directly alter physiological processes of plants and leads to their extinctions (Reddy and Hodges, 2000). The physiological alteration forces the plant to change their original place or migrate to alive themselves. As a result cold and temperate forests are replaced by mixed forest (EPI, 2012). Botkin *et al.* (2007), report also shows a decreasing genetic diversity and rapid migration of plant species. This process would have adverse impacts on plant species and habitat quality all over the globe.

Meanwhile, Ethiopia's plant biomes and its rich biodiversity have already affected by climate change, although species composition and diversity is expected to change due to individual species response to climate change conditions (Hély *et al*., 2006). IPCC (2002) reported that like other sub-Saharan countries, Ethiopian afro-montane forest ecosystems are vulnerable to climate change. Vanacker *et al*. (2005) report also stated that in some parts of Ethiopia several ecosystems including forests are shown to be highly sensitive to short-term availability of water due to climate variability.

Similarly, based on biome sensitivity assessments, closed canopy forests are very sensitive to small decreases for precipitation that plants receive during the growing season (Hély *et al*., 2006). Shrub and grassland vegetation those have shallow and dense root systems are also depends highly upon the timing, intensity and duration of rainfall (Hély *et al*., 2006). As a result in Ethiopia, climate change is expected to significantly alter biodiversity as species struggle to adapt to changing conditions (Lovett *et al*., 2005). In addition, due to its climate sensitive native fauna, Ethiopia may be particularly become vulnerable to exotic and invasive species colonization (Lemenih 2010; Malcolm *et al*., 2002). Beside, invasive species and other species with high fertility and dispersal capabilities have been shown to be highly favored by and adaptive to variable climatic conditions (Malcolm *et al*., 2002). Prosopis tree is the current phenomena in Afar areas of Ethiopia (Lemenih 2010). Moreover, their fast-growing nature and adaptation to marginal environments (degraded, i.e., poor soil nutrients, water logging and free grazing situations) are also contributed for their invasion of large areas (Achalu 2004; Lemenih 2010). The projected rapid rise in temperature combined with other stresses, could lead to numerous localized extinctions. If some plant species are not able to respond to climate change, the result could be increased vulnerability of ecosystems to natural and anthropogenic disturbance, resulting in species diversity reductions (Malcolm *et al*., 2002). Plant species those have a capacity to migrate and change merely adapted to climate change.

Therefore, the fate of species with limited capacity to disperse would be extinction. To be able to better conserve biodiversity in the future, it is imperative to understand how species and ecosystems are likely to change under varying climate change scenarios.

Conclusion and Recommendation

The potential direct effects of climate change assessed here, such as changes in water availability, soil properties, plant species diversity; and losses of forest resources all could have further indirect effects on food security and ecosystems. Vulnerability and causality to climate change is high in Ethiopia. Climate change could significantly affect the hydrological cycle, altering the intensity and temporal and spatial distribution of precipitation, surface runoff and ground water recharge, with various impacts on different natural ecosystems and human activities. Arid and semi-arid areas are particularly vulnerable to changes in water availability related to climate change. Changes in average temperatures and in precipitation patterns have also an influence on soil process and properties mainly via altering organic matter. There is the possibility that soils could contribute increasing amounts of greenhouse gases to the atmosphere, losing their ability to act as a sink for carbon as global temperatures increase, and there is the chance that we will see negative impacts on the physical and chemical properties of the soils that are essential for crop production. Through better soil management and improved tillage practices, carbon sequestration could be enhanced and climate change impact on soil could be minimized. The impacts of climate change and climate variability on forest ecosystems have evident around the world and further impacts could be unavoidable. The best solution could be the use of short rotation timber species and selection of climate smart species to minimize cost of management and enhance reforestation efforts in the country. Climate change increases water use efficiency for most forest trees species belongs to C_3 plants and then increase productivity. The damage of climate change to forestry is also more than its benefit as the extinction of tree species could not be compensated by increased productivity. Hardwood species are more susceptible to drought than softwood trees.

