Determining the Effect of Climate Change on Seasonal Crop Water Requirements of Irrigated Lowland Rice (*Oryza sativa*) under Different Climatic Environments

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ABSTRACT

Changes in temperature and rainfall pattern can lead to negative impacts on crop production. Limited water resources for agricultural production can also lead to a considerable yield reduction. In this study, climate projections at different greenhouse gas emission scenarios were used in determining the effect of climate change on seasonal crop water requirement (CWR) and irrigation requirement (IR) of lowland rice at different climatic environments. Climate projections from year 2020 to 2059 were generated using MarkSim. Crop evapotranspiration and irrigation requirements of lowland rice were simulated using FAO CROPWAT. Analysis of projected maximum and minimum temperatures and rainfall showed increasing trend through time. Seasonal CWR and IR showed highest projected change at 2050. Highest projected change in CWR during wet and dry seasons were 4.01% and 3.84% in Muñoz, Nueva Ecija, 3.30% and 3.54% in Los Baños, Laguna and 4.12% and 4.34% in Cabagan, Isabela, respectively. Highest projected change in IR during wet and dry seasons were 10.16% and 1.38% in Muñoz, 22.81% and 4.76% in Los Baños and 5.07% and 7.44% in Cabagan, respectively. The results showed that the irrigation requirements must be considered in improving the capacity of irrigation systems to satisfy the increasing water demand of rice brought about by climate change.

Keywords: crop water requirement, irrigation requirement, climate change, FAO CROPWAT, irrigated lowland rice

INTRODUCTION

The Philippines is the world's eighth largest producer of rice but imports about 10% of its annual consumption requirements. In 2015, the Philippines imported about 1.8 million tons of rice to meet the domestic demand (Domingo, 2015). Increase in greenhouse gas concentration in the atmosphere, caused by anthropogenic and natural activities, resulted in observed increase in temperature, changing rainfall pattern, and frequent occurrence of extreme weather events such as drought, flooding and strong typhoons.

Climate change has been one of the major concerns of agricultural sector in the Philippines due to its impacts on crop production. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) (2011) reported that the maximum and minimum temperatures during the last 60 years have increased by 0.36˚C and 1.0˚C, respectively. An increase of 0.6 ˚C from 1981-2010 climatological normal was observed in the annual mean temperature in 2016. Salvacion, *et al*. (2018) also observed an average increase of 0.34 mm in monthly rainfall based on Climate Research Unit time series data (1951 to 2015). However, the strong occurrence of El Niño in 2015 resulted to below normal rainfall in most parts of the country in the first half of 2016 (Oscar M. Lopez Center for Climate Change Adaptation and Disaster Risk Management Foundation, Inc. (OMLC) & PAGASA, 2018). This affected around 556, 721 hectares of agricultural lands, majority of which are corn (46%) and rice (41%) (Food and Agriculture Organization of the United Nations (FAO), 2016). Damage on agricultural produce was reported to be around 790, 239 metric tons amounting to almost US$ 11.45 billion production loss (The Economic and Social Commission for Asia and the Pacific (ESCAP) & The United Nations Development Programme (UNDP), 2016).

Similar to other rice-producing countries, rice production in the Philippines is vulnerable to climate change. About 10% decrease in rice yield is associated with every 1°C increase in temperature. It was also reported that rice yield in the Philippines during dry season dropped by 15% for each 1°C increase in seasonal mean temperature. By 2100, a drop of 50% in rice yield is expected in Indonesia, Philippines, Thailand, and Vietnam (Redfern, Azzu, & Binamira, 2012). Moreover, the decline in rice yield can be attributed to decreasing water supply especially during dry season and other rice production constraints such as natural calamities, declining land area, pest and diseases, and soil fertility.

Efficient water resources distribution is very important to provide sufficient food supply in the country. According to Zhao and Nan (2007), comprehensive understanding of crop water requirement is essential especially in irrigated farming to improve water use efficiency. Crop water requirements vary significantly during growing period due to variation in crop canopy and climatic conditions (Allen, Pereira, Raes, & Smith, 1998). Knowing the water requirement of irrigated crops during their respective growth stages is significant for efficient water management and reduce unproductive water losses such as percolation and seepage.

Various studies have used FAO CropWat as a decision support tool to perform calculations on reference evapotranspiration, CWR, and IR of the different crops. It is also be used for assessing yield responses under various climate conditions, and development of crop irrigation schedules and water supply schemes for improved planning and water management of irrigation practices (Babu, R.G., Babu, G.R., & Kumar, 2015; Wane & Nagdeve, 2014; Nayak, Choudhary & Pandram, 2016).

In this study, climate projections using Representative Concentration Pathways (RCPs) as greenhouse gas emission scenarios are generated to evaluate the effect of climate change on the seasonal crop water requirement and irrigation requirement of lowland rice areas under different climatic environments.

MATERIALS AND METHODS

Climate Projections Using MarkSim

Three rice production areas located in (1) Muñoz, Nueva Ecija (15˚ 44’ N, 120˚ 55’ E.) (2) Los Baños, Laguna, (14˚ 9’ N, 121˚ 15’ E) and (3) Cabagan, Isabela (17˚ 25’ N, 121˚ 49’ E) were considered in the study. These areas represent Type I, Type III, and Type IV climate, respectively. These climate types are based on modified Corona’s classification adopted by the PAGASA.

