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Impact of Climate Change on Potato Yield (*Solanum tuberosum* L.) At Mekelle Areas, in Northern Ethiopia

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Abstract: Despite Potato *(Solanum tuberosum* L.*)* is regarded as a high potential food security crop, its production in Ethiopia is much less than the average world potato production. Potato is sensitive to high temperature and moisture deficits. For this reason, potato production is said to be vulnerable to the anticipated climate change. The objective of this study was to assess the impacts of projected future climate on potato yield taking into account baseline climate (1992– 2010) as benchmark. Potato experiment was carried out during the cropping season in 2012 at two sites (Mekelle University (MU) and Mekelle Agricultural Research Center (MARC) in Mekelle areas with the objectives of calibrating and validating AquaCrop model, which was subsequently used for simulating potato yield under both baseline and future climate. There were three treatments of water: Full Supplementary (FSI), Deficit Irrigation (DI) and Rainfed (RF) treatments laid out in RCBD with three replications each. Potato variety Jalene was calibrated and validated in AquaCrop model. Potato yield under future climate (2020, 2050 and 2080) with A2 and B1 CO_2 emission scenarios was simulated using AquaCrop model. Simulation results showed that potato yield decrease in rainfed treatments, whereas, increased in FSI and DI treatments in Mekelle area. The application of supplementary irrigation (full and deficit irrigation) under the future climate increased potato yield by 89.3 to 107.6% and 68 to 92% at MU site, respectively as compared to rainfed. Similarly, 68.4 to 92.0% and 71.6 to 94.2% yield increase due to full and deficit irrigation were observed respectively at MARC. This indicates the negative impact of climate change can be compensated by application of supplementary irrigation. The effect of different CO_2 concentrations showed that the highest yield was obtained under A2 whereas lowest yields were obtained under B1 in 2050 and 2080 at both locations. This indicates potato responds positively to elevated CO_2 concentration. The performance evaluation results indicated the model could be used for management and climate impact analysis studies.

Key words: Impact · Climate Change · AquaCrop model · Calibration · Validation · Simulation

INTRODUCTION

Climate change is the largest threat ever faced the world as it affects the earth's natural resources widely from tropical to arctic and from sea to land and atmosphere [1]. According [2] reports warming of the climate system is unequivocal and scientists are more than 90% certain that it is primarily caused by increasing concentrations of greenhouse gases (CO_2, CH_4, O_3, CFCs and Nitrous oxide) produced by human activities such as the burning of fossil fuels and deforestation. It has been indicated that agriculture is affected negatively by climate change [3] and it could hamper the realization of Green Revolution in African [4]. Crop production in Ethiopia is challenged by many factors, of which climate-related disasters like drought and flood, pests and diseases, soil erosion, shift in rainfall pattern and decline in available water are the major ones [5]. About 90% of crop production in Ethiopia is obtained from rainfed agriculture [6], which makes the country vulnerable to weather vagaries.

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Climate change raises serious concerns about the sustainability of crop production due to its extreme climatic events that are inevitable consequences of climatic variability and change. Climate change has already been exerted its effect on the ecosystem of Ethiopia. Indicators like temperature has increased by 1.3°C in 1960-2006 [7] and rainfall variability has also increased and becomes erratic and unusual [8]. It has been observed that a rainfall trend in Ethiopia during the last half century has significantly reduced towards Tigray, northern Ethiopia [9]. Variability in precipitation in the region has been manifested with extended dry spell, erratic and highly variable in space and time, which resulted in occurrence of recurrent drought and famine [10].