Accordingly, Ethiopia in general has more of hardwood species and it requires concerted efforts to conserve and propagate genetically superior hardwood species with appropriate of species that matching the agroecologies. This would affect the livelihood of forest dependent communities by damaging the products and service obtained from the forest. Increasing ecosystem deterioration (e.g., changes in water availability, soil fertility, species diversity losses and losses of agricultural lands and flooding) arising from climate variability and change integrated with inappropriate land-use would aggravate socio-economic and environmental problems. Improved silvicultural practices, resistant tree/shrub species selection via tree breeding and propagation would be the most important way to cope the adverse impacts of climate change. Therefore, the research wing should focus on identification and selection of tree/shrub species those are favored and/or negatively affected by climate change and generate adaptation options. The adaptation strategies to different climatic environments should fit and vary across the diverse agro-ecology of the country.

Adaptive options through integrated approaches to river basin and landscape management that take account of current and longer-term issues, including climate change is paramount important. Preparing for climate change would enhance the safety, well-being, and livelihoods of Ethiopian citizens.

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Woody and Non-Woody Fuel Biomass Resources in the Central Highlands of Ethiopia

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Introduction

Of the different biomass energy sources, fuel wood provides approximately 78% of the total energy demand, while animal dung and crop residues provide 12% and 9%, respectively (Woody Biomass Inventory and Strategic Planning Project-WBISPP, 2004).

Early studies examined these responses within the context of fuel wood production and consumption although there are a number of studies on fuel wood production and consumption in Asian and African countries, the empirical evidence is still limited. Kumar and Hotchkiss (1988) reported that households in Nepal cope with fuelwood scarcity by increasing the time spent for collection. Similarly**,** Cooke (1998a, 1998b) concludes that when households in Nepal are faced with shortages of environmental goods, as measured by shadow prices, they spend increasing amounts of time for collecting these environmental goods, without affecting agricultural productivity, such that by withdrawing the reallocated time from other activities.

The extent to which such widespread use of biomass as fuel energy sources in respect to the availability and rate of consumption in Ethiopia remains uncertain. Thus, a survey study, which could be undertaken in watershed scale, would able to provide useful information that could help the sustainable utilization of forest and plant biomass resources.

The objective of this study is to assess available energy resources (woody and non-woody) in the model watersheds and to estimate the amount and rate of consumption of fuel biomass resources in the model watersheds.

Methodology

The study area

The study was conducted in Borodo and Girar Dakuna model watersheds of Ethiopia. Borodo watershed is found in Dendi District, central Ethiopia. Specifically, the watershed is located 9°02'N and 38° 07'E with an altitude of 2210 to 2720 meters above mean sea level. The slope ranges from 0 to 118 %. The watershed covers 374 ha of land with Vertisol being the dominant soil type. The climate is of mild sub-tropical having weather with a daily temperature ranging from 15 to 23 °C. The site experiences a bimodal rainfall with a mean annual value of 1042 mm (HARC, 2010).

Scattered small-scale plantations, naturally grown tree, and shrub species are distributed on different landscapes of the Borodo watershed. The natural vegetation in most parts of the watershed is scattered with the exception of Danno Forest, which is situated in the upstream of the watershed. The forest is an important source of fuel wood, fodder, construction materials, and farm implements. It also provides shade and honey for the inhabitants. Acacia spp., *Croton machrostachyus* and *Podocarpusfalcatus* grow naturally and are scattered in the crop land. *Eucalyptus camaldulensis* and *Eucalyptusglobulus* are dominant among planted trees in different niches in the watershed.

On the other hand, Girar and Dakuna are two kebeles in which the model watershed incorporates. The watershed is found in ChehaWoreda, Guraghe Zone of Southern Nations, Nationalities and Peoples Regional State (SNNPRS), Ethiopia. The Woreda capital, Imdibir town, is located about 180 km from Addis Ababa and 30 km from the present zonal capital of Wolkite. *Imdibir*means mother-forest and is the combination of two words in the Guraghe language, *Im* which means mother and *dibi*Which means forest. This name indicates that the area was once covered by forests (Molla and Feleke 1996).

Land is a scarce resource among the Guraghe people. The Woreda is known for its Enset-based farming system in which both perennial and annual crops are grown. In addition to Enset (*Ensete ventricosum)*, most of the other crops grown are perennial, such as Chat (*Chataedulis*), coffee (*Coffee arabica*), mango (*Mandiferaindica*), avocado (*Perseaamericana*), lemon (*Citrus orientifolia*), and orange (*Citrus sinensis*). These perennial trees and shrubs could contribute for natural resource management and mitigation of climate change in the area. Planting eucalyptus (*Eucalyptus camaldulensis*and*E. globulus*) trees for cash income is also becoming common practice in the area (Holeta Agricultural Research Center 2011). The area has a slope of 0-9% with an altitude range of 2170 to 2440 meters.

