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Climatic Factors Affecting Maize Grain Yield in Different Growing Areas of the Philippines

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Seasonal climate variation is one of the problems faced by Filipino maize farmers, due to varying climatic elements such as solar radiation, rainfall, relative humidity, and air temperature. This study determined the seasonal productivity of selected maize varieties in the major growing areas in the Philippines, and identified the yield-limiting climatic factors specific to location and growing season. Grain yield, covering two wet and dry seasons (2016-2018) from seven field trials (representing 3 climatic types) of the National Corn Testing (NCT) were used in the study. Climatic data (2016-2018) were gathered from the PAGASA weather station nearest to the trial site. Significant variation in the monthly solar radiation, rainfall, relative humidity, and the mean temperature (309.1-786.6 MJ m^{-2}, 19.9-667.5 mm, 64.3-91.4%, 18.8-35.8°C, respectively) were observed across seven locations. Relative humidity significantly varied by season. Mean temperatures below 30°C and mean relative humidity of more than 80% were observed across locations. Grain yield variations due to season (3394.8-9985.1 kg ha^{-1}), location (1382.4-11931.4 kg ha^{-1}), and climate type (3052.1-8650.9 kg ha^{-1}) were highly significant. Grain yield was significantly affected by cumulative solar radiation specific to variety and season. Solar radiation use efficiency (SRUE) during wet season was highly variable, and consistently higher SRUE was observed during dry season. Grain yield of the three varieties were correlated with growing degree days (GDD) during wet and dry seasons (r = 0.28, 0.29, and 0.33). The grain yield of 30B80 was more affected by cumulative solar radiation (r = 0.46), while USM Var10 (r = 0.33) was more associated with GDD. Solar radiation and minimum temperature positively affect the grain yield of variety 30B80, while maximum temperature and relative humidity had negative effect. Solar radiation was the major yield-limiting factor for variety 30B80, whereas maximum temperature and solar radiation increased the grain yield of IPB Var11. The major yield-limiting factor for IPB Var11 was relative humidity. Grain yield of USM Var10 increased with solar radiation, while relative humidity and maximum temperature had negative effect. Location was the maize yield-limiting factor, whereas relative humidity affected the grain yield of USM Var10 dominantly. Significant seasonal climate variation can be observed in the major maize growing areas resulting in different seasonal productivity, while solar radiation and relative humidity are the major yield-limiting climatic factors. Moreover, the hybrid variety, 30B80, can be recommended for dry season in Batac, Tupi, and Baybay; wet season in Ubay; and both wet and dry season in Maramag, Kabacan, and Ilagan as a high-yielding maize variety.

Keywords: climate variation, climate type, national corn testing, solar radiation use efficiency, growing degree days

Abbreviations: DM – dry matter, RGR – relative growth rate, NCT – National Corn Testing, OPV – open polinated variety, SR – solar radiation, RH – relative humidity, T_{min} – minimum temperature, T_{max} – maximum temperature, T_{mean} – mean temperature, RF – rainfall, PAGASA - Philippine Atmospheric, Geographical and Astronomical Services Administration, CSR – cumulative solar radiation, GDD – growing degree days, IRRI – International Rice Research Institute

INTRODUCTION

Maize (*Zea mays* L.) is one of world's leading cereal crops next to rice and wheat in terms of production and productivity (Fosu et al. 2004; JICA 2016). Maize has been cultivated for thousands of years in many parts of the world as a most important food crop (Maccann 2005). It is a multipurpose crop, serve as food for human, feed for animals and poultry, and fodder for livestock. It is also a rich source of raw material for the industry where it is being extensively used in the preparation of cornstarch, corn-dextrose, cornflakes, etc. (Khaliq et al. 2004). In 2019, the harvest area in the Philippines is about 612,000 ha and the average yield is 2.95 t ha^{-1} (PSA 2019). Moe (2016) reported that low yield of maize in the country is attributed to poor crop management, under utilization of novel technologies, but not due to adherence of fertilizer recommendations. Maize is largely grown under rainfed lowlands, upland plains, and rolling to hilly agro-ecologies in the Philippines. Generally, maize production in the upland areas peaks from July to September, while lean months are from January to June (USDA 2016; PSA 2020). Upland regions of Mindanao have the largest area (102,601 ha) planted to maize and the highest production (320,776 tons) in the Philippines (Gerpacio et al. 2004; USDA 2016; PSA 2020).

Maize is a C4 plant, which efficiently use carbon dioxide (CO_2), solar radiation, water, and nitrogen (N) in photosynthesis than C3 crops, resulting in higher production of dry matter (DM) (Huang et al. 2006). Maize is grown over a wide range environment from sea level to as high as 3000 masl elevations, with 250-5000 mm of rainfall per year (Sheikh et al. 2017). Maize is a hardy crop compared to rice and wheat having 3-4 months' growing period (Sheikh et al. 2017). Increasing temperature at flowering is a major threat during reproductive stage (Gayatonde and Vennela 2016). Temperature above 36° greatly reduces pollen viability, and temperature above 35° can reduce ovary fertilization in maize (Siebers et al. 2017; Dupuis and Dumas 1990). Maize pollen germination adversely affect germination at 38° (Herrero and Johnson 1980). Chatterjee (1998) observed that an increase in temperature beyond optimum 35°C consistently decreases maize yield, i. e. an increase in temperature by 1-2°C, decreases potential yields by 7-12%. An increase in 50 ppm CO_2 may increase yield by only 0.5 %. However, the beneficial effect of 700 ppm CO_2 is nullified by 0.9°C increase in temperature. Low temperatures (< 21°C) during the vegetative growth reduces relative growth rate (RGR) of maize (Soldati et al. 1999).