Global Climate Models (GCMs) predict that climate change will bring higher temperatures, altered precipitation and higher levels of atmospheric carbon dioxide [2]. Potato yield increased due to high CO_2 concentration [11]. The yield increases by about 10 percent for every extra 100 ppm. However, with climate change not only CO_2 concentrations increase, but also the climatic growing conditions will be altered. The test crop, potato, is very heat sensitive and its temperature requirement for optimal tuber growth ranges between 16 and 22°C [12]. Higher temperatures favor foliar development and retard tuberization [13] Potato crop faced challenges from changing seasonal rainfall patterns due to its sensitivity to soil water deficits [14]. Therefore, at high temperatures and under sub-optimal water supply, the positive effects of an increased CO_2 concentration could compensate the yield loss is uncertain. The development of crop growth models has increased understanding of the link between climate change and crop productivity. According to [15], crop models used to integrate current knowledge from various disciplines that include agro-meteorology, soil physics, soil chemistry, crop physiology, plant breeding and agronomy into a set of mathematical equations to predict growth, development and yield.

Different models were tested in simulating the growth and development of the crop such as SUBSTOR, WOFOST, APSIM and AquaCrop models [16]. Taking into account its data requirement, user friendliness, its application in climate change scenarios, AquaCrop model was found to be the most suitable crop model for this study. One important application of AquaCrop is to compare the attainable against actual yields in a field, farm, or a region and the use of water productivity values normalized for atmospheric evaporative demand and of carbon dioxide concentration that confer the model an extended extrapolation capacity to diverse locations and seasons, including future climate scenarios [17]. Although most people in Tigray depend on climate sensitive sector, information on the impact of climate change on agricultural production is scant. Moreover, detailed information on the current and possible future climate change impact on potato production in the region, in particular is not available. This study could also help policy makers to integrate and implement relevant adaptation strategies from national to local scale. Therefore, this research seeks to investigate the future potential of potato yield under predicted future climate and find possible ways of addressing the impact.

Objective: The general objective of this study was to assess the impact of climate change on potato yield in the study area.

The specific objectives were:

- To predict potato yield under the future climate
- To assess impacts of supplementary irrigation on future potato production
- To evaluate the effects of different CO2 scenarios on potato yield
- To calculate the yield change caused due to climate change

MATERIALS AND METHODS

Description of the Study Area: The experiment was conducted during the cropping season in 2012 at two sites (Mekelle agricultural research center (MARC) and Mekelle University (MU) in Mekelle area. Mekelle is found 780 kilometers north of the capital, Addis Ababa, MU (of 39°6' E long. and 13°3'N lat.) and MARC (39°43'E long. and13°39'N lat.) sites are found at the outskirt of Mekelle city with an elevation of 2112 and 2070 m.a.s.l. The climate is mainly semi-arid and for most of the region the major rainy season (locally called *kiremt*) lasts for 2 to 3 months, occurs between mid- June and mid-September. The annual rainfall of the study area is unimodal with about 80% of the precipitation falling in a two and half month's period during summer. The mean annual rainfall and daily maximum and minimum temperature at MU are 545mm, 25.3°C and 12.5°C [18], respectively whereas, the annual rainfall and daily maximum and minimum temperature at MARC are 527 mm, 26.11°C and 11.7°C [19], respectively. The soil type at Mekelle University is cambisol soil with sandy clay loam texture whereas at MARC, the soil type is vertisol with clay texture.

Experimental Material and Design: Jalene Potato variety was used as planting material. Seed tuber was obtained from Alage farmers based seed system supported by International Potato Center (CIP) and Tigray Research Institute. Seed tubers having 3-4 sprouts and medium sized tubers were selected for planting. Jalene variety is early maturing (90-120 days) and suited for areas having an altitude of 1600-2800 m.a.s.l with rainfall 750-1000 mm [20]. Planting was carried out at MU and MARC sites on 17th of July 2013 and 18th of July, 2012, respectively.

There were three water treatments: Rainfed (RF), Deficit Irrigation (DI) and Full Supplementary irrigation (FSI). The experiment was laid out in RCBD design replicated three times. Seed tubers were planted at 15 cm depth with a spacing of 0.75 m*0.30 m between rows with a plot size of 6 cm*9 cm each having 8 rows respectively.

Supplemental irrigation was applied manually using furrow until maturity. In this research FSI stand for supplementary irrigation after cessation of rainfall whereas DI stands for four times supplementary irrigation applied in four days interval after tuber initiation.