Sampling technique and data collection

A household survey was conducted using a semi-structured questionnaire. Stratified and simple random sampling methods were used to select the respondents from the five villages found in Borodo watershed and four villages in Girar Dakuna Watershed. From each village/got of Borodo and Girar Dakuna watersheds, 20 and 25 respondents, respectively were selected and 100 respondents from each watershed interviewed.

Before the survey begin, an aggregation of the households was made based on age, sex, and wealth, and finally structured questionnaire was used for assessment. The questionnaire also included a household's daily amount and type of fuel used for cooking, heating, baking e*njera* and for lighting. Fuel biomass consumption was assessed after identifying the commonly used fuel types in their respective locality. The data was analyzed using Microsoft Excel and SPSS software and presented using descriptive statics associated with tables, charts, and graphs.

Results and Discussion

Sources of energy for household activities

Age and Sex of the respondents

According to the respondents in Borodo watershed, majority of them were within the age group of 30 to 50 years (44%), followed by 20 to 30 years (36%) of age. Most of the respondents in Borodo watershed were male accounting for 59 %. In Girar Dakuna watershed the majority of the respondents were with-in the age group of 41 to 50 years (42%), followed by 31 to 40 years (31%) of age. Similarly, to Borodo, 60 % of the respondents at Girar Dakuna were male.

Sources of energy for enjera making

According to the study, 75% of the respondents use fuel wood, 20% uses agricultural residue and the remaining 5 % use animal dung for making enjera in Borodo watershed while in the model watershed of Girar Dakuna, 100 % of the respondents use fuel wood for making endear. This shows that Girar Dakuna have larger reliance on woody biomass fuel resources to make enjera as compared to households in Borodo watershed.

Sources of energy for cooking and heating

Based on the survey, all of the respondents in Borodo Watershed use fuel wood as their major sources of energy for cooking. On the other hand, to get heat energy, 71 % of the respondents use fuel wood and charcoal, 24 % use fuel wood, agricultural residue and charcoal while 5 % use fuel wood and agricultural residue as major source. Generally, 71% of the respondents use woody biomass while the remaining 29% use mixed (woody and non-woody) energy sources for heating purpose.

In Girar Dakuna watershed, 100 % of the respondents use fuel wood for cooking and heating that reveals the dominance of woody fuel biomass resource as a major source of energy for cooking and heating in the model watershed.

Perception of respondents on woody and non-woody fuel sources

In Borodo watershed, 63 % of the respondents believed that there is shortage of woody biomass fuel resource. Similarly, the majority (96 %) of the respondents believed that there was shortage of non-woody biomass fuel resource, while 3% believed that there was sufficient source of non-woody fuel resource and 1% of the respondents have no idea of the availability of non-woody biomass fuel resource. This shows that the majority of the localities believed that there is lack of both woody and non-woody fuel biomass resources in the Borodo watershed area. On the other hand, in Girar Dakuna, only 19 % of the respondents believed that there is shortage of woody biomass fuel resource while 80 % of the respondents believed that there is no shortage of woody biomass fuel resource. The remaining 1 % had insufficient idea regarding the non-woody biomass fuel resources,

Place of getting fuel wood/Methods and places of acquiring fuel food

Based on the survey made in Borodo watershed, 77% of the respondents acquired fuel wood (woody-biomass fuel resource) by collecting from their local area while 23 % purchased from the market. This implies that the majorities of the local people use the forest around their vicinity and cut trees in order to get woody biomass fuel resource. This in turn is believed to have an adverse effect on the forest cover of the area leading to land degradation and deforestation. Meanwhile, in Girar Dakuna watershed, 96 % of the respondents collected their sources of energy while 4 % purchased from their nearby market.

