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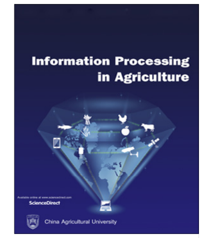

Effect of climate on provincial-level banana yield in the Philippines

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A B S T R A C T

This study assessed the effect of climate on banana yield in the Philippines using provincial level yield data and different climatic variables (i.e. annual rainfall, frequency of wet days, precipitation seasonality, annual mean temperature, temperature seasonality, and annual mean diurnal temperature range) derived from Climate Research Unit – Time Series (CRU-TS) dataset from year 1991–2016. First, trend analysis was applied to the time series of banana yield data for each province to determine presence of linear trend. Then, based on the result of linear trend analysis, multiple regression analysis was used to assess the effect on climate on provincial-level banana yield. Trend analysis showed that 71% of banana producing area in the country experience significant yield trend while multiple regression analysis showed that only 10% of the banana producing areas in the country is significantly affected by climate. Compared to rainfall, temperature variables, specifically temperature seasonality has the greater influence on provincial-level banana yield in the Philippines.

1. Introduction

Information about yield-climate relationship can provide basis for within-year-crop forecasting, and projecting impact of future climate change [1,2]. According to Ray et al. [3] approximately a third (30–39%) of global crop yield variability is due to climate variability. Yield-climate relationship can be derived using either biophysical models or empirical/statistical method [1,4–7]. Ecophysiological models or crop models are some of the example of biophysical models that attempts to predict crop growth and development under specific environmental condition [8]. These models used mathematical description of different physiological, chemical, and physical processes to simulate crop growth and development as function of time [8]. The use of biophysical models on assessing the effect on climate on crop yield requires high data input for model parameterization and validation that includes soil nutrient and water status, planting date and density, and weather data (rainfall, temperature, and solar radiation) [8,9]. Also, some of these biophysical models do not consider the effects of crop pests and diseases [1,9]. Meanwhile, the use of empirical/statistical (regression) models can provide flexibility to integrate both physiological and other determinants of crop yield [4]. In addition, empirical/statistical models can capture the net effect of crop physiology, crop management, and pest dynamics [6]. Furthermore, quantitative evaluation of uncertainties is possible on empirical/statistical models [6,10].

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In the case of the Philippines, several studies have directly or indirectly quantify impact of climate on crops. However, most of these studies focus only on major crops. For example, using provincial level data on production, area, and yield, delos Reyes and David [11] quantified the effect of El Niño on rice production in the Philippines. Koide et al. [12], and Blanc and Strobl [13] estimated the impact of rainfall and typhoon occurrence on rice yield and production in the country. On the other hand, although not directly quantifying the effect of climate on crop, Salvacion and Martin [14], Salvacion [15], and Salvacion [16] indirectly assessed the effect of climate on corn suitability in the Philippines. This study aims to quantify the effect of climate on provincial-level banana yield in the Philippines using empirical/statistical method.

2. Methodology

2.1. *Banana in the Philippines*

Banana (*Musa spp.*) is an important cash crop in the Philippines [17]. In 2015, the country exported around 1.8 million metrics tons of fresh bananas amounting to almost USD658 million [18]. Based on crop statistics of the Philippine Statistics Authority (PSA), three varieties of banana are commonly grown in the country namely: (1) Saba (ABB), (2) Lakatan (AAA); and (3) Cavendish (AAA). Volume of production is split among these varieties and is reported to be around 52% for Cavendish, 28% for Saba, and 10% for Lakatan. In terms of area harvested, around 41% of the country's banana production area is devoted to Saba, 20% to Cavendish, and 12% to Lakatan. As for spatial distribution, Saba and Lakatan are grown in almost all parts of the country while the growing of Cavendish is highly concentrated in the southern portion of the Philippines (Fig. 1).

2.2. *Data*

2.2.1. *Yield, and climate data*

Provincial level yield data from 1991 to 2016 were calculated from banana production and area reported by the Philippines Statistics Authority [19]. Provinces with more than 5 years of missing data were excluded in the analysis. Meanwhile, climate data for this study were extracted from Climate Research Unit Times Series (CRU-TS) data [20,21]. The CRU Time Series data include monthly rainfall (mm), monthly maximum and minimum temperature (°C), and monthly frequency of wet day (days). Different annual measures and climatic indices (Table 1) were derived from this data set. Zonal statistic (i.e. mean) methodology in geographic information system (GIS) was used to derive climatic variables and indices for each province for the year 1991 to 2016. CRU-TS data have been widely used for climate impact analysis on crops [22–24]. Salvacion et al. [25] have evaluated CRU-TS and found good agreement with observed monthly rainfall in the Philippines.