Crop Management: Land preparation, planting date, weeding, fertilizer application and method, earthling up/heap and other agronomic practices of the crop were applied as per the recommendation of the Ethiopian Agricultural Research Organization [20]. Late blight of potato was observed during tuber initiation period but controlled using fungicide.

Data Collected: Data collection was carried out according to AquaCrop's minimum data requirement. The minimum data requirements were phenology (days to maximum canopy cover, start of senescence, maturity), sequential dry biomass and final tuber yield [21]. Date of maturity was recorded when the majority of the plants in a plot has changed the color from green to yellow.

Days to maximum canopy cover was taken when potato reached at its maximum canopy cover. Days to start of senescence was recorded when senescence of leaves started

Canopy Cover was measured using a photo taken using an overhead digital camera and was analyzed using image analyzer software.

Sequential dry biomass was measured every 10 days interval by taking dry biomass of the stem, leaves, root, stolen and tuber. The dry weight was recorded after air-drying the fresh samples and further oven drying at 65°C for 72 hours [22].

Harvest index was determined as the ratio of dry weight of tubers to the total dry biomass weight. This was taken at harvest.

Final dry tuber yield (ton/ha) was taken from two middle rows of plot with an area of 4.5 m * 1.5 m.

Meteorological Data: Long term (1992–2010) weather data including daily rainfall, sunshine hours, maximum and minimum temperature, air humidity and wind speed of Mekelle station were obtained from the National Meteorological Service Agency (NMSA) of Ethiopia. Before analysis, data were scanned for missing values and/or typographical errors. The climatic data of 1992–2010 periods were used as the baseline period for climate change impact assessment. Three future climate projection periods, 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099) was chosen for detail impact assessment studies. For a matter of discussion, the multiyear three projected time series yields were simulated using the model and averaged to represent the corresponding three time series: 2020s, 2050s and 2080s, respectively. Projected future climate variables (maximum and minimum temperature and rainfall) were obtained by using the model output of $HadCM_3$ under A2 and B1 emission scenario. B1 emission scenarios were used to compare the effect of CO_2 without changing the other climate variables obtained by A2 scenario. A2 story line is characterized by lowest per capita growth, continuously increasing population growth and slowest and fragmented technological development [23]. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies [23].

Seasonal weather data such as air temperature (min and max), relative humidity, wind speed and sunshine hours were taken to calculate the reference evapotrnspiration (ETo). ETo was calculated based on FAO Penman-Monteith equation [24] using ETo calculator by as input for AquaCrop.

Hargreaves' method (HM) was used to calculate future ETo after it was proved to have similar values as using Penman Montheith method. It also requires only temperature (maximum and minimum) and incident radiation [25].

$$Eto = 0.0023 * (Tmean + 17.8) \times (Tmax - Tmin)^{0.5} \times Ra \quad \text{Eq (1)}$$

where ETo is the reference evapotranspiration (mm d^{-1}), Tmax, Tmin and Tmean are the daily maximum, minimum and mean air temperatures (°C), respectively; 0.0023 is the original empirical constant proposed by [25]; and Ra is the water equivalent of the extraterrestrial radiation in mm d^{-1}.

A2 and B1 emission scenarios were used to compare the effect of CO_2 fertilization on potato. ***Soil data:*** Soil physical properties were studied by taking sample from the experimental field before planting. Undisturbed soil samples were gathered at various depth every 15 cm to a depth of 60 cm. Soil texture, field capacity, wilting point and water content at saturation were determined in the laboratory.

Soil Physical Properties: Soil moisture was measured every 10 days and at 15 cm interval up to 60 cm using gravimetric method. Fresh soil sample were weighed before after oven dried at 105°C for 24 hours in an oven drier and dried soil samples were then reweighed again in order to estimate the moisture content in the soil.