Amount and rate of consumption

As illustrated below in Table 12, 31 % of the respondents use 35 – 40 kg of fuel wood for 2 days, 42 % use the same amount for 3 to 4 days and the remaining 27 % use for 4- 8 days. Whereas, 75 % of the respondents use 35-40 kg agricultural residue for 2 days, 17 % for 3 days, 8 % for a week, and again 8% use for two weeks the same amount of agricultural residue. According to cow dung, 49, 43, and 8 % of the respondents use 1 quintal for 3 days, a week, and 10 days, respectively.

*T*able1. Fuel and consumption rates at the study watersheds

Fuel source	Rate (kg)	Days	%	Days	%	Days	%
		Borodo					
Woody	35-40	2	31	3-4	42	4-8	27
Agricultural residue	35-40	2	75	3	17	7-14	8
Cow dung	100	3	49	7	43	10	8
Charcoal	100	30	55	60	40	14	5
Girar Dakuna							
Woody	50	2	75	3-4	25	-	-

According to the respondents, the consumption of charcoal in the model watersheds 55% and 40 % of the respondents use about 1 quintal for a month and 1 quintal for two months, respectively. While 5 % of the respondents use the same amount for 2 weeks. None of the respondents used electricity for their household activity since there was no electricity supply in the model watersheds. Generally, 100 % of the respondents used kerosene for lighting purpose.

In Girar Dakuna watershed, 75 % of the household respondents used 0.5 quintal of fuel wood for 2 days household activities while the remaining 25 % used the same amount for 3 to 4 days.

Generally, when the household woody and non-woody energy consumption in both watersheds compared, there was a higher rate of consumption and heavy reliance on woody biomass in Girar Dakuna than Borodo; while pressure on the forest area in Girar Dakuna was more intense than that of Borodo watershed. The difference may be due to less crop residue and cow dung product in Girar Dakuna compared to Borodo because of shortage of crop and livestock production in the area. On the other hand, the use of mixed energy sources in Borodo helps decrease the exacerbated pressure on the forest area which is one of the major sources of woody biomass fuel resources (Figure 1)

As shown in figures 1 and 2 below, the household woody biomass fuel wood consumption for different household activities in Gurage Girar Dakuna watershed highly depends on woody biomass fuel resource (Fuel wood) and on the contrary there is a less dependency on woody biomass fuel resource in Borodo watershed. One common thing observed in both watersheds is that households in both watersheds use non-woody biomass fuel resource (Kerosene) for lighting purpose and there is also absence of electricity supply in both watersheds.