2.3. *Statistical yield modeling*

For statistical yield modeling, this study implemented a similar approach used by Lobell et al. [1] and Lobell [5]. First, linear trend (Eq. (1)) was fitted to yield time series of each province. Then, based on the result of linear trend analysis, a multiple regression was used to analyze the effect the dif-

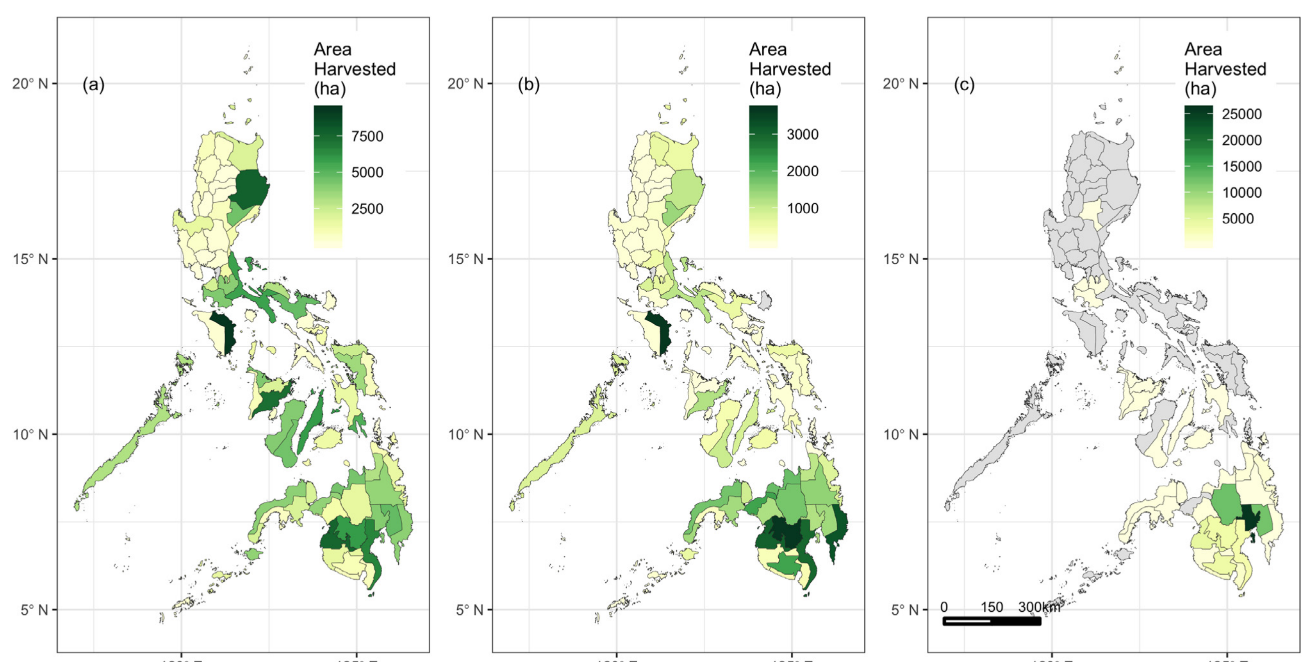

Fig. 1 – Map of area planted per province to (a) Saba, (b) Lakatan, and (c) Cavendish in the Philippines (Data Source: [19]. Note: Grey color fill on the map means "No Data".

Table 1 – List of climatic variables used in yield modeling.