Marksim® DSSAT was used in generating the present-day climate and multiple years of future climate data (2020-2059). It includes a total of seventeen (17) Global Circulation Models (GCMs) that were part of the IPCC’s Fifth Assessment Report (AR5). Different greenhouse gas emissions pathways were also included ranging from low, moderate, and high emissions pathways (Climate Change Agriculture and Food Security (CCAFS), 2015).

Climate projections were done under four RCP scenarios (i.e. RCP 2.6, RCP 4.5, RCP 6.0, and RCP

8.5). The RCPs were derived according to its radiative forcing concentration (i.e. 2.6 W/m2, 4.5 W/m2, 6.0 W/m2, and 8.5 W/m2) at year 2100 relative to pre-industrial levels (Van Vuuren *et al*., 2011). Specifically, monthly projections of minimum temperature, maximum temperature, and rainfall were generated for the study. The average of monthly projections for both wet (July-November) and dry (January-May) seasons were done for the year 2020-2039 centered at 2030, and year 2041-2059 centered at 2050.

Table 1. Summary of crop data used in the study.

CROP DATA	GROWTH STAGES					
	Nursery	Land Preparation	I	II	III	IV
Kc dry	0.70	0.30	0.50		1.05	0.70
Stage (days)	25	20(total)				
Rooting depth, m		5 (puddling)	0.1		0.23	
Puddling depth, m		0.15				
Nursery area, %	10					
Critical depletion, frac	0.2		0.2		0.2	0.2
Yield response, f			1	1.09	1.32	0.5
Crop height, m					1	

Table 2. Summary of soil data used in the study.

SOIL DATA	VALUE	
	Heavy	Medium
Total available soil moisture (FC-WP), mm/meter	200	290
Maximum rain infiltration rate, mm/day	40	40
Maximum rooting depth, cm	900	900
Initial soil moisture depletion (as % TAM), %	0	0
Initial available soil moisture, mm/meter	200	290
Drainable porosity (SAT-FC), %	6	12
Critical depletion for puddle cracking, fraction	0.6	0.4
Maximum percolation rate after puddling, mm/day	3.4	3.4
Water availability at planting, mm WD	50	50
Maximum water depth, mm	50	50

Crop Water Requirement Projections

FAO CropWat was used to estimate the crop water required based on climate, crop, and soil inputs (Clarke, 1998). The crop water requirement of lowland rice for each location during wet and dry seasons was calculated at present year, at 2030 and at 2050. Projected monthly climatological data (maximum and minimum temperatures and rainfall) for year 2020-2039 centered at year 2030, year 2040-2059 centered at year 2050, and present-day climate were used to calculate crop water requirement of rice under different RCPs scenarios. Comparison of projected crop water requirement at 2030 and 2050 to present day crop water requirement was done by calculating the percent change under different RCPs scenarios. The crop water requirement derived from present day climate was used as baseline data.

Effective rainfall was computed based on USDA Soil Conservation Service method using the equations (Babu *et al*., 2015):

$$PE_{eff} = P_{month}\ x\ \frac{125-0.2P_{month}}{125}\quad for\ P_{month} < 250\ mm$$

Equation 1

$$PE_{eff} = 125 + 0.1xP_{month}\quad for\ P_{month} > 250\ mm$$

Equation 2

where PE is effective rainfall (mm); P_{month} is monthly rainfall (mm).

The data from the study of Fernandez, *et al*. (2016, unpublished) were used in setting up the crop data as summarized in Table 1. The default value of rooting depth at the mid-season stage was modified from 0.60 m to 0.23 m based on the average root length measured from the actual field experiments.

Also, the default value of puddling depth was changed from 0.40 m to 0.15 m. The critical depletion fraction and yield response factor were based on the default values.

Default soil data values in FAO CROPWAT were used (Table 3). Values for heavy soil were used both in Los Baños and Muñoz while values for medium soil were used in Cabagan. The soil type for each location was based on the data from Department of Agriculture Bureau of Agricultural Research (DA-BAR).

Irrigation Requirement

Irrigation requirements of lowland rice were determined using FAO CropWat. The irrigation requirement of a crop is defined as the amount of water required to bring soil moisture level at field capacity. If leaching requirement is less than 10%, it is often ignored from the equation (Etissa, Dechassa, & Alemayehu, 2016).

$$IR = ETc - (PE + Wb) + LR$$

Equation 3

where IR is irrigation requirement (mm); ET_c is crop evapotranspiration (mm); PE is effective rainfall (mm); Wb is initial water stored; and LR is leaching requirement (mm). Projected irrigation requirements of lowland rice (at 2030 and 2050) at selected study sites were generated using future climate data derived from MarkSim.