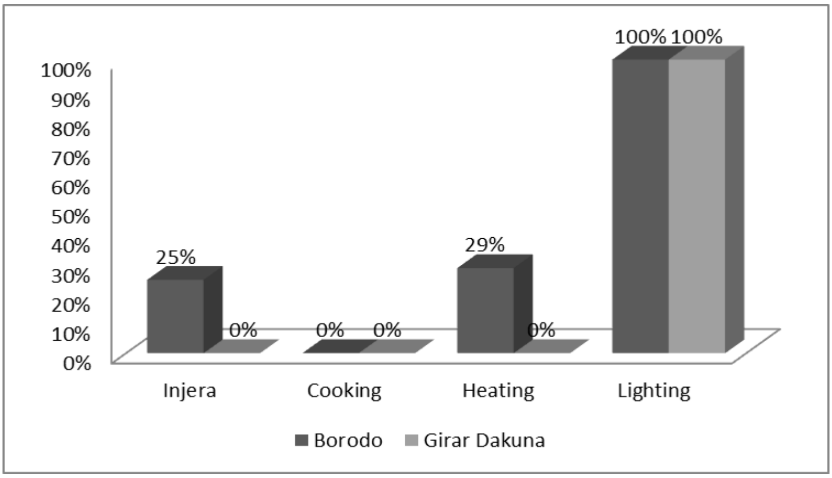

Figure 1. *Household woody biomass fuel consumption for household activities*

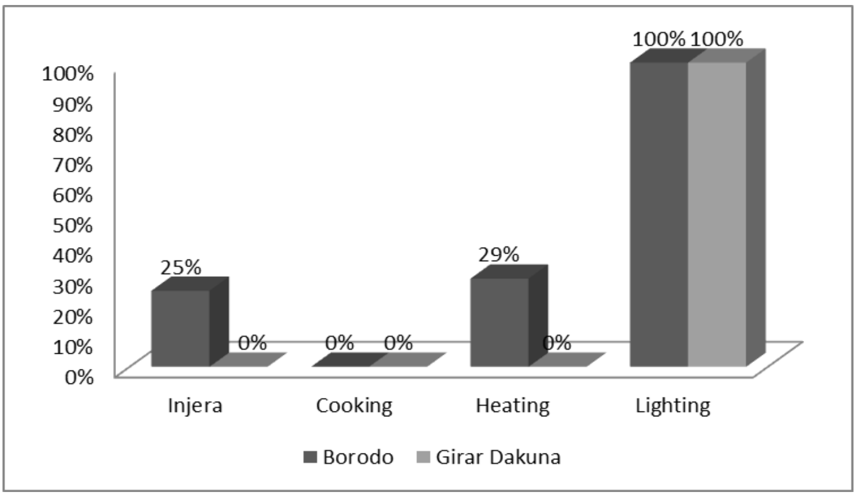

Figure 2. Household non- woody biomass fuel consumption for household activities

Implications for soil and water resources

The heavy dependence on woody biomass mainly fuel wood result in high pressure on the forest resource leading to deforestation. This in turn will lead to soil erosion, loss of forest biodiversity and alteration of habitat for enormous amount of living things. Soil erosion could also causes loss of ground water since the water that should have infiltrated to the ground will be turnout to surface runoff and washed away towards rivers and which could leads to loss of soil nutrients, which ultimately contributes for the occurrence of desertification. These all could contribute to low productivity leading to poverty.

Conclusion

The pressure on fuel wood might lead to an alarming rate of deforestation which at the end of the day that could cause land degradation and decline of soil fertility. Policy makers could need to focus on investment that strengthening institutional arrangement in the energy sector, on development of alternative energy resources, on building the capacity of rural communities and in facilitating credit schemes to utilize biomass resource with the efficient technologies; and increasing prevalence of multipurpose trees in order to avert biomass resources degradation and subsequent escalation of food security and poverty in the regions. Policy measures should thus target technological innovation both from demand perspective and supply side to ensure sustainable production and utilization of biomass resources that can cater energy security.

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The economic impact of climate change on *tef (Eragrostic tef)* production in Central Rift Valley of Ethiopia

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Introduction

Tef (*Eragrostis tef*) is a very important crop to Ethiopia both in terms of production and consumption. Tef is the dominant cereal in over 30 of the 83 high-potential agricultural weredas/districts by area planted and second only to maize in production and consumption (Bekabil *et al.*, 2011; ATA, 2013). In 2011/12, it was estimated that tef made up more than 20 percent of all the cultivated area in Ethiopia, covering about 2.7 million hectares and grown by 6.3 million farmers (reference).

Studies to address the economic impact of climate change on Ethiopian agriculture in general and tef crop in particular and the farm level adaptations that farmers make to mitigate the potential impacts of climate change are very few. This could seriously limit policy formulation and decision making in terms of adaptation and mitigation strategies.

The few studies conducted so far revealed that the performance of *tef* greatly influenced by moisture stress and significant variations has been reported in their response to drought (Dejene, 2009). Some research findings suggested that yield loss in *tef* due to drought stress could reach up to 40 % (Shiferaw, 1991). According to these studies, tef will lose 24 % of the current climatically suitable area due to water deficit occurring at different developmental stages of the plant that affected the productivity of the crop.

Therefore, the objective of this study was to assess the economic impact of climate change on tef production in the CRV of Ethiopia and inform policy makers on proper adaptation options to counteract any harmful effects of adverse change.

Methodology

The study area

The study was conducted in Adama and Ada'a Districts of the East Shewa zones in Ethiopia. In both districts, tef was a very important crop, both in terms of production and consumption. The agro ecologically of the two districts are different. Data from six weather stations (three from each district) were used to analyze the marginal impact of climate change on tef income in the two districts (Table 1.). The study depended on the average temperature and precipitation of the country's main cropping season (*meher*) (i.e. June, July, August, and September). The summer temperature and precipitation data were averaged over 30 years from 1980 to 2010.