Variable	Abbreviation	Description	Unit
Annual Rainfall	AR	Total annual rainfall calculated from monthly CRU rainfall data	mm
Frequency of Wet Days	FWD	Total number of wet days (rainfall <1 mm) in a year	days
Precipitation Seasonality	PS	Coefficient of variation of monthly rainfall within a year	%
Annual Mean Temperature	AMT	Annual mean temperature	°C
Temperature Seasonality	TS	Amount of temperature variation within a year based on monthly temperature averages	°C
Annual Mean Diurnal Temperature Range	AMDR	The different between average annual maximum and minim temperature	°C

Note: CRU refers to the Climatic Research Unit of the University of East Anglia (https://crudata.uea.ac.uk/cru/data/hrg/).

ferent climate variables on banana yield. In cases where significant linear trend of banana yield was observed, residuals from the linear trend analysis were used as the dependent variable (Eq. (2)) with the assumption that such residuals were the "technology-adjusted yield" [1]. On the other hand, when linear trend of yield time series is not significant, the provincial level calculated yield was used as dependent variable in the multiple linear regression (Eq. (3)). Results from statistical analysis were mapped to determine the spatial distribution of linear trend and effect of each climatic variable for each province.

$$Y_t = \beta_0 + \beta_1 t \quad (1)$$

where **Y** is the banana yield and **t** is time.

$$YR = \beta_0 + \beta_1 X_1 + \beta_n X_n \quad (2)$$

where **YR** is the yield residual and **X** is different weather variables (see Table 1)

$$Y = \beta_0 + \beta_1 X_1 + \beta_n X_n \quad (3)$$

where **Y** is the yield and **X** is different weather variables (see Table 1).

3. Results

3.1. Banana yield, and climate in the Philippines (1991–2016)

From 1991 to 2016, provincial level banana yield in the Philippines averaged around 10.8 tons/ha, maximum of 64.4 tons/ha, and minimum of 0.57 tons/ha. Higher yield were found on provinces in the south central portion of the country compared to the others (Fig. 2). This can be attributed to the presence of big and commercial banana plantations in these areas. In terms of climate, the average annual rainfall (AR) from 1991 to 2016 in the Philippines is around 2559 mm/year, with minimum of 970 mm/year and a maximum of 5848 mm/year. Higher annual rainfalls were observed on the Northeastern portion compared to the rest of the country (Fig. 3a). Higher frequency of wet days (FWD) values were also observed in the Southeastern part of the country (Fig. 3b). On the average, FWD is around 176 days, with minimum of 97 days, and maximum of 284 days. On the other hand, in terms of precipitation seasonality (PS), the calculated CV

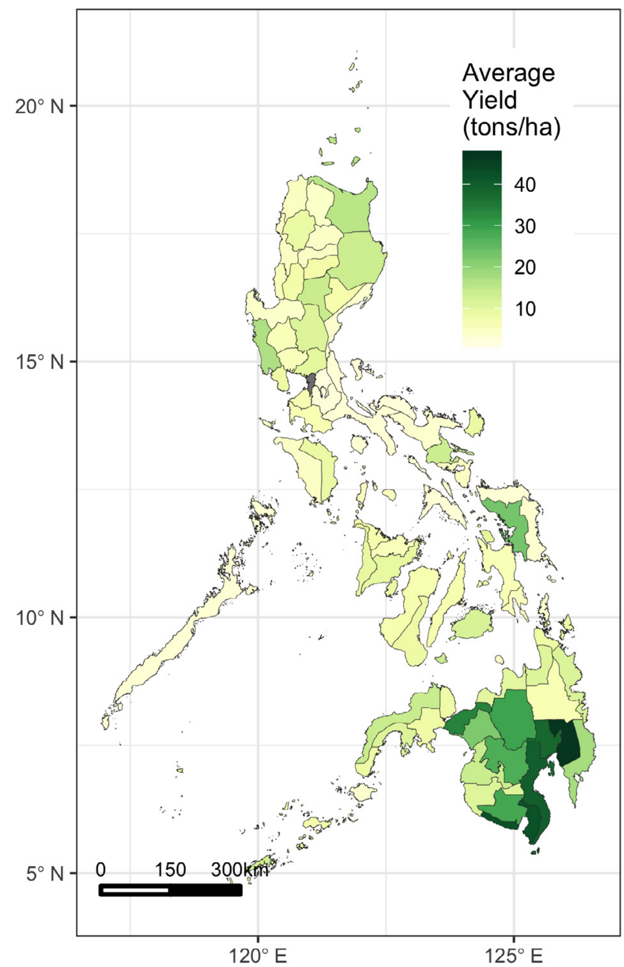

Fig. 2 – Average provincial level yield of banana in the Philippines from 1991 to 2016.

ranges from 23 to 200%, with the mean around 73%. A Northwest to East gradient of PS was also observed (Fig. 3c). In terms of temperature, the average AMT is around 26 °C, with the low of 20.9 °C, and high as 28.3 °C. As expected, lower values of annual mean temperature (AMT) were observed in areas with relatively higher elevation in the Northern region of the country (Fig. 3d). The average temperature seasonality