Projection Analysis

Regression analysis was performed to determine the strength or degree of association between the generated present-day climate based on MarkSim and the observed 30-year normal averages from the agrometeorological stations. The difference between projected and present-day temperatures were computed to determine the deviation of the projected temperatures (at 2030 and 2050) from the present-day temperature and is given by the equation:

$$T_{PC} = T_{Pj} - T_{Pr}$$

Equation 4

where T_{PC} is projected change in temperature; T_{Pj} is projected temperature; T_{Pr} is present day temperature.

Projected change in rainfall, expressed in %, was used to analyze rainfall variation and is given by the equation:

$$R_{PC} = \frac{(R_{Pj} - R_{Pr})}{R_{Pr}} x\ 100\%$$

Equation 5

where R_{PC} is projected change in rainfall; R_{Pj} is projected rainfall; R_{Pr} is present day rainfall. Positive projected change in rainfall means an increase in the magnitude of projected rainfall from the present day. Negative projected change means a decrease in the magnitude of projected rainfall from the present day.

Comparison of projected crop water requirement to the present-day crop water requirement analysis was done by computing the projected change in crop water requirement (%) of lowland rice. Equation used is given by:

$$CWR_{PC} = \frac{(CWR_{Pj} - CWR_{Pr})}{CWR_{Pr}} x\ 100\%$$

Equation 6

where CWR_{PC} is projected change in crop water requirement; CWR_{Pj} is projected crop water requirement; CWR_{Pr} is present day crop water requirement.

Projected change in irrigation requirement, expressed in %, was used to analyze the increase or decrease of irrigation requirement of lowland rice. The present irrigation requirement was used as the baseline for the computation. Positive projected change in IR means an increase in irrigation requirement of lowland rice and vice versa. Equation used is given by:

$$IR_{PC} = \frac{(IR_{Pj} - IR_{Pr})}{IR_{Pr}} x\ 100\%$$

Equation 7

RESULTS AND DISCUSSION

Comparison of observed 30-year normal and generated present-day climate

The generated present-day climate and the observed 30-year normal averages were compared using linear regression analysis (Figure 1). The study site in Cabagan was not included in the analysis due to limited number of years of historical data.

Rainfall analysis in Muñoz and Los Baños showed high values of R2 (0.99 and 0.95, respectively). This means that 99% and 95% of the total variation in generated weather data can be explained by the linear relationship between the observed and generated weather data in Muñoz and Los Baños, respectively. Maximum and minimum temperatures in Muñoz showed high values of R2 (0.84 and 0.92, respectively). In Los Baños, results showed high R2 values of 0.98 and 0.99 for maximum and minimum temperatures, respectively. Due to high correlation between the observed 30-year normal and the generated present-day climate of the two sites (Los Baños and Muñoz), it can be inferred that MarkSim can provide a good estimate of the present-day climate for all study sites including Cabagan.

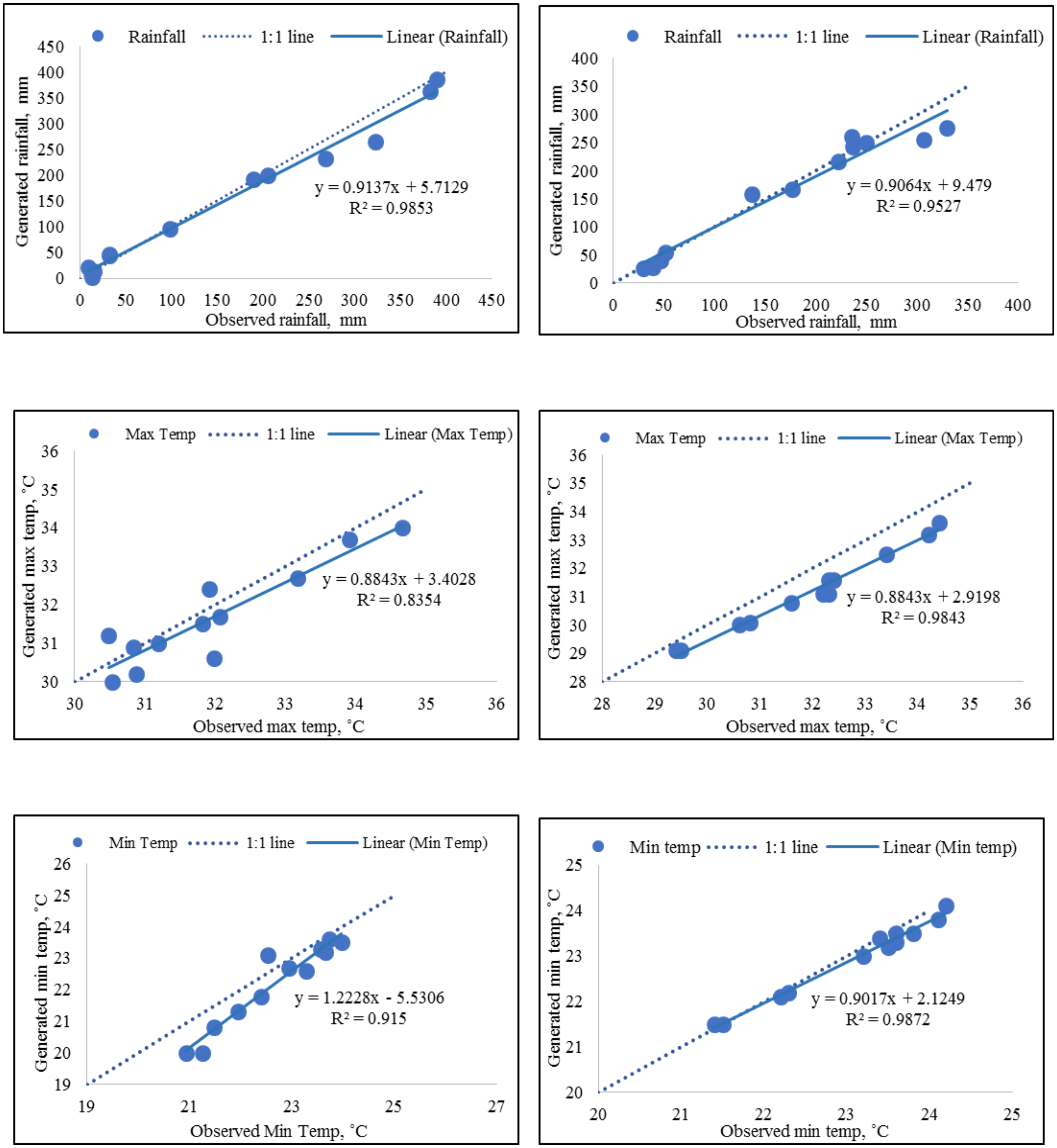
Projected change in seasonal temperature