Philippine maize farmers are beset with seasonal climate variations that may have caused high variations in their planting dates. Khin (2016) and Moe (2016) reported that grain yields of maize varieties had higher variations under monthly plantings from February to May in Los Baños conditions. Also, Kumara (2021) unpublished data suggested that varying monthly planting dates during off-season (February - September) highly influence on maize yield under Los Baños condition. The sowing date influences maize yield due to varying environmental conditions (solar radiation, rainfall, relative humidity, and soil and air temperatures) that affect canopy functions and crop development during crop growing period (Muchow and Davis 1998; Singh 1999; Khin 2016; Moe 2016; Kumara 2021). There are four types of climates in the Philippines according to the Modified Coronas Classification, based on average monthly rainfall (PAGASA 2015). Potential grain yield of maize varies across regions due to differences in solar radiation, temperature, and rainfall on temporal basis (cropsreview.com).

Considering the seasonal differences in climatic elements across major maize growing areas in the Philippines, there is a need to evaluate yield variability of maize varieties recommended by the National Seed Industry Council (NSIC). Hence, this study determined the seasonal productivity of selected maize varieties in different maize growing areas in the Philippines, and identify the yield-limiting climatic factors specific to growing season per location classified by climatic types.

MATERIALS AND METHODS

Two dry and two wet-season (2016–2018) yield data from the National Cooperative Testing (NCT) field trials were used in this study. Maize yield data was obtained from seven growing locations, namely: Batac (18° 03′ 28″ N, 120° 33 21 E); Maramag (7° 51′ 33″ N, 125° 03′ 07″ E); Ilagan (17° 07′ 32″ N, 121° 53′ 17″ E); Tupi (6° 21′ 53″ N, 124° 55′ 22″ E); Ubay (9° 58′ 32″ N, 124° 24′ 24″ E); Kabacan, (7° 06′ 55″ N, 124° 50′ 12″ E); and Baybay (10° 44′ 45″ N, 124° 47′ 40″ E). Based on the yield and climatic data from the 3-year dataset, variations in seasonal maize grain yield across seven locations and four growing seasons were determined.

Three recommended maize varieties by the NSIC were laid out in a randomized completely block design with four replications. The maize varieties used are one hybrid (30B80) and two open pollinated varieties (OPV) (USM Var10 and IPB Var11) to analyze grain yield variability and to identify the major yield-limiting climatic factors across growing seasons and locations.

Across locations, NCT field trials followed uniform cultural practices. Experimental areas were plowed twice at a 30 cm depth, followed by two harrowing, and final leveling before planting. Planting density of 66,667 plants ha^{-1} were maintained through 20 x 75 cm spacing. Seeds were planted on ridges at 3-5 cm depth. Recommended fertilizer applications in trial sites were based on soil analysis. Pest and disease management were done according to standard recommendations or as needed.

Climatic data, such as: daily solar radiation (SR); daily relative humidity (RH); daily minimum (T_{min}), maximum (T_{max}) and mean temperatures (T_{mean}), and daily rainfall (RF) were gathered from nearest weather station of the Philippine Atmospheric, Geographical and Astronomical Services Administration (PAGASA) (Ilocos Norte, Bukidnon, Isabela, Cotabato, Danis Bohol, Maguindanao, and Leyte). Cumulative solar radiation (CSR) and growing degree days (GDD) were computed based on planting and harvest dates. Planting and harvest dates were also used to estimate the duration of each variety's exposure to prevailing climate during the growing cycle. GDD were calculated each day as maximum temperature plus minimum temperature divided by two then minus base temperature (10°C) (McMaster and Wilhelm 1997).

Grain yields in NCT trials were obtained from two inner row plots. Grain yields were adjusted to a hectare-basis (kg ha^{-1}) at 15% grain moisture content (MC) using the formula:

$$GY = HGY\ (gm^{-2}) \times \frac{1}{1000} \times \frac{10000}{1\ ha} \times \left[\frac{100 - MC}{85}\right]$$

where GY is grain yield (kg ha^{-1} at 15% MC); HGY is harvest grain yield (g m^{-2}); and MC is grain moisture content (%).

Solar radiation use efficiency (SRUE) of each variety and growing season was calculated based on grain yield and cumulative solar radiation during the growing season using the formula,

$$SRUE = GY/CSR$$

where SRUE is solar radiation use efficiency (kg MJ^{-1} ha^{-1} per growing season); GY is grain yield (kg ha^{-1} per growing season); CSR is cumulative solar radiation (MJ per growing season) for total growing season).

All yield data were checked for normal distribution and homogeneity of variance over seasons and locations using STAR version 2.0.1 Statistical Software of the International Rice Research Institute (IRRI). Treatments (varieties, locations, seasons) means were compared using Turkeys Honest -Significant Difference (HSD) Test. Stepwise regression analysis was to determine the degree of covariation of independent variables affecting the grain yield of maize varieties.

RESULTS AND DISCUSSION

Varying Climatic Elements in Different Climatic Types and Cropping Season

Batac, Ilocos Norte is one of the study sites classified under Type I climate. Type I climate has two seasons: dry from November to April; and wet during the rest of the year. High rainfall occurs during the months of June to September (Figure 1a). Batac had relatively higher cumulative solar radiation (CSR) during dry season than wet season (Figure 1b). T_{max}, T_{min}, and T_{mean} were higher from April to July. On other hand, T_{mean} was higher during wet season than dry season in Batac (Figure 1c). Relative humidity was higher during wet season than dry season, while initial stage had higher RH than end of dry season (Figure 1d).

Maramag, Bukidnon, and Kabacan, North Cotabato belong to Climate Type III. These sites had no pronounced maximum rainy months with a dry season lasting for 1-3 months, either from December to February or from March to May. This sites almost resembles Type I climate although it has short dry season. Wet and dry seasons had RF below 400 mm over the year, except in Maramag during dry season 2017 with 450.7 mm (Figure 2a).