Table1. Description of stations

District	Station	Latitude	Longitude	Altitude (m)	PCP Sumer	Summer temperature		
						Max	Min	Average
Adama	Chefe Donsa	8.97	39.12	2392	660.95	18.59	10.32	14.46
	Debrezeit	8.73	38.95	1900	610.63	25.29	13.08	19.19
	Mojo	8.60	39.10	1763	697.35	27.10	13.00	20.05
Ada'a	Melkassa	8.40	39.31	1540	499.84	27.71	15.41	21.56
	Nazeret	8.55	39.28	1622	609.92	27.29	15.91	21.60
	Wonji	8.48	39.25	1540	558.58	27.42	14.73	21.07

Source: MARC agro-meteorology department (2013).

Data source, type and method of collection

Primary data were collected from sample farm households in the district. A pretested structured questionnaire was used to collect primary data at household level. The questionnaire was designed to elicit information on a variety of topics including on household demographic characteristics, resource endowments, production, income, agricultural services, and awareness to climate change and adaptation strategies of the respondents. The interviews with the farmers took place during the 2013/2014 season.

Sampling design

A two-stage sampling technique was applied to select sample households for this study. In the first stage, Adama and Ada'a districts were selected from the CRV region purposively. Then, 3 kebeles were selected from each district based on production of tef and proximity. In the second stage, 121 households from Adama and 101 households from Ada'a were selected randomly using probability proportional to size sampling technique (Table 2).

Table 2. Sample size and distribution

District		Sex of the household head		Total
		Female	Male	
Adama	N	6	115	121
	%	4.96	95.04	100
Ada'a	N	7	94	101
	%	6.93	93.07	100
Total	N	13	209	222
	%	5.86	94.14	100

Method of data analysis

To meet the stated objectives, Ricadian approach of studying economic impact of climate change was used. The Ricardian method is an empirical approach to studying sensitivity of agricultural production to climate change based on cross-sectional data. The method was developed by Mendelsohn et al. (1994) to measure the economic impact of climate on land prices in the USA. The model assumes that impacts of changes in climate attributes (temperature, rainfall) like other long-term economic phenomena are capitalized in land values/revenues. Climate change affects crop yields and hence farm revenues capitalized in land value changes over time.

The Ricardian model examines how a set of endogenous variables (input) and exogenous variables (temperature and precipitation), affects farm value. The model is based on the observed response of crops and farmers to varying climate, i.e. it uses actual observations of farm performance in different climatic regions (Mendelsohn et al., 1994; Ouedraogo, 2006). Specifically, we examine the performance of tef productions and income in the low lands and mid altitude areas of Ethiopia. The model measures how long-term tef profitability varies with local climate, while controlling for other factors.

Following Mendelsohn *et al*., (1994) we write the standard Ricardian model that relies on a quadratic formulation of climate as follows:

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + u$$

Where V is the dependent variable, *tef* revenue, u is an error term and F and F^2 capture linear and quadratic terms for temperature and precipitation, Z is soil variables and G is set of socioeconomic variables. The introduction of quadratic terms for temperature and precipitation respectively reflects the non-linear shape of the response function between net revenues and climate. From the available literature, we expect that farm revenues will have a U-shaped relationship with temperature. When the quadratic term is positive, the net revenue function is U-shaped, but when the quadratic term is negative, the function is hill-shaped.

The study relied on monthly temperature and precipitation data collected from Melkassa agricultural research center agro-meteorology and GIS department. The dependent variable was measured as tef net revenue per hectare of cropland calculated as gross revenue from tef less total variable cost of production that includes the cost of household labor in 2012/13 cropping season.

To predict the impact of climate change on tef income, models that analyze the behavior, components and interactions of climate systems were used. These models are global climate models or general circulation models (GCMs). In this study we adopted three such models including PCM (Parallel Climate Model (PCM), HadCM3 (Hadley Centre for Climate Prediction and Research, England) and CGM (Canadian Centre of Climate Modelling and Analysis) to make comparison. We used these predicted country level scenarios as described in Deressa (2007).

Results and Discussion

Descriptive and inferential statistics

The results of the descriptive and inferential analysis (Table 3) of 222 households show that households in the two districts are significantly different in terms of age, family size, livestock ownership, annual rainfall and tef net revenue per hectare all in favor of households in Ada'a district. The average net revenue generated per hectare was about 738 USD. Households in Ada'a District generate significantly higher tef income than households in Adama District (P<1%).