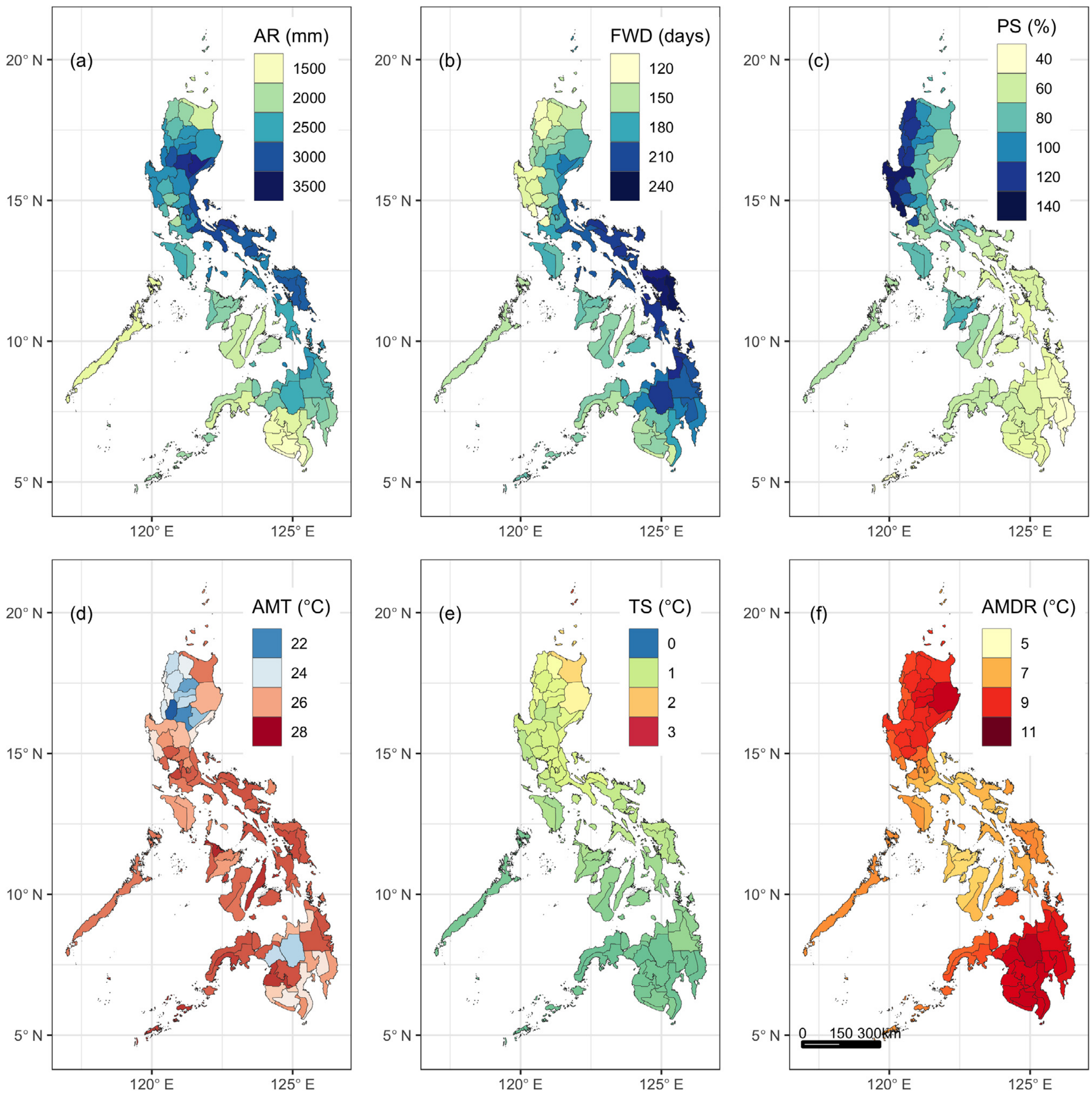

Fig. 3 – Average (a) annual rainfall-AR, (b) frequency of wet days-FWD, (c) precipitation seasonality-PS, (d) annual mean temperature-AMT, (e) temperature seasonality-TS, and (f) annual mean diurnal temperature range-AMDR in the Philippines from 1991 to 2016 based on Climate Research Unit Time Series data.