SR was relatively higher during wet season than dry season in Maramag and Kabacan sites (Figure 2b). Monthly temperature had similar patterns relatively over a year in both sites. T_{Mean}, T_{max}, and T_{min} were below 30°C throughout the year. Highest T_{max} and lowest T_{min} were 31.3 and 20.4°C, respectively in Kabacan, while 29.1 and

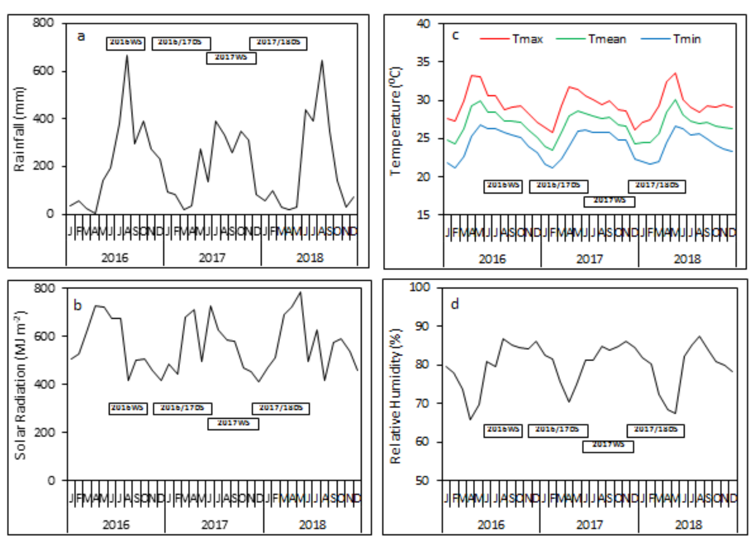

Fig. 1. Monthly rainfall, solar radiation, temperature, and relative humidity from 2016-2018 in Batac, Ilocos Norte with Climate Type I for wet and dry season.

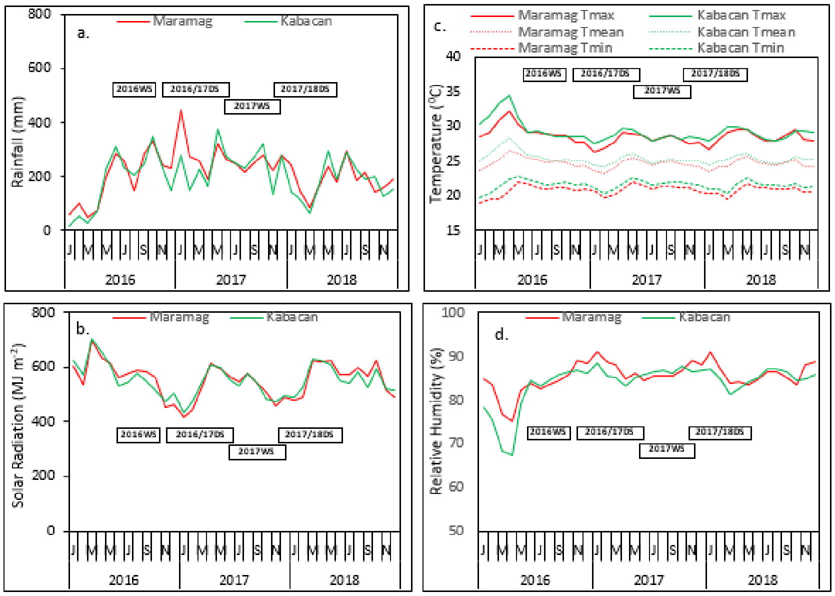

Fig. 2. Rainfall, solar radiation, temperature, and relative humidity from 2016-2018 in Maramag, Bukidnon, and Kabacan, North Cotabato with Climate Type III for wet and dry season.

19.5°C in Maramag (Figure 2c). Relative humidity during dry season (91.1%) was higher than during wet season (87.9%) as shown in (Figure 2d).

High temperature stress severely affects flowering of maize and reduce the grain yield by limiting seed setting rate (Prasad et al. 2017; Alam et al. 2017; Lizaso et al. 2018; Wang et al. 2019). Schoper (1987) and Sánchez (2014) reported that optimum temperature for anthesis is 30.5°, while Carberry (1989) and Sánchez (2014) observed that maize pollen germination stops beyond 38°.

Despite the change in pollen morphology, pollen viability is not affected at 36° (Wang 2019). Several studies reported that upper threshold temperatures for maize during flowering were identified at 30°C by McMaster and Wilhelm (1997), 32°C by Nielsen and Hinkle (1996), and 34°C by Birch et al. (1998). Temperature ranges in sites with Climate Type III were 20 - 30°C, favorable for maize growth and yield formation. Ilagan, Isabela, Tupi, South Cotabato, Ubay, Bohol, and Baybay, Leyte sites belong to Climate Type IV. Generally, under this climate type, RF is evenly distributed throughout the year. Type IV resembles Type II more closely since it has no dry season. Baybay had higher RF (203.8 - 617.5 mm) during November to February (DS), while Ilagan had higher RF (267.6 - 403.1 mm) during June to September (WS). Other sites had evenly-distributed RF during the year (Figure 3a).

Highest SR was received during March to August in 2016, 2017, and 2018 in these sites, while the rest of the year had less SR (497.3 - 727.8 MJ m^{-2}). On the other hand, dry season had less SR than wet season, which had higher SR initially. Ilagan had highest SR (727.8 MJ m^{-2}) during dry season, while lowest SR at 309.09 MJ m^{-2} in Baybay and Ubay during dry season (Figure 3b).

Ilagan had the highest T_{max} (35.8°C) and lowest T_{min} (18.8°C) during dry season. Consequently, the highest temperature fluctuation of 18.8 - 35.8°C within a year was reported in this site. Highest T_{max} and lowest T_{min} (29.2°C and 21.8°C) during dry season were observed in Tupi, although with relatively lower temperature fluctuations (21.8 - 29.2°C). Highest T_{max} and lowest T_{min} (30.9°C and 24.6°C) during dry season was noted in Ubay. Temperature fluctuations of 24.4 - 30.2°C over year prevailed in this site. 30.2°C and 24.4°C were relatively the highest T_{max} and lowest T_{min}, respectively, within the year in Ubay. Baybay had temperature fluctuations of 24.4 - 30.2°C. Across the sites, highest difference in temperature (17°C) within a year was observed in Ilagan, and lowest (5.8°C) in Tupi (Figure 4a).