Table 3 shows the summary of projected change in maximum temperature at 2030 and 2050 during wet and dry seasons in Muñoz, Los Baños, and Cabagan sites. Results showed increasing projected change in maximum temperature with increasing RCPs emission scenarios in all study sites. Also, increasing projected change can be seen at 2030 and 2050. In Muñoz, highest projected change was 1.68˚C and 1.67˚C under RCP 8.5 at year 2050 during wet and dry seasons, respectively. Highest projected change in Los Baños were 1.60˚C and 1.64˚C at year 2050 under RCP 8.5. In Cabagan, highest projected change was 1.73˚C and 1.70˚C at year 2050 under RCP 8.5.

Table 4 shows the projected change in minimum temperature under different RCPs emission scenarios at year 2030 and at year 2050. Highest projected change in Muñoz were observed at year 2050 under RCP 8.5 with values 1.74˚C and 1.79˚C during wet and dry seasons, respectively. In Los Baños, highest projected change was 1.72˚C and 1.74˚C at year 2050 under RCP 8.5. Projected change in Cabagan were 1.79˚C and 1.73˚C under RCP 8.5 at year 2050. Similar with the maximum temperature, increasing projected change can be seen with increasing RCPs emission scenario and with increasing time.

Table 3. Projected change in seasonal rainfall under different RCPs scenarios.

SCENARIO	YEAR	MUÑOZ (%)		LOS BAÑOS (%)		CABAGAN (%)	
		Wet	Dry	Wet	Dry	Wet	Dry
RCP 2.6	2030	+0.92	-0.86	+1.78	+1.19	+0.76	+0.36
	2050	+1.34	-0.61	+3.42	+0.64	+1.26	+1.75
RCP 4.5	2030	+3.09	-1.85	+1.62	+0.67	+3.47	+3.46
	2050	+3.28	-0.19	+2.86	+3.70	+4.60	0.00
RCP 6.0	2030	-1.32	-2.42	-0.12	-2.67	-0.63	-1.46
	2050	+0.10	-3.60	+2.24	-2.35	-0.04	-0.18
RCP 8.5	2030	+2.77	-0.04	+2.76	+2.62	+1.90	+0.91
	2050	+4.981	+2.06	+4.76	+5.04	+4.02	+3.22



(a) (b)

Figure 1. Linear regression analysis on rainfall, maximum temperature, and minimum temperature in (a) Muñoz, Nueva Ecija and (b) Los Baños, Laguna.

One of the major effects of climate change is the increase in temperature. The increase in projected maximum and minimum temperatures under different RCPs scenarios were the consequence of increasing concentration of greenhouse gases in the atmosphere. Increase in the seasonal maximum and minimum temperature changes were evident and through time, the increase in temperature is inevitable if no action was done to reduce the global greenhouse gases emissions.

If no mitigation will be implemented, the increasing greenhouse gases emissions will further enhance the effect of climate change resulting in increased in temperature. From the study of PAGASA (2011), it was revealed that the number of hot days and warm nights have increased while cold days and cool nights have decreased. These changes are due to the effect of increase in temperature. This means the Philippines will get warmer especially during dry season. Studies on the effect of climate change in the Philippines revealed that maximum and minimum temperatures increased by 0.36˚C and 0.1 ˚C from 1951-2010, respectively (Murphy & Tembo, 2014.). Also, PAGASA (2011) reported that mean temperatures in the Philippines will increase in 2020 by 0.9-1.1 ˚C and in 2050 by 1.8-2.2 ˚C. It was also projected that largest increase in temperature will be during summer season.