(TS) in the country is around 0.88 °C, maximum TS is 3.12 °C while the minimum is around 0.233 °C. There is a north to south gradient of high to low TS in the Philippines (Fig. 3e). Lastly, the average annual mean diurnal temperature range (AMDR) in the country from 1991 to 2016 was around 8.1 °C while the maximum is around 11 °C and minimum of 5 °C. Compared to the central part, higher AMDR were observed in northern and southern portion of the country (Fig. 3f).

3.2. *Trends in banana yield*

Based on the analysis, around 57 provinces (71%) in the Philippines showed significant yield trend from 1991 to 2016. On the average, banana yield in the Philippines changed by 0.075 tons/ha/year. The maximum change in yield trend was calculated for the province of Bukidnon (2.52 tons ha^{-1} $year^{-1}$) while the minimum was calculated for the province of

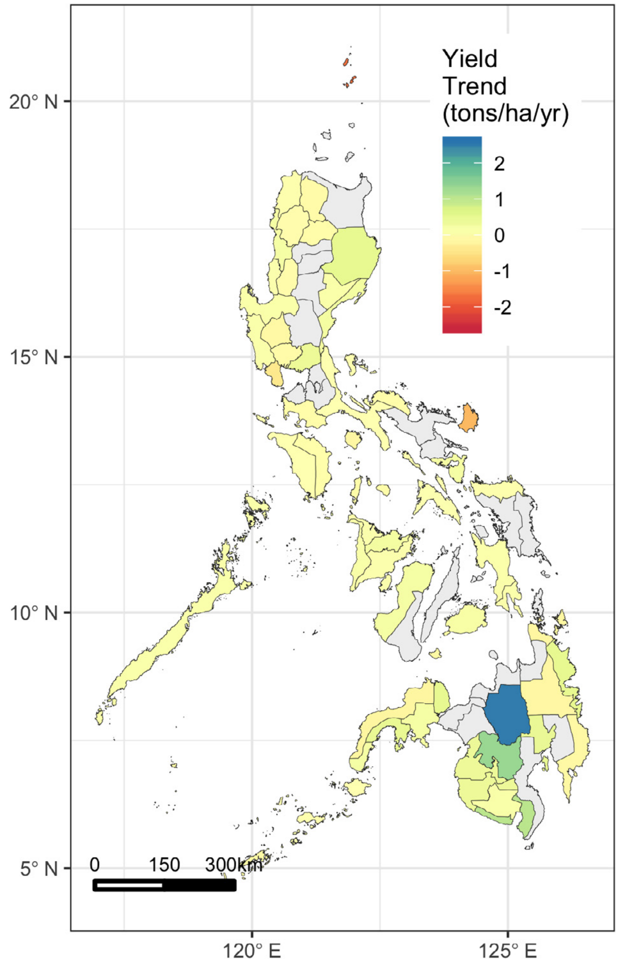

Fig. 4 – Provincial level yield trend of banana in the Philippines. Note provinces filled with grey color means the observed trend is not significant.

Catanduanes (−1.0 tons ha^{-1} year^{-1}). Aside from these two provinces, the observed yield trend in other parts of the country is within 1.0 tons ha^{-1} year^{-1} (Fig. 4). High yield in trend in the province of Bukidnon can be attributed to the presence of banana (Cavendish) plantation in the area.

3.3. *Provincial level effect of climate*

Only 8 out of 82 (9.76%) provinces showed significant multiple linear regression model of yield against annual climatic indices (Table 2). These provinces include: (1) Bohol; (2) Camarines Sur; (3) Capiz; (4) Cebu; (5) Isabela; (6) Northern Samar; (7) South Cotabato; and, (8) Zamboanga Sibugay. Among these provinces the highest calculated R^2 (0.73) was for the province of Zamboanga Sibugay while the lowest calculated R^2 (0.48) for the provinces of Camarines Sur and Capiz. Also, it can be noted that there is a West to East and North to South trend in the value of R^2 among these provinces (Fig. 5). Among the climate variables, temperature has the greater impact on banana yield compared to rainfall. Regression coefficients for TS, AMT, and AMDR were higher than 1 while regression coefficient of AR, FWD, and PS were all less than 1. However, the effect of climate varies by provinces.

Table 2 – Calculated R^2 and p-value for the 8 provinces in the Philippines where climate is a significant determinant of banana yield.