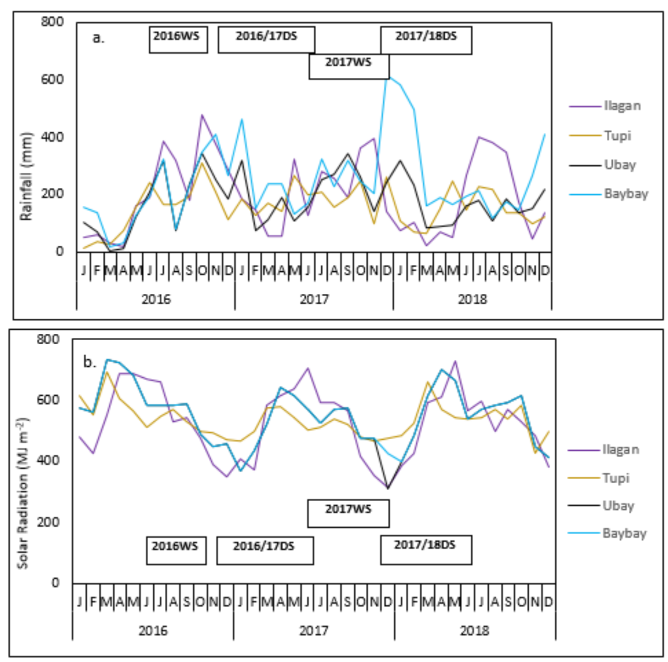

Fig. 3. Rainfall and solar radiation from 2016-2018 in Ilagan, Tupi, Ubay, and Baybay with Climate Type IV for wet and dry season.

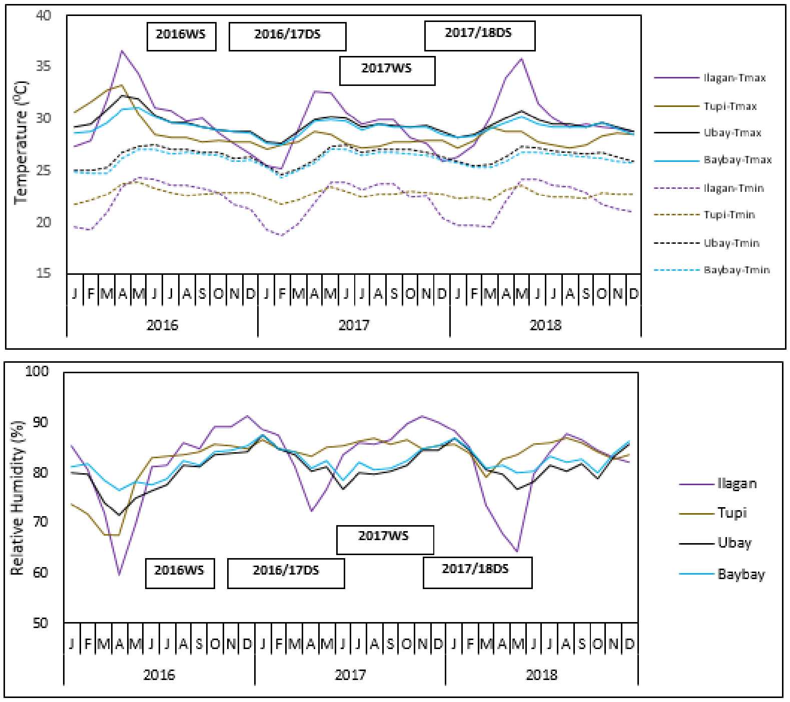

Fig. 4. Temperature and relative humidity from 2016-2018 in Ilagan, Tupi, Ubay and Baybay with Climate Type IV for wet and dry season.

Increase in daily T_{min} and T_{max} are reflected on the increase in daily T_{mean}, and such extreme events could be detrimental on grain yield formation (Meehl et al. 2007). Ilagan, Tupi, Ubay, and Baybay had similar trend of RH during wet and dry seasons within a year. All sites had low RH from March to May. Although, dry season had low RH than wet season in general, highest RH (91.36%) was recorded during dry season 2016, while lowest (59.66%) during dry season 2018 in Ilagan. All four sites had more than 75% mean RH during wet and dry seasons, except Ilagan during dry season (Figure 4b). Very high or low RH would reduce maize grain yield. On the other hand, RH is negatively correlated with grain yield (TNAU 2016). Omoyo (2015) reported that moderately high RH (60 - 70%) is beneficial for corn growth and grain yield production.

Grain Yields Under Varying Climatic Types and Cropping Seasons

Grain yield variations (6308.19 – 8481.67 kg ha^{-1}) were high during dry season, while dry season (7716.6 kg ha^{-1}) had higher grain yield than wet season (4151.08 kg ha^{-1}) in Batac (Climate Type I) (Figure 5). For Maramag and Kabacan sites (Climate Type III), high grain yield variation (4543.1 – 9148.4 kg ha^{-1}) were observed during wet season. Maize grain yield in Maramag was higher (7190.69 kg ha^{-1}) during wet season, while this was observed during dry season (7037.71 kg ha^{-1}) in Kabacan (Figure 5).

Grain yield variations during wet season were high in Ilagan (3990.1 - 7416.3 kg ha^{-1}) and Ubay (6597 - 10641.6 kg ha^{-1}) while during dry season in Tupi (2444.3 - 7522.5 kg ha^{-1}) and Baybay (7542 - 9698.3 kg ha^{-1}). Ilagan and Baybay had more stable grain yields during wet and dry seasons, respectively (Figure 5). Generally, Climate Type I had high mean grain yield during dry season, while not significant in Climate Type III and IV during wet and dry seasons.

Grain Yields Under Varying Climatic Type and Growing Location

The grain yield of three maize varieties across seven locations with Climate Type I, III, and IV are shown in Figure 6. Baybay with Climate Type IV had highest mean grain yield (8350.5 kg ha^{-1}), while higher grain yield variation ranged 4180.6 – 8650.9 kg ha^{-1} in Ubay. Tupi with Climate Type IV had lowest average grain yield (5359.2 kg ha^{-1}), while grain yield variation ranged 3052.1 – 7340.7 kg ha^{-1}. Maramag and Kabacan, with Climate Type III, had similar range of grain yield variation (5256.4 - 8087.4 and 5202.7 - 8021.3 kg ha^{-1}), with not significantly different mean grain yields of 6546.7 and 6607.1 kg ha^{-1}, respectively. Batac with Climate Type I had mean grain yield of 5933.8 kg ha^{-1} with high grain yield variation. Based on mean grain yield variations as classified by climate types and locations, yields were more variable in locations with Climate Types I and IV (Figure 6).