The increase in temperature through time can have a negative effect on the production of rice. Since temperature greatly influences the length of growing period and yield, extreme high and/or low temperature changes can cause a negative effect (temperature stress) on the rice plant. According to Nguyen (2005), grain sterility is the most damaging effect of heat stress resulting in large percentage of grain sterility with 1 or 2 hours of high temperature during the period of anthesis. During vegetative and ripening stage, high temperature of >35°C and >30° C, respectively can alter grain filling and quality of the rice (Karn, 2014; Sridevi & Chellamuthu, 2015; Yoshida, 1981). From the study conducted by Peng *et al.* (2004), rice yield decreases by as much as 15% with every 1˚C increase in the mean temperature during dry season and for every 1˚C increase in the minimum temperature, rice yield can be reduced by as much as 10%.

Based on the projected maximum and minimum temperatures, increase in temperature through time was evident and possible reduction on rice yield is expected. One of the adaptations and mitigation strategies suggested by Nguyen (2005) and Peng *et al.* (2004) was the selection of appropriate planting date. Due to variation of temperature throughout the year, proper selection of planting date wherein the reproductive and grain filling phases will fall within months with low temperature can minimize the negative effect of increasing temperature on rice yield. Also, using rice varieties that can tolerate high temperature and is high yielding can be used.

Table 4. Projected change in seasonal crop water requirement of lowland rice under different RCPs scenarios.

SCENARIO	YEAR	MUÑOZ (%)		LOS BAÑOS (%)		CABAGAN (%)	
		Wet	Dry	Wet	Dry	Wet	Dry
RCP 2.6	2030	2.24	2.14	2.12	2.11	1.84	1.86
	2050	2.29	2.10	0.62	1.98	2.36	2.31
RCP 4.5	2030	2.93	2.72	1.99	2.48	2.07	2.27
	2050	3.44	3.84	2.66	3.23	3.04	3.27
RCP 6.0	2030	2.48	2.60	1.81	1.94	2.39	2.56
	2050	3.31	2.93	2.30	2.88	3.06	3.27
RCP 8.5	2030	2.42	2.39	2.09	1.85	2.39	2.62
	2050	4.01	3.69	3.30	3.54	4.12	4.34

Projected Change in Seasonal Rainfall

To quantify the projected increase or decrease of rainfall during wet and dry seasons under different RCPs scenarios, projected change in seasonal rainfall was computed as shown in Table 3. The present-day climate served as the basis for the calculation. Based on the results, it was evident that an increase in rainfall can be experienced during wet season in periods 2030 and 2050 under different RCPs scenarios except for RCP 6.0 at year 2030 with a decrease in rainfall of about 1.32% in Muñoz. During dry season in Muñoz, a decreasing amount of rainfall can be seen in periods 2030 and 2050 under different RCPs scenarios. However, an increase in rainfall of about 2.06% can be seen at RCP 8.5 in period 2050 during dry season.

In Los Baños, projected rainfall change showed increasing amount of rainfall both during wet and dry seasons under different RCPs scenarios. However, during wet season at year 2030, RCP 6.0 showed decreasing amount of rainfall of about 0.12%. During dry season, both periods (2030 and 2050) showed decreasing amount of rainfall of about 2.67% and 2.35%, respectively under RCP 6.0. In Cabagan, an increase in the amount of rainfall was evident both during wet and dry seasons under different RCPs scenarios except for RCP 6.0 where a negative percent rainfall change was computed both during wet and dry seasons in periods 2030 and 2050.

There are no observable trends on the magnitude of the projected rainfall change which can be attributed to the effect of the geographical location and the climate type of the three study sites. On the seasonal changes in rainfall, during wet season, rainfall values increase as seen in the three study areas making wet season still wetter. During dry season, a reduction in rainfall can be seen in Muñoz making it drier while an increase in rainfall can be seen in the other two study sites. With these, possible flooding can be expected during wet season while droughts can be experienced during dry season. All RCPs scenarios for both periods have positive percent change except RCP 6.0 at year 2030 and year 2050 which resulted in a negative percent change indicating a decrease in the amount of rainfall both during wet and dry seasons in the three study sites.

Changes in the amount of rainfall is a significant factor that can affect rice productivity. Similar to temperature, offset on the planting dates can be done based on the variability in the onset of rainy season. According to Nguyen (2005), most rice varieties can stand at least 6 days of complete submergence before 50% of the rice plants die. If submergence lasts for 14 days, mortality rate becomes 100%. With the variability in rainfall, frequent occurrence of rainfall and typhoon can cause flooding during wet season. During dry season, drought can be experienced due to absence of rainfall.

Irrigated lowland rice are vulnerable to drought stress. The occurrence of El Niño in 2009 resulted in a decrease of rice production by 3.31% due to drying up of irrigation systems (Redfern *et al*., 2012) According to Kang, Khan, and Ma (2009), water availability and crop production will decrease with the increasing temperature and rainfall variations. Also, decrease in rainfall will lead to higher irrigation demand.

Projected Changes in Seasonal Crop Water Requirement of lowland rice

Table 4 shows the computed projected change in seasonal CWR in Muñoz, Los Baños, and Cabagan. Results showed increase in crop water requirement of rice at year 2030 and year 2050 both during wet and dry seasons in the three study sites.