Irrigation Scheduling: Crop water requirement and irrigation schedule was determined using Cropwat software (Version 8.0) based on climatic, soil and crop data inputs. The following parameters were used to run CropWat software:

Crop water requirement was calculated as kc x ETo. Crop coefficient (kc) was obtained from FAO paper no. 56 [24]. Irrigation water was conveyed into the plant directly using plastic pipe hence the application efficiency was estimated to be 90%.

Data Analysis: Validated AquaCrop model (Version 4.0) was used to simulate potato dry tuber yield under current and changed climate. A comparison was made between the observed and predicted yield to assess the impact of climate change on tuber yield of Potato. The projected average yield for the three time series was obtained by taking the average of 30 years predicted yield. Yield changes were calculated by the formula:

$$Yd\ (\%) = \left(\frac{S_i - O_i}{O_i}\right) * 100 \quad \text{Eq(2)}$$

where, Yd, is yield difference; Si, is simulated yield; Oi is observed yield

RESULTS AND DISCUSSION

Impacts of Climate Change on Potato Yield (Considering Rainfed Agriculture): Analysis of Potato yield in current and future climate under A2 scenario for rainfed treatment at MU showed that potato yield decreased by 21.73% and 5.05% in 2020s and 2080s, respectively (Table 1). Similarly at MARC, yield decreased by 14.69% and 1.31% in 2020 and 2080s, respectively (Table 3). Whereas, under B1 emission scenario, Potato yield decreased at a decreasing rate from 22.63% to 11.31% at MU and 15.86 to 0.78% at MARC sites in 2020s and 2080s respectively (Table 1 and 3). The reduction in yield might be due to the early cessation of rain fall which do not complete the growing period of the crop combined with extended dry spells within the growing season in the study area. However, the relatively lower yield reduction in 2080s might be due to the increased CO_2 concentration which might have positive impact on yield due to the increased photosynthetic capacity of leaves. This finding is in agreement with [26] who reported most plants grow faster under elevated CO_2 even under stress conditions.

Combined Effect of Rainfall, Temperature and CO_2 on Future Potato Yield: Analysis of Potato yield in current and future climate under A2 scenario for full supplementary (FSI) and Deficit irrigation (DI) treatments indicated yield increased by 3.11 to 17.72% and 16.60 to 29.58% under DI treatments from 2050s and 2080s, at MU, respectively (Table 1). Similarly at MARC, yield has increased by 3.61% to 14.45% in FSI and 13.34% to 27.73% in DI treatments in 2050s and 2080s, respectively (Table 3).Whereas, at MU under B1 emission scenario, potato yield under FSI and DI treatments showed yield increment of 2.56% in 2080s and 5.84 to12.27% in 2050s and 2080s. Similarly, yield increment of 0.94% in 2080s and 5.46 to 9.27% at MARC in 2050 and 2080 (Table 1 and 3). The yield increase might be due to the elevated CO_2 concentration especially at the end years combined with supplementary irrigation applied on the existed rainfed. However, the projected temperature is still in the range at which potato yield would not be significantly damaged. The overall indication of this study showed if appropriate adaptation options have been taken, the negative impact of climate change would be minimized.

Impact of Different Supplementary Irrigation on Future Potato Yield Under Changed Climate: Use of full supplementary and deficit irrigation as adaptation option for the changed climate showed that yield increased as

Table 1: Comparison of observed potato dry yield (t/ha) with predicted under different climate scenarios at MU.

		Predicted											
		2020_s				2050s				2080s			
TRT	Observed	B1	DV(%)	A2	DV(%)	B1	DV(%)	A2	DV(%)	B1	DV(%)	A2	DV(%)
FSI	10.94	9.58	-12.43	9.87	-9.80	10.54	-3.66	11.28	3.11	11.22	2.56	12.89	17.72
DI	9.94	9.85	- 0.91	9.86	-0.80	10.52	5.84	11.59	16.60	11.16	12.27	12.88	29.58
RF	6.54	5.06	-22.63	5.12	-1.71	5.2	-0.49	5.7	-12.84	5.8	-11.31	6.21	-5.05

TRT-Treatment, (-) shows yield decreases, DV-Yield deviation between Observed and predicted