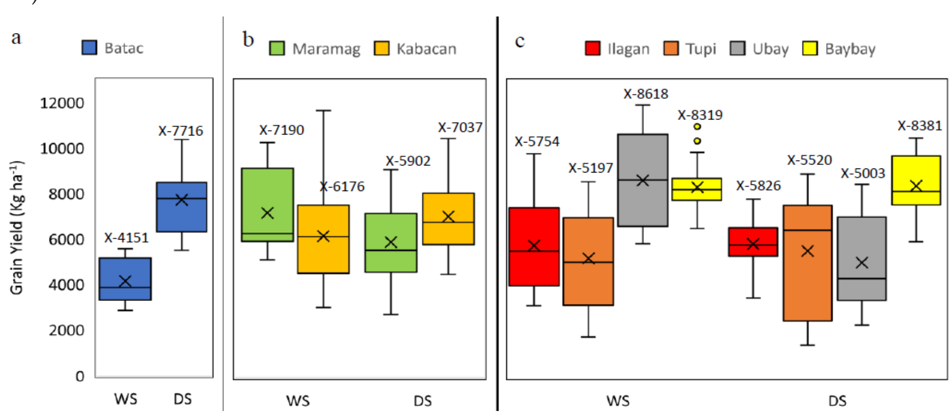

Fig. 5. Grain yield variation by climate type and season (a - Climate Type I; b - Climate Type III; c -Climate Type IV; WS - wet season; DS - dry season; X - mean grain yield).

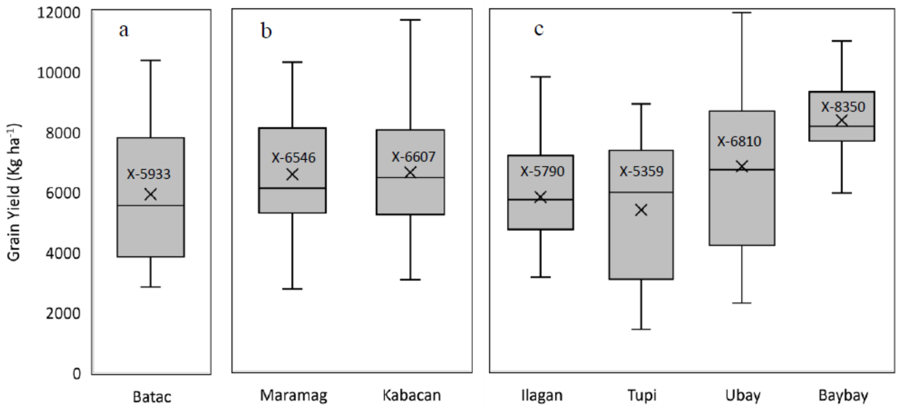

Fig. 6. Grain yield variation by climate type and location (a - Climate Type I, b - Climate Type III, c - Climate Type IV), X - mean grain yield.

Although Type IV climate had evenly-distributed rainfall throughout the year, Ubay with Climate Type IV had lower solar radiation during dry season than wet season. This could be the reason for low average grain yield of Ubay during dry season for the three varieties. IPB Var11 and USM Var10 had lower grain yield (3721.3 and 3394.8 kg ha^{-1}) during wet season in Batac than 30B80 (5337.1 kg ha^{-1}). The hybrid variety, 30B80, had the highest grain yield during dry season in Batac, Tupi, and Baybay, while during wet season in Maramag, Ilagan, Ubay, and Kabacan. Lower grain yield during wet season could be attributed to low solar radiation during the cropping season (Figures 3, 4 and 7).

Grain yield of the three maize varieties were not significantly different during wet and dry seasons in sites, except Batac and Ubay where higher grain yields are observed during dry and wet seasons (Table 2).

Higher grain yields of 30B80 were observed in Batac, Tupi, and Baybay sites during dry season (9294, 8036, and 9985 kg ha^{-1} respectively), while during wet season in Maramag, Ilagan, Ubay, and Kabacan (9488, 6658, 10581, and 8284 kg ha^{-1} respectively). IPB Var11 had highest grain yield during dry season in Batac, Maramag, and Ilagan (7195, 6537, and 5918 kg ha^{-1} respectively), while during wet season in Tupi, Ubay, Kabacan, and Baybay (4369, 8098, 5204, and 8001 kg ha^{-1} respectively). USM Var10 had highest grain yield during dry season in Batac, Ilagan, Tupi and Baybay (6660, 5109, 4383, and 7886 kg ha^{-1}), while in Maramag Ubay, and Kabacan during wet season (5903, 7175 and 5041 kg ha^{-1}).

Grain Yield Variation

Analysis of variance for grain yield for the three varieties grown in seven location sites during wet and dry seasons are shown in Table 1. ANOVA results revealed that the location, variety, location x season and location x variety were found to have significant difference on grain yield at 5% level of significance, while seasons, season x variety and location x season x variety had no significant difference.

Grain yield of 30B80, IPB Var11 and USM Var10 varieties during wet and dry seasons of 2016-2018 in seven locations are shown in Figure 7. Variety 30B80 had the highest grain yield in most of the location sites during wet and dry seasons, except during dry season in Ubay. Highest grain yield 10580.6 kg ha^{-1} was observed during wet season, while lowest (4883.7 kg ha^{-1}) during dry season in Ubay. IPB Var11 had higher grain yield than USM Var10 in all location sites for both wet and dry seasons. Moreover, IPB Var11 had the highest grain yield during dry season in Ubay.

Table 1. Analysis of variance for grain yields of three maize varieties during wet and dry seasons in seven maize growing locations.