Table 3. Descriptive statistics of socioeconomic and climate variables

Variable	Adama (n=121)		Ada'a (n=101)		Total (n=222)		t /χ2
	Mean	SD	Mean	SD	Mean	SD	
Sex (% Male head)	95.04		93.07		94.14		0.39
Age	40.64	11.68	44.96	12.23	42.60	12.10	-4.30***
Education	3.54	3.45	3.44	2.94	3.49	3.22	0.10
Family size	5.84	2.85	6.60	2.42	6.19	2.69	-0.76**
Cultivated land(Ha)	2.02	1.33	2.29	1.49	2.14	1.41	-0.27
TLU	4.73	3.19	6.55	3.35	5.56	3.38	-1.83***
Annual temp(0c)	21.56	0.00	19.19	0.00	20.48	1.18	2.37
Annual rainfall	499.84	0.00	610.63	0.00	550.24	55.29	-110.79
Net revenue/ha(USD)	658.80	484.22	833.25	490.75	738.17	493.83	-3173.23***

*Note: ***, ** and * means significant at the 1%, 5% and 10% probability level respectively.*
Average exchange rate for year 2012/13 was used ($1= 18.19 Birr)

Over the period of 1980-2010, Adam district has higher temperature while Ada'a District received higher amount of rainfall. Results of further analysis showed that there was a statistically significant difference in precipitation and temperature between stations in the two districts. Generally, there was slightly increasing trend in temperature and while there is a decreasing trend in precipitation

Ricardian analysis

Appropriate diagnostic measures were used to check for the existence outlying observations, heteroscedasticity, and multicollinearity. Outlying observations with extreme influence (residual value of >2.5) were removed from analyses. To this effect 6 observations were discarded. Results of multicollinearity test showed that there was no serious problem of multicollinearity detected (Table 4). the test for the presence of heteroscedasticity using Breusch-Pagan test showed that there was no heteroscedasticity problem at 5% probability level (p= 0.0688) and therefore robust method was applied to correct the model. The model in general was significant at 1 % level of significance showing the appropriateness of the model for estimation. To correct problem of linearity the dependent variable was transformed on logarithmic form as such all interpretation was made based on the transformed model.

Table 4. Ricardian regression estimates of the net crop revenue (LNNRH) model

Variable	Coef.	SE	t
High summer temperature	-0.46616	6.68034	-0.07
Average temperature	0.001268	0.163016	0.01
Precipitation	-0.05458	0.023194	-2.35**
Precipitation square	0.000047	0.00002	2.35**
Age (ln)	-0.38029	0.1691	-2.25**
Education	0.02317	0.012223	1.9*
Family size	-0.01922	0.018234	-1.05
Credit access	0.109786	0.093467	-1.17
TLU	0.038067	0.014951	2.55**
Vertisol (soil)	-0.8519	0.128567	-6.63***
Cultivated land(ln)	0.120339	0.08384	1.44
_CONS	35.83355	74.04711	0.48
Number of obs		216	
F(10, 204)			
Prob > F		0.0000	
R-squared		0.1945	
Root MSE		0.57536	

Note: *** ,** and * means significant at the 1%, 5% and 10% probability level respectively.

Results of the model indicate that net revenue per hectare is negatively related to both high summer temperature and precipitation (Table 3). This implies that high summer temperatures and precipitation are harmful to tef production. However only precipitation was found to statistically significantly ($p<0.05$) affect net revenue by reducing it by more than 5% for a percentage increase. This may be due to the nature of the crop which is highly susceptible to water logging, particularly on Vertisols (Tulema et al., 2008).

Household size, age and nature of soil being Vertisols were found to have an inverse and significant relationship with tef net revenue. Household size was negatively related to the dependent variable. This may be due to the consideration of family labor cost in the model. The case of age might be explained by the strength that is needed in smallholder agriculture. Vertisols negative relationship may be because of its water logging nature. As expected livestock and land ownership has a positive relationship with net revenue while that of livestock was significant. This implies a complementarily relationship between farming and livestock keeping.