Table 2: Comparison of observed and simulated potato dry yield under different climate scenarios at MARC (t/ha)

		Predicted											
		2020s				2050s				2080s			
TRT	Observed	B1	DV(%)	A2	DV(%)	B1	DV(%)	A2	DV(%)	B1	DV(%)	A2	DV(%)
FSI	12.73	11.19	-12.10	11.53	-9.43	12.40	-2.59	13.19	3.61	12.85	0.94	14.57	14.45
DI	11.54	11.10	- 3.81	11.44	-0.87	12.17	5.46	13.08	13.34	12.61	9.27	14.74	27.73
RF	7.69	6.47	-15.86	6.56	-14.69	6.77	-11.96	7.34	-4.55	7.63	-0.78	7.59	- 1.30

Table 3: Predicted yield deviation at different irrigation management treatments at MU

	2020s		2050s		2080s	
	B1	A2	B1	A2	B1	A2
TRT Comparison	DV(%)	DV(%)	DV(%)	DV(%)	DV(%)	DV(%)
FSI-DI	-2.7	0.1	0.2	-2.7	0.5	0.1
FSI -RF	89.3	92.6	102.7	97.9	93.4	107.6
DI-RF	94.6	92.6	102.3	103.3	92.4	107.4

Table 4: Predicted yield deviation at different irrigation management treatments at MARC

	2020s		2050s		2080s	
	B1	A2	B1	A2	B1	A2
TRT Comparison	DV(%)	DV(%)	DV(%)	DV(%)	DV(%)	DV(%)
FSI-DI	0.8	0.8	1.9	0.8	1.9	-1.2
FSI -RF	73.0	75.8	83.2	79.7	68.4	92.0
DI-RF	71.6	74.4	79.8	78.2	65.3	94.2

compared with rainfed treatment by 92.8% to 107.6% from 2020_s to 2080_s in A2 scenarios at MU respectively (Table 2). Similarly, the use of supplementary irrigation on the existed rainfed treatment under changed climate substantially increased yield at MARC by 71.6 to 94.2% in 2020s and 2080s respectively (Table 4). This indicates that impact of climate change can be minimized by using better supplementary irrigation management options.

On the other hand, application of full supplementary irrigation had no significant effect as compared with deficit irrigation in both sites (yield deviation is small) (Table 2 and 4). This indicates deficit irrigation might be enough to obtain high yield. Therefore, it seems that use of deficit irrigation is effective as the extra water used in supplementary irrigation is saved for additional investment for potato production in extra land. Moreover, the current rainfed production system needs additional water requirement due to climate change. This calls for adoption of competent water harvesting technologies by farmers.

Impact of CO_2 Concentration on Potato Yield under Changed Climate: The analysis of yield as affected by the CO_2 emission scenario (A2 to B1) indicated yield was increased by 3.03 to 14.9% in FSI, 0.1 to 15.4% in DI and 1.19 to 9.6% in RF treatments from 2020s to 2080s at MU (Table 5). Similarly at MARC, Yield obtained by A2 as compared with B1 exceeded by 3.0 to 13.4% in FSI, 3.1 to 16% in DI and 0.5 to 8.4% in RF treatment (Table 6).

Table 5: Yield difference due to CO_2 concentration difference (%) at MU

	2020s	2050s	2080s
TRT Comparison	DV(%)	DV(%)	DV(%)
FSI	3.03	7.0	14.9
DI	0.10	10.2	15.4
RF	1.19	9.6	7.1

Table 6: Yield difference due to CO_2 concentration difference (%) at MARC

TRT comparison	2020s	2050s	2080s
	DV(%)	DV(%)	DV(%)
FSI	3.0	6.4	13.4
DI	3.1	7.5	16.9
RF	1.4	8.4	0.5