Source of Variance	DF	Sum of Squares	Means of Squares	F value	PR (>F)
Location (L)	6	299245538.8	49874256.47	36.83	0.0000*
Replication	49	66351636.67	1354115.034	0.76	0.8731ns
Season (S)	1	653.7045	653.7045	0.00	0.9847ns
Variety (V)	2	421348360.3	210674180.1	118.50	0.0000*
S x V	2	2674577.691	1337288.845	0.75	0.4724ns
L x S	6	311910056.7	51985009.46	29.24	0.0000*
L x V	12	63107797.11	5258983.092	2.96	0.0007*
L x S x V	12	33509375.22	2792447.935	1.57	0.1007ns

*- Significant at 5% level of significance by HSD, ns- not significant.

Average grain yield of maize varieties during wet and dry seasons across seven locations are shown in Table 2. Higher grain yields of 30B80, IPB Var11 and USM Var10 varieties obtained during dry season in Batac with Climate Type I and during wet season in Ubay with Climate Type IV. Grain yields of the three maize varieties did not differ during wet and dry seasons in Maramag and Kabacan having Climate Type III, and Ilagan, Tupi, and Baybay with Climate Type IV, while highest grain yield during wet seasons in Ubay of the three maize varieties (Table 2).

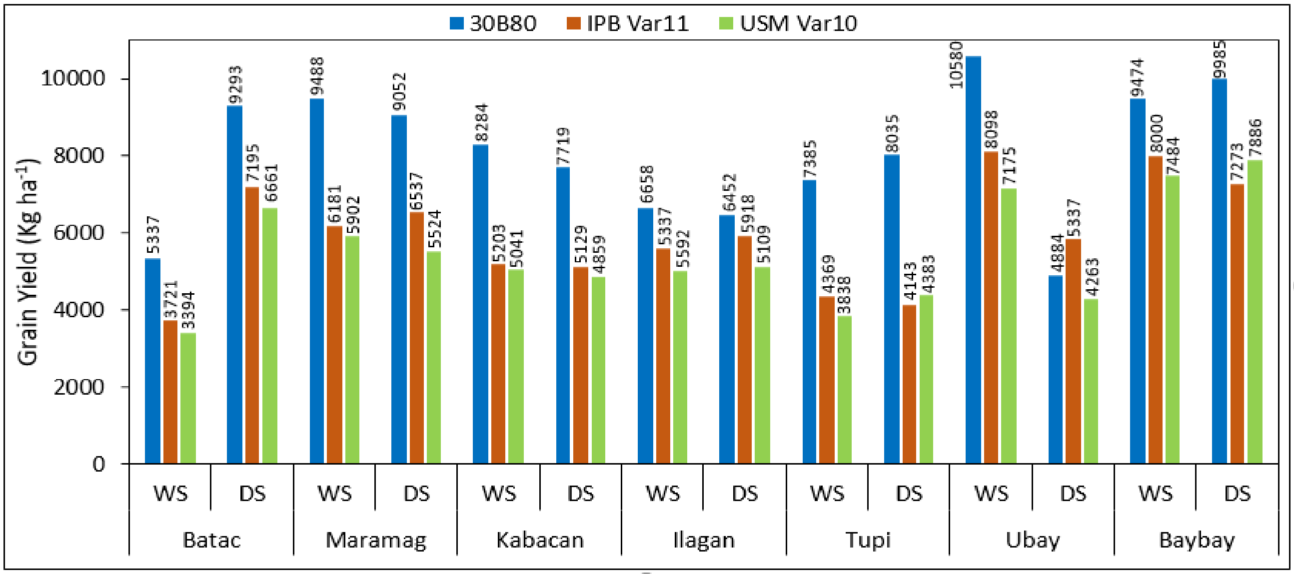

Fig. 7. Average grain yield (kg ha^{-1}), during wet and dry seasons across locations.

Grain Yield as Affected by Solar Radiation during Wet and Dry Seasons

Grain yields of 30B80, IPB Var11, and USM Var10 varieties as affected by cumulative solar radiation during wet and dry seasons are shown in Figure 8.

The amount of solar radiation during maize growing period significantly differed across locations. Relatively, dry seasons had higher solar radiation than wet seasons. During dry season, grain yield of 30B80 was positively (moderate) correlated (R^2 = 0.5395) with cumulative solar radiation while weak positive relationship (R^2 = 0.3043) in USM Var10. The grain yield of the three varieties had weak relationship with cumulative solar radiation during wet season. The hybrid variety, 30B80, was more responsive to solar radiation during dry and wet seasons, while other varieties were responsive (positive) during dry season. Considering the significant interaction between variety and season, 30B80 appeared to have the maximum response to solar radiation during dry season.

Solar Radiation Use Efficiency

The solar radiation use efficiency (SRUE) of 30B80, IPB Var11, and USM Var10 during wet and dry seasons in seven locations are shown in Figure 9.

The variety, 30B80, had the highest mean SRUE during wet season (4.22) and dry season (4.21). On the

Table 2. Grain yield of maize varieties during wet and dry seasons in seven locations.

Location	Grain Yield (kg ha^{-1})								
	30B80			IPB Var11			USM Var10		
	WS	DS	Mean	WS	DS	Mean	WS	DS	Mean
Batac	5337^{b}	9294^{a}	7315^{cd}	3721^{b}	7195^{a}	5458^{cd}	3395^{b}	6660^{a}	5027^{bc}
Maramag	9488^{a}	9052^{a}	9269^{ab}	6181^{a}	6537^{a}	6359^{cd}	5903^{a}	5524^{a}	5713^{b}
Ilagan	6658^{a}	6453^{a}	6555^{d}	5592^{a}	5918^{a}	5755^{bc}	5013^{a}	5109^{a}	5061^{bc}
Tupi	7335^{a}	8036^{a}	7685^{cd}	4369^{a}	4143^{a}	4256^{d}	3839^{a}	4383^{a}	4111^{c}
Ubay	10581^{a}	4884^{b}	7732^{cd}	8098^{a}	5863^{b}	6980^{ab}	7175^{a}	4263^{b}	5719^{b}
Kabacan	8284^{a}	7719^{a}	8001^{bc}	5204^{a}	5129^{a}	5166^{cd}	5041^{a}	4860^{a}	4950^{bc}
Baybay	9474^{a}	9985^{a}	9729^{a}	8001^{a}	7273^{a}	7637^{a}	7484^{a}	7886^{a}	7685^{a}
Mean	8165	7917	8041	5881	6008	5945	5407	5060	5234
Location (L)	*	*		*	*		*	*	
Season (S)	ns	ns		ns	ns		ns	ns	
Variety (V)	*	*		*	*		*	*	
S x V	ns	ns		ns	ns		ns	ns	
L x S	*	*		*	*		*	*	
V x L	*	*		*	*		*	*	
L x S x V	ns	ns		ns	ns		ns	ns	