The increase in maximum crop water requirement (4.01%) was obtained in Muñoz, at year 2050 under RCP 8.5 during wet season while 3.84% during dry season of the same year at RCP 4.5. In Los Baños, maximum increase of 3.30% and 3.54% was found at year 2050 under RCP 8.5 during wet and dry seasons, respectively. An increase of 4.12% and 4.33% at year 2050 under RCP 8.5 was found in Cabagan during wet and dry seasons, respectively. The changes in temperature and rainfall through time lead to an increase in the water requirement and uptake of rice plant. Also, the effects of these changes vary considerably from region to region due to difference in climatological environment.

According to Fujihara, Tanaka, and Watanabe (2008) as cited by Kang *et al*. (2009), water shortage will not occur if water requirement of the crop will not increase. However, the study showed increase in crop water requirement of irrigated lowland rice due to climate change. Due to rising temperatures and rainfall fluctuations, water resources such as rivers, groundwater, etc. will be insufficient to support water requirements of crops. Thus, effective irrigation methods and proper allocation of water resources is needed so that there is enough supply for agricultural use.

Projected Seasonal Irrigation Requirement of Lowland Rice

The projected seasonal irrigation requirement in Muñoz, Los Baños, and Cabagan sites under different RCPs scenarios were summarized in Tables 5, 6, and 7, respectively. Results showed that irrigation requirement at 2030 and 2050 during dry season will be higher than during wet season. This can be due to the fact that during wet season, rainfall received by the site were higher resulting in a lower irrigation requirement. The high irrigation requirement during dry season can be due to high temperature with relatively low effective rainfall resulting in increased irrigation requirement in order to meet crop water needs.

In Muñoz, the irrigation requirement during wet season was highest at 2050 under RCP 6.0 and lowest at present year. Irrigation requirement in Los Baños was highest at 2050 under RCP 8.5 while lowest under RCP 4.5 of the same year. Irrigation

Table 5. Summary of projected seasonal irrigation requirement of irrigated lowland rice in Muñoz, Nueva Ecija.

YEAR	SCE-NARIO	WET SEASON		DRY SEASON	
		IR (mm)	Projected change (%)	IR (mm)	Projected change (%)
Present		148.60		729.50	
2030	RCP 2.6	156.00	4.98	719.50	-1.37
	RCP 4.5	149.00	0.27	729.80	0.04
	RCP 6.0	161.90	8.95	732.40	0.40
	RCP 8.5	153.80	3.50	726.40	-0.42
2050	RCP 2.6	156.30	5.18	716.50	-1.78
	RCP 4.5	152.10	2.36	736.10	0.90
	RCP 6.0	163.70	10.16	727.70	-0.25
	RCP 8.5	154.90	4.24	739.60	1.38

Table 6. Summary of projected seasonal irrigation requirement of irrigated lowland rice in Los Baños, Laguna.

YEAR	SCE-NARIO	WET SEASON		DRY SEASON	
		IR (mm)	Projected change (%)	IR (mm)	Projected change (%)
Present		185.00		706.10	
2030	RCP 2.6	189.70	2.54	700.30	-0.82
	RCP 4.5	195.90	5.89	718.50	1.76
	RCP 6.0	205.50	11.08	731.50	3.60
	RCP 8.5	167.10	-9.68	700.50	-0.79
2050	RCP 2.6	200.30	8.27	716.20	1.43
	RCP 4.5	161.40	-12.76	701.10	-0.71
	RCP 6.0	170.10	-8.05	728.00	3.10
	RCP 8.5	227.20	22.81	739.70	4.76

Table 7. Summary of projected seasonal irrigation requirement of irrigated lowland rice in Cabagan, Isabela.

YEAR	SCE-NARIO	WET SEASON		DRY SEASON	
		IR (mm)	Projected change (%)	IR (mm)	Projected change (%)
Present		175.40		603.30	
2030	RCP 2.6	180.70	3.02	618.60	2.54
	RCP 4.5	181.40	3.42	619.80	2.73
	RCP 6.0	171.50	-2.22	642.80	6.55
	RCP 8.5	180.10	2.68	620.10	2.78
2050	RCP 2.6	182.20	3.88	619.60	2.70
	RCP 4.5	183.80	4.79	622.20	3.13
	RCP 6.0	170.80	-2.62	648.20	7.44
	RCP 8.5	184.30	5.07	629.90	4.41

requirement in Cabagan was highest at 2050 under RCP 4.5 and lowest under RCP 6.0 of the same year during wet season. During dry season, the irrigation requirement in Muñoz was highest at 2050 under RCP 8.5 and lowest at RCP 2.6 of the same year. Irrigation requirement in Los Baños during dry season was highest at 2050 under RCP 8.5 while lowest at 2030 under RCP 2.6. In Cabagan, the irrigation requirement was highest at 2050 under RCP 6.0 and lowest at present year.