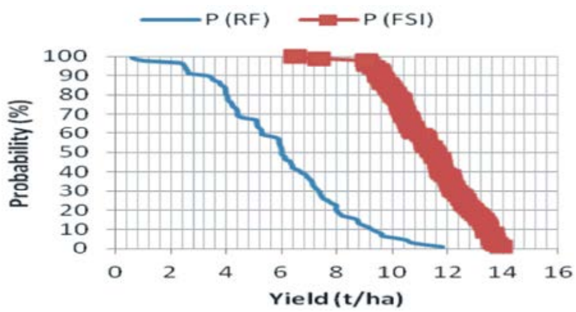

Fig. 1: Probability of exceedance (%) of yield obtained by FSI and RF under A2 scenario at MU

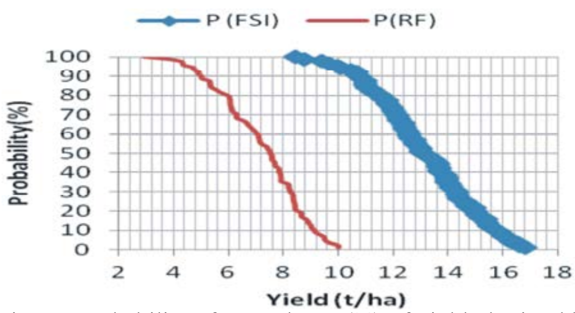

Fig. 2: Probability of exceedance (%) of yield obtained by FSI and RF under A2 scenario at MARC

This indicates potato responds positively to elevated CO_2 concentration due to its fertilization effect. This result is in agreement with [27] who reported that CO2 concentration and assimilation are positively correlated and a 10% increase in tuber yield is estimated for every 100 ppm increase in CO_2 concentration. [28] also reported that elevated CO_2 increased rates of net photosynthesis by 56%, reducing their stomatal conductance by 55%, increasing water-use efficiencies by 90% and increased tuber dry mass production by 85%, respectively.

Yield Exceedance Probability: The probably of getting certain levels of intended yield within a given period of time is determined using a probability of exceedance statistical technique. For example, under A2 scenario with FSI and RF, farmers would be able to obtain 9.2 t/ha at a probability of 90% and 10%, respectively at MU site (Fig. 1). Similarly, the probability of obtaining the same yield under A2 scenarios with FSI and RF condition, at MARC site was nearly 100% and nearly (10%), respectively (Fig. 2). This indicates the probability of getting higher yield under rainfed condition is very low implying the importance of supplementary irrigation for growing potato under the future climate.

CONCLUSION

Potato is regarded as a high potential food security crop due to its high yield per unit area and short maturity crop as compared with other cereals. However, due to its sensitivity to high temperature and moisture deficits, the production of the crop is very low as compared with the world average production. One of the factors for the low yield is the impact of climate change. So that the objective of this research is to analyze the impact of climate change on potato yield.

The comparative analysis of potato yield in changing climate showed that yield was decreased at decreasing rate across all years and scenarios keeping the current Rainfed management at both sites. Yield decrements were also showed in 2020-2050s using Full Supplementary (FSI) except in A2 and in 2020s using Deficit Irrigation (DI) management in both scenarios. However, yield increased at increasing rate in 2080 and 2050-2080 by FSI and DI management respectively at both sites.

The comparative potato yield analyzed as influenced by different CO2 concentration showed yield deviation starting from $2050\text{-}2080_s$. Highest yield increments were observed under A2 scenario whereas the lowest yield increment was observed under B1 scenario for the projected years 2050s and 2080s under both FSI and DI treatments at both sites.

Observed and Predicted results indicated that potato when supplied with deficit irrigation (DI) showed similar yield increase as compared with supplementary irrigation under current and predicted future climate by scenario and years. This indicates the current rainfed cultivation demands supplementary irrigation due to climate change. The overall indication of this study showed if appropriate adaptation options have been taken, the negative impact of climate change would be minimized.

However, further research on adaptation options like appropriate planting date combined with the onset, cessation of the rains and the seasonal dry spells, use of resilient varieties to climate change and optimum fertility level should be studied. It is also advisable to include the effect of weeds, disease and pests incidence on Potato yield under changing climate.

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