Mean followed by the same letters (by row for seasons and by column for mean yields) are not significantly different at 5% level of significance by HSD. *- Significant at 5% level, ns- not significant.

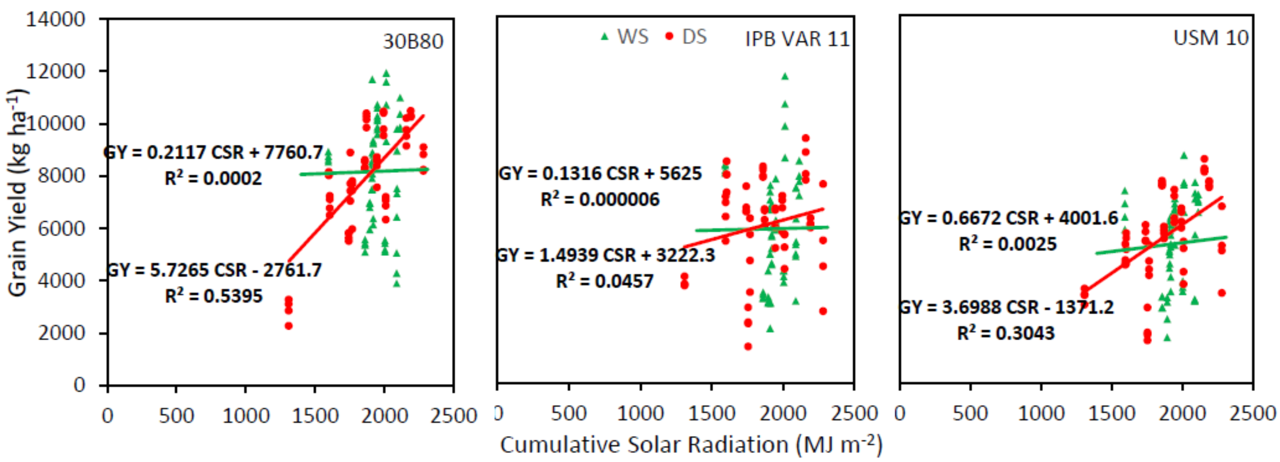

Fig. 8. Grain yield of 30B80, IPB Var11 and USM Var10 maize varieties as affected by cumulative solar radiation during wet and dry season (GY = grain yield, CSR = cumulative solar radiation, WS = wet season, DS = dry season).

other hand, USM Var10 had the lowest mean SRUE with 2.8 and 2.95 during wet and dry seasons respectively. Generally, 30B80 had high SRUE during in wet season, which was consistent during dry season. On the other hand, IPB Var11 and USM Var10 had high during SRUE dry season only. In terms of SRUE variability, the three varieties showed high variations during wet season, but stable during dry seasons across locations (Figure 9).

Andrade (1993) reported that SRUE and mean temperature are closely related during maize growing period, and low mean temperature reduces the SRUE. The mean temperature was less during wet season. This may be the reason for higher variations of SRUE during wet season in this study. Dry season had relatively higher solar radiation use efficiency than wet season.

Grain Yield and Growing Degree Days

Grain yield of 30B80, IPB Var11 and USM Var10 maize varieties as affected by GDD during wet and dry seasons are shown in Figure 10. All varieties showed relationship between grain yield and GDD during wet and dry seasons. USM Var10 had positive (weak) relationship (R^2 = 0.2601) between grain yield and GDD during dry season, while not seen in other varieties. The relationship between grain yield and GDD was relatively strong during dry season than wet seasons for all varieties. The variety, 30B80, had the highest grain yield response to GDD during both dry and wet seasons, although all three varieties received a similar range of GDD.

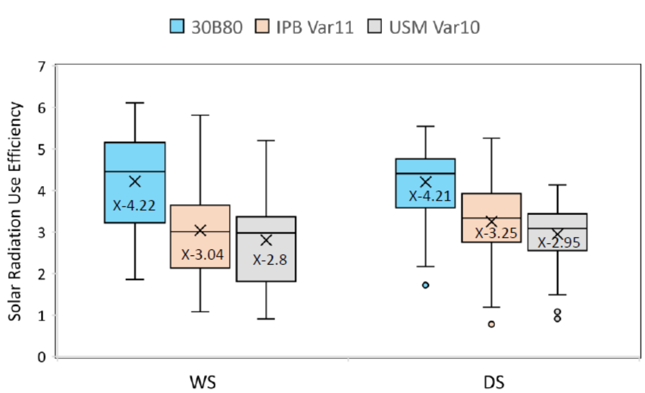

Fig. 9. Solar radiation use efficiency of maize varieties during wet (WS) and dry season (DS).

The GDD requirement of maize is dependent on the cultivar to reach certain development stage (Wang 1960; Sacks and Kucharik 2011). But, Liu et al. (2013) reported that environmental conditions also affect GDD requirements of maize. The reasons for different relationships between grain yield of varieties with CSR and GDD in this study are specific to variety characteristics and environmental conditions.

Effect of Growing Location and Climatic Factors on Grain Yield of Maize Varieties

Interaction of 30B80 with Growing Location and Climatic Factors. Results of stepwise regression analysis for grain yield of 30B80 across different locations and seasons are shown in Table 3.