Province	R^2	p-value
Bohol	0.51	0.021
Camarines Sur	0.48	0.035
Capiz	0.48	0.035
Cebu	0.51	0.023
Isablea	0.49	0.029
Northern Samar	0.51	0.021
South Cotabato	0.62	0.002
Zamboanga Sibugay	0.73	0.029

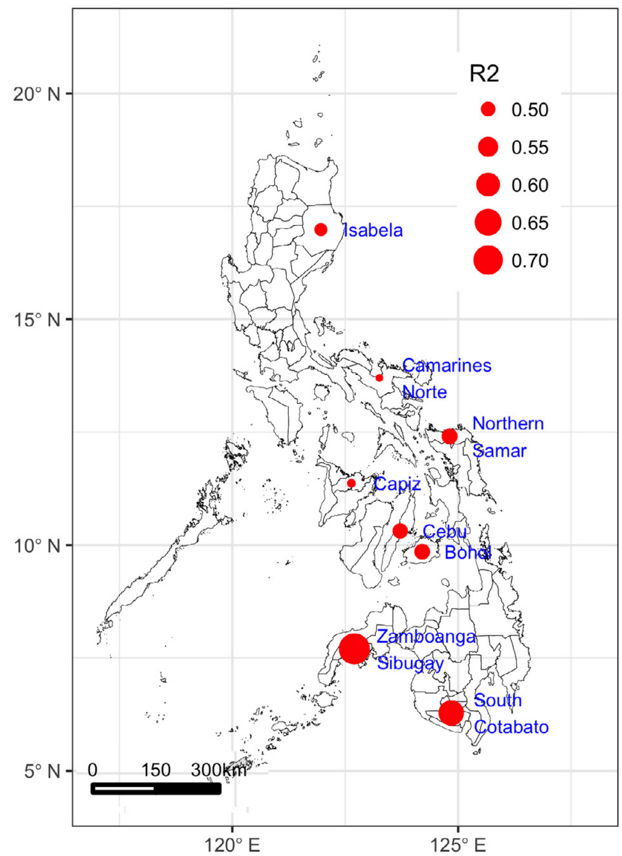

Fig. 5 – Location map of 8 provinces with significant multiple linear regression model of climatic variables showing calculated R^2.

For example, positive effect of TS was observed for 5 out of the 8 provinces that showed significant effect of climate on banana yield. Highest (27.96) TS coefficient was calculated for province of Bohol while the lowest (−8.53) was calculated for the province of Capiz. This means the higher monthly temperature variation within the year favors banana yield in the province of Bohol while the opposite occurs in the province of Capiz. Similar to TS, the effect of AMDR is also positive to 5 out of 8 provinces. Again, the province of Bohol showed the highest regression coefficient (8.12) while the province of Cebu showed the lowest (−7.29). This means that

Table 3 – Calculated regression coefficient of different annual climatic indices for the 8 provinces in the Philippines where climate is a significant determinant of banana yield.

Province	AR	FWD	PS	AMT	TS	AMDR
Bohol	−0.001	0.020	−0.042	2.349	27.964	8.121
Camarines Sur	0.000	0.000	0.016	−0.371	−0.558	0.405
Capiz	0.003	−0.065	−0.038	−3.541	−8.527	−2.836
Cebu	−0.001	0.041	0.042	1.641	5.464	−7.292
Isabela	0.002	−0.067	0.022	−0.564	−0.080	−0.949
Northern Samar	0.000	0.012	0.003	−0.401	0.844	0.219
South Cotabato	−0.001	−0.018	−0.037	1.794	9.170	4.764
Zamboanga Sibugay	−0.004	0.122	0.022	−5.964	3.264	5.278

Note: AR – annual rainfall; FWD – frequency of wet days; PS – precipitation seasonality; AMT – annual mean temperature; TS – temperature seasonality; and, AMDR – annual mean diurnal temperature range.

higher difference between the monthly maximum and minimum temperature is beneficial to the banana crop planted in province of Bohol compared to Cebu. Meanwhile, higher AMT negatively affects yield of 5 out of 8 provinces. The highest negative impact (−5.96) was calculated for the province of Zamboanga Sibugay while the highest positive effect was calculated for the province of Bohol (2.35). Table 3 shows the calculated regression coefficient for each climatic variable for the 8 provinces.