The projected increased in irrigation requirement in Muñoz during wet and dry seasons can be as high as 10.16% and 1.38% at 2050, respectively. In Cabagan, the projected increase in irrigation requirement was highest at 2050 with 5.07% and 7.44% increase during wet and dry seasons, respectively. The projected increases in irrigation requirement in Los Baños are 22.81% and 4.76% at 2050 during wet and dry seasons, respectively. High irrigation requirement during the wet season was observed in Los Baños at year 2050 under RCP 8.5 despite an increase in seasonal rainfall. In general, higher total rainfall does not translate into higher effective rainfall. Rain water may be lost in the field due to run off, deep percolation, and seepage. Furthermore, high maximum and minimum temperature were observed during the period and consequently increased crop evapotranspiration.

Crop water requirement needs to be satisfied through irrigation for the crops to attain its optimal growth. It can be seen that irrigation requirement both during wet and dry seasons increases with increasing RCPs emission scenarios. Also, irrigation requirement will increase through time. A study on the assessment of high yield constraints in Asia showed that poor irrigation water management accounts for 23% losses on maximum possible yield (Herdt & Wickham (1975) as cited by Tabbal and Moya (1983)). The reduction on yield was attributed to water shortages during the growing season. Sufficient irrigation capacity from the irrigation system is necessary to satisfy the increasing demand of irrigation requirement of rice as a result of climate change.

However, based on the reports of National Irrigation Administration-Upper Pampanga River Integrated Irrigation Systems (NIA-UPRIIS) in Nueva Ecija, the current irrigation capacity cannot supply the program area intended for irrigation by as much as 8.97% (Toquero, Teaño, Agbayani, & Galapon, 2013). From the study of Lee and Huang (2014), future irrigation requirement will increase by as much as 7.1% during the first cropping season and 2.1% in the second cropping season. Since current irrigation capacity is insufficient, improvement of irrigation water management is necessary. With the right amount of water at a proper time of distribution, irrigation requirement of rice can be satisfied while reducing percentage of tail end areas.

SUMMARY AND CONCLUSION

This study was conducted primarily to project seasonal crop water requirements and irrigation requirements of lowland rice under different RCPs emission scenarios on present day, at 2030 and at 2050. Results of climate projections i.e. maximum and minimum temperatures and rainfall showed an increasing projected change in maximum and minimum temperatures at 2030 and at 2050 when compared with the present day with increasing RCPs emission scenarios. Analysis showed that warmer temperatures will be experienced through time and relatively warmer during dry season. Also, months with low temperature may become less and will eventually get warmer through time. The increase in temperature can greatly influence the length of growing period of rice and can have a negative effect on rice yield due to heat stress. Variation of rainfall can be due to the effect of geographical location and climate types.

The increase in temperature due to climate change will result to higher water uptake of rice plant. The projected crop water requirement of irrigated lowland rice under different RCPs scenarios showed an increasing crop water requirement through time and with increasing RCPs emission scenarios. Crop water requirement during wet season was lower compared during dry season due to warmer climate conditions observed during dry season.

The projected irrigation requirements of lowland rice at 2030 and 2050 were higher than the present day. Also, the projected irrigation requirement during dry season was higher compared to the wet season.

The current capacity of our irrigation system for lowland rice is not sufficient enough to meet the projected increase in irrigation requirement. The lack of water supply increases the possibility of higher tail- end areas and consequently lower the attainable rice yield. Irrigation capacity and efficiency improvements are necessary to cater the increasing water demand especially for the agricultural sector. Various schemes of development of irrigation systems such as run-of-the river diversion, storage or reservoir, and pumping systems should be prioritized especially on rice producing areas vulnerable to climate change. Proper planning of redistribution of water over the given area to decrease maximal and increase minimal inflows is one of the best possible manner to meet downstream water demands. Another practical approach of improving water use efficiency in rice production is by the use of alternate wetting and drying method (AWD). AWD can increase water productivity at the field level by reducing seepage and percolation losses without significant loss in rice yields.

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LITERATURE CITED

ALLEN, R.G., PEREIRA, L.S., RAES, D., & SMITH, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome, Italy: Food and Agriculture Organization of the United Nations. Retrieved from http://www.researchgate.net/

BABU, R.G., BABU, G.R., & KUMAR, H.V.H. (2015). Estimation of crop water requirement, effective rainfall and irrigation water requirement for vegetable crops using CROPWAT. International Journal of Agricultural Engineering 8(1). 15-20. doi 10.15740/HAS/IJAE/8.1/15-20

CLARKE, D. (1998, October). CropWat for Windows: User Guide. Retrieved from https://tarwi.lamolina.edu.pe/

CLIMATE CHANGE AGRICULTURE AND FOOD SECURITY (CCFAS). (2015). Marksim GCM: Weather Generating Tool. Retrieved from https://ccafs.cgiar.org/

DOMINGO, R.W. (2015, January 3). Philippines seen importing 1.8M tons of rice in 2015. Philippine Daily Inquirer. Retrieved from http://business.inquirer.net/

ETISSA, E., DECHASSA, N., & ALEMAYEHU, Y. (2016). Estimation of yield response (ky) and validation of CropWat for tomato under different irrigation regimes. Irrigation & Drainage Systems Engineering 5 (2), 167. doi:10.4172/2168-9768.1000167