Impacts of future climate projections

Uniform scenario

Marginal analysis was done on net tef revenue per hectare using uniformly changed temperature and precipitation levels. These uniform scenarios assume that only one aspect of climate changes and that the change is uniform across the country. These scenarios increase temperature by 2.5% and 5% and reduce precipitation by 7% and 14% (Deressa, 2007)

Results in Table 5 indicate that the net revenue per hectare of tef responded positively to both increasing temperature and reduction in precipitation. However statistically significant ($p<0.001$) result was observed only for the case of precipitation. A decrease in precipitation by 7 and 14 percent increased net revenue per hectare by 11.6 and 14% respectively. This may imply that decrease in precipitation will increase net revenue which may be as a result of reduction in water logging.

Table 5. Marginal analysis using uniform scenario

Scenario	Margin	SE	z	P>z
+2.5%	8.1	18.0	0.45	0.654
+5%	6.9	34.7	0.2	0.842
-7% PCP	11.6	1.0	11.93***	0.00
-14% PCP	14.0	2.0	7.03***	0.00
+2.5%-7% PCP	10.4	17.2	0.6	0.546
+5%-14% PCP	11.6	33.0	0.35	0.726

Climate predictions of SRES models

Table 6 shows the predicted values of temperature and precipitation from the three models for the years between 2050 and 2100. The predicted values for the scenario analysis were used from Deressa (2007) which is the hydrological component of the project from Colorado University. The prediction indicates that all the models forecasted increasing temperature levels for the years 2050 to 2100. When the result is seen with respect to precipitation, the CGM2 predicted decreasing precipitation for the years 2050 to 2100. Both HaDCM3 and PCM predicted increasing precipitation over these years.

Table 6: Climate predictions of SRES models

Model	Temperature			Precipitation		
	Current	2050	2100	Current	2050	2100
CGM2	21.25	24.51	29.26	76.77	64.75	50.27
HADCM3	21.25	25.07	30.66	76.77	83.53	93.46
PCM	21.25	23.50	26.69	76.77	80.83	85.67

Source: Deressa (2007).

The marginal analysis for the combined temperature and precipitation shows a mixed result using the above predictions (Table 7.) There is a positive impact only for CGM2 model which may be related to the reduction in precipitation in this scenario. For the remaining two models i.e. HADCM3 and PCM there is a decrease in net revenue per hectare of tef. These models generally imply there will be a variability and risk in tef production due to climate change which needs to be addressed by policy makers. Considering the importance of tef in the national economy this variability and risk might create a great shock for smallholder farmers as well as the consumers. Therefore, a clear strategy should be in place to increase the adaptive capacity of farmers and the resilience of the economy.

Table 7. Marginal analysis using Climate predictions of SRES models

Model		Margin (%)	SE	Z	P>z
CGM2	2050	5.62	25.53	0.22	0.826
	2100	11.31	54.32	0.21	0.835
HADCM3	2050	-4.89	33.19	-0.15	0.883
	2100	-13.02	72.59	-0.18	0.858
PCM	2050	-2.71	22.17	-0.12	0.903
	2100	-6.81	44.43	-0.15	0.878

Tef income did not respond to marginal changes in temperature in all climate change scenarios considered. It may be because Tef is a C4 plant which is genetically adapted for growth in hot dry climates. C4 species have an evolutionary advantage of a photosynthetic pathway over C3 species such as wheat and cool season grasses. This C4 pathway results in efficient water use and allows plants to photosynthesize faster under high heat and light conditions than C3 species (Pandey and Sinha, 1972; Flores et al., 2009).

Conclusions

This study explored the economic impact of climate change on tef production in Ethiopia. The study used primary household level data together with secondary climate data and implemented the Ricardian cross-sectional approach. The primary data was collected from 222 households in Adama and Ada’a Districts. Data was collected on the household characteristics, tef production, income and other institutional variables using a structured questionnaire.

The results of the study show that climate affects tef net revenue in Ethiopia. A decrease in precipitation by 7 and 14 percent increased net revenue per hectare by 11.6 and 14% respectively in the case of uniform scenario. This may imply that decrease in precipitation will increase net revenue, which may be because of reduction in water logging. The marginal analysis of combine temperature and precipitation shows a mixed result. There is a positive impact only for CGM2 model, which may be related to the reduction in precipitation in this scenario. For the remaining two models i.e. HADCM3 and PCM there is a decrease in net revenue per hectare of tef. These models generally imply there will be a variability and risk in tef production due to climate change that needs to be addressed by policy makers. Best bet adaptation options need to be identified and promoted.

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