4. Discussion

Banana growth and development is highly influenced by temperature [26,27]. Extreme, higher, and lower temperatures have negative impact on banana growth and development [26]. According to Robinson and Saúco (2010) optimum temperature for balance growth and development of banana is around 27 °C. Dry matter assimilation (growth) in banana stops at 14 °C while beyond 31 °C the crop is subject to heat stress and possible cessation of development [27]. Bunch development also stops above 38 °C or below 9 °C [26]. In the case of this study, although negative regression coefficient of annual mean temperature (AMT) were observed for the provinces with higher temperature range than the optimum condition for banana, the opposite (positive regression coefficient) were also observed in some provinces (Table 3). Studies on the impact of temperature seasonality (TS) and annual mean diurnal temperature range (AMDR) in banana are limited. In other crops, Lobell [28] reported contrasting effect of AMDR on national-level cereal yield of different countries. For example, strong negative effect of AMDR was observed for wheat yield in Australia and Canada while the opposite was observed in France [28]. Similar observation on negative effect AMDR to rice yield on most countries included in the study except for China, India, and Bangladesh [28]. For corn, negative impact of AMDR was observed for the US [28]. According to Lobell [1] the positive impact of diurnal temperature range (DTR) on crops can be associated with higher solar radiation while the negative impact can be associated with greater evapotranspiration losses, which can lead to water stress. Also, according to Najafi et al [29] DTR is an indicator of the available energy for crop growth.

According to Robinson and Saúco [27], next to temperature, rainfall determines the suitability of banana in an area. This can explain the result of this study why coefficient of rainfall variables is less than those of temperature. On the other hand, banana requires constant and ample supply of water to provide the optimum condition for its shallow root system and permanent green vegetation [27,30,31]. Low soil moisture and water stress for a long period of time can reduce banana production [32,30]. Van Asten el al. [32] reported that in Uganda, areas with rainfall less than 1100 mm yr^{-1}, yield losses in banana can ranged from 20 to 65%. Also, for every 100 mm decline in rainfall results to 8–10% bunch weight [32]. In the case of this study, although the average rainfall during the study period is more than 1100 mm yr^{-1} (Fig. 3a), the inter annual rainfall variability and seasonality can explain the variation in the coefficient of rainfall on banana yield [30]. According to Robinson and Saúco [27], banana needs at least 25 mm of water per week and a rainfall that is evenly distributed throughout the year. Lastly, the effect of soil type, which was not explored in this study, might also explain the spatial variation of response of banana to rainfall and temperature observed in this study.

Similar to other empirical studies, the results from this study should be treated with caution. Empirical studies are subject to certain assumptions [1]. In the case of this study, relationships between climate variable and yield data were assumed to be linear in nature. Inherent uncertainty on the climate variables and methodology process climate data (zonal statistics) to match provincial level yield data in this study should also be noted. In the case of this study, zonal statistics were calculated for the entire province. Further refinement can use maps of cropland areas or specifically banana growing regions in each province.

In addition, this study did not consider other factors such as soil, management regimes, occurrence of pest and disease, and typhoons, which can greatly affect yield level of banana in different provinces in Philippines. According to Leng and Huang [33] models developed from averages of climate variables does consider extreme weathers and climate anomalies that may affect stage specific crop growth and development. However, empirical models developed from historical crop yields and climate are extensively used in several studies and accepted as an efficient tool [33,34]. Lastly, including all possible variables that may affect crop production will result to over-parameterized, overly-fitted, and poor performing model [33,34].

5. Conclusion

This study assessed the effect of climate on the provincial-level banana yield data in the Philippines using historical crop yield data and CRU-TS monthly data. Spatially varying yield trend as well as significant effect of climate was observed.

Out of 82, only in 8 provinces in the country where significant effect of climate on banana yield was observed. Among climate variables tested in this study, temperature variables showed higher influence to banana yield in the Philippines compared to rainfall. Among temperature variables, temperature seasonality (TS) showed the highest effect on banana yield followed by annual mean diurnal temperature range (AMDR), and lastly, annual mean temperature (AMT). Results from this study can served as a baseline for different research and policies in the country that is geared toward climate smart production especially in the case of banana. However, further studies are also recommended such as yield gap analysis to determine the influence of other factors (i.e. soils, management, diseases, and occurrence of typhoons) that can also affect the current banana yield potential in the Philippines.

Declaration of Competing Interest

The author declares no conflict of interest.

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