FERNANDEZ, C.G.P., SALUDES, R.B., DORADO, M.A., & STA. CRUZ, P.C. (2016, Unpublished). Seasonal evapotranspiration and percolation of irrigated lowland rice (Oryza sativa) under different climatic environments. Graduate Thesis. Graduate School, University of the Philippines Los Baños, College, Laguna 4031

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). (2016). 2015-2016 El Niño early action and response for agriculture, food security and nutrition: Update # 10. Rome, Italy: Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org

KANG, Y., KHAN, S., AND MA, X. (2009). Climate change Impacts on crop yield, crop water productivity and food security- A review. Progress in Natural Science, 19 (12), 1665-1674. doi: 10.1016/j.pnsc.2009.08.001

KARN, P.K. (2014). The impact of climate change on rice production in Nepal. Kathmandu, Nepal: South Asian Network for Development and Environmental Economics. Retrieved from http://opendocs.ids.ac.uk/

LEE, J.L., and HUANG, W.C. (2014). Impact of climate change on irrigation water requirement in Northern Taiwan. Water, 6 (11). 3339-3361. doi: 10.3390/w6113339

MURPHY, C. and TEMBO, M. (2014.) Observed and projected climate change in the Philippines, Honduras, Kenya, Malawi, and Ethiopia. Retrieved from http://www.trocaire.org/

NAYAK, T.R., CHOUDHARY, M.K., and PANDRAM, V.K. (2016) Modelling the crop water requirement using CropWat: a case study of Samrat Ashok Sagar (Halali) project command.

NGUYEN, N.V. (2005). Global climate changes and rice food security. Rome, Italy: Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org

Oscar M. Lopez Center for Climate Change Adaptation and Disaster Risk Management Foundation, Inc. (OMLC) & Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). (2018). State of the 2016 Philippine climate. Metro Manila, Philippines: OMLC

PHILIPPINE ATMOSPHERIC, GEOPHYSICAL AND ASTRONOMICAL SERVICES ADMINISTRATION (PAGASA) (2011). Climate change in the Philippines. Retrieved from http://dilg.gov.ph/

PENG, S., HUANGE, J., SHEEHY, J.E., LAZA, RC., VISPERAS, R., ZHONG, X., GRACE, S.C., GURDEV, S.K., and KENNETH, G.C. (2004). Rice yields decline with higher night temperature from global warming. Proceedings of the National Academy of Science of the United States of America, 101 (27). 9971-9975. doi 10.1073/pnas.0403720101

REDFERN, S.K., AZZU, N., AND BINAMIRA, J.S. (2012). Rice in Southeast Asia: Facing risks and vulnerabilities to respond to climate change. Proceedings of Building Resilience for Adaptation to Climate Change in the Agricultural Sector (pp 295-314). Rome, Italy: Food and Agriculture Organization of the United Nations. Retrieved from http://www.researchgate.net/

SALVACION, A.R., MAGCALE-MACANDOG, D.B., STA.CRUZ, P.C., SALUDES, R.B., PANGGA, I.B., CUMAGUN, C.J.R. (2018) Exploring spatial patterns of trends in monthly rainfall and temperature in the Philippines based on Climate Research Unit grid. Spatial Information Research. https://doi.org/10.1007/s41324-018-0189-8

SRIDEVI, V. & CHELLAMUTHU, V. (2015). Impact of weather on rice-a review. International Journal of Applied Research 1 (9). 825-831. Retrieved from www.allresearchjournals.com

TABBAL, D.F. and MOYA, T.B. (1983) Water management practices and irrigation requirements for rice. Proceedings in Rice Production Manual, 4th ed. University of the Philippines Los Baños, Laguna 4031. ISBN: 971-110-005-3

THE ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC (ESCAP) & THE UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP) (2016, September 29). ENSO country report: Regional consultative workshop on El Niño in Asia-Pacific. Retrieved from http://www.unescap.org/

TOQUERO, F.M., TEAÑO, F.L., AGBAYANI, A.S. and GALAPON, K.D. (2013). National Irrigation Association operating and maintenance performance: Seasonal report. NIA-UPRIIS Division I, Pantabangan, Nueva Ecija 3124

WANE, S.S. & NAGDEVE, M.B. Estimation of evapotranspiration and effective rainfall using CropWat. International Journal of Agricultural Engineering 7(1). 23-26. Retrieved from www.researchjournal.co.in

VAN VUUREN, D.P., EDMONDS, J., KAINUMA, M., RIAHI, K., THOMSON, A., HIBBARD, K., HURTT, G.C., KRAM, T., KREY, V., LAMARQUE, J., MASUI, T., MENSHAUSEN, M., NAKICENOVIC, N., SMITH, S.J., ROSE, S.K. (2011). The representative concentration pathways: an overview. Climate Change 109. 5-31 doi 10.1007/s10584-011-0148-z

YOSHIDA, S. (1981). Fundamentals of rice crop science. Retrieved from http://books.irri.org

ZHAO, C. & NAN, Z. (2007). Estimating water needs of maize (Zea mays L.) using the dual crop coefficient method in the arid region of Northwestern China. African Journal of Agricultural Research, 2 (7), 325-333. Retrieved from http://www.academicjournals.org/ ■