Table 3. Stepwise regression analysis for factors effecting on grain yield of 30B80 across growing locations and growing seasons.

Source	Coefficient	*P* Value	R Square	R Square (ADJ)
Constant	96707			
Solar Radiation	6.371	0	0.25	0.22
Location	7629	0	0.21	0.20
Maximum Temperature	-2928	0	0.13	0.13
Relative Humidity	-606.7	0	0.06	0.06
Minimum Temperature	1324	0	0.05	0.05

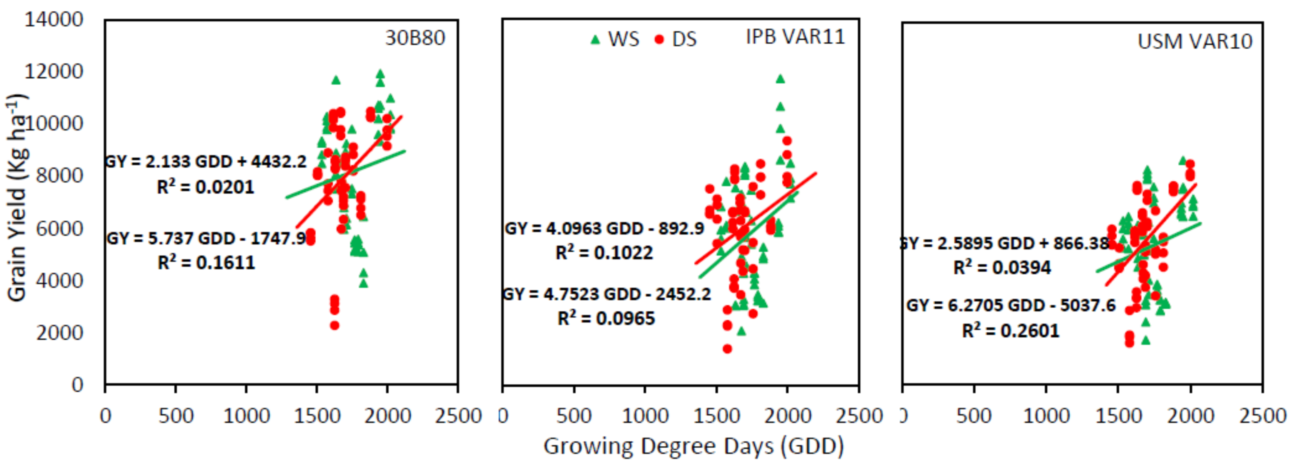

Fig. 10. Grain yield of 30B80, IPB Var11 and USM Var10 maize varieties as affected by growing degree days during wet and dry season (WS = wet season, DS = dry season, GY = grain yield).

SR, locations, T_{max}, RH and T_{min} had significant (5% level) contributions to the grain yield of 30B80 variety. SR, location and T_{min} had positive effect on grain yield, while T_{max} and RH were observed to have negative effect on grain yield. SR and locations had 0.25 and 0.21 R^2 values, respectively. These two factors are the main limiting factors affecting the grain yield of 30B80.

Interaction of IPB Var11 with Growing Location and Climatic Factors. Results of stepwise regression analysis for grain yield of IPB Var11 across different growing locations and growing seasons are shown in the Table 4. Results revealed that the location, T_{max} and SR were significant (P value < 0.05). RH and growing season did not significantly (P value> 0.05) affect the grain yield of IPB Var11. On the other hand, RH and T_{max} apparently had negative impact. In this study, SR had positive impact on grain yield of IPB Var11. In general, location (R^2 = 0.30) is the main limiting factor for the grain yield of IPB Var11 across growing areas, while RH was dominantly affected on grain yield.

Table 4. Stepwise regression analysis for factors effecting on grain yield of IPB Var11 across growing locations and growing seasons.

Source	Coefficient	*P* Value	R Square	R Square (ADJ)
Constant	45056			
Location	2806	0.000	0.29	0.25
Relative Humidity	-171.4	0.078	0.06	0.05
Maximum Temperature	-1134	0.000	0.03	0.03
Solar Radiation	3.43	0.005	0.03	0.03
Season	541	0.141	0.01	0.00

Table 5. Stepwise regression analysis for factors effecting on grain yield of USM Var10 across growing locations and growing seasons.

Source	Coefficient	*P* Value	R Square	R Square (ADJ)
Constant	39883			
Location	2907	0.000	0.35	0.32
Relative Humidity	-246.8	0.002	0.12	0.12
Maximum Temperature	-717	0.000	0.02	0.02
Solar Radiation	3.055	0.002	0.05	0.05

Interaction of USM Var10 with Growing Location and Climatic Factors. ANOVA from stepwise regression for grain yield of USM Var10 across different locations and seasons revealed that the locations, RH, T_{max} and SR were significant at P value < 0.05 (Table 5). RH and T_{max} had negative effect on grain yield, while SR had positive impact on grain yield of USM Var10. Generally, location is the limiting factor (R^2 = 0.36) for the grain yield of USM Var10 across growing areas. RH, on the other hand, appeared to be dominant climatic element (R^2 = 0.12) affecting USM Var10 grain yield.

SUMMARY AND CONCLUSION

Significant variations in rainfall and solar radiation was observed across locations. Higher SR was recorded during start of wet season and towards the end of dry season. Average mean temperatures were below 30°C, while T_{max} and T_{min} were 35.84°C and 18.77°C, respectively. High RH (91.1%) was recorded during dry seasons, while wet season had low (87.9%). Average RH was more than 80% across locations.

Growing locations with Climate Type I had higher mean grain yield and grain yield variations during dry season. Mean grain yield was not significantly different during wet and dry seasons in locations with Climate Type III, while higher grain yield variation was during wet season. Mean grain yield and grain yield variations did not vary during wet and dry seasons of locations with Climate Type IV. Grain yield variations by climate type and location were highly significant. Baybay had consistent and higher mean grain yield, while Ubay had higher grain yield variations. 30B80 variety had higher mean grain yield during wet and dry seasons relative to the other varieties. Generally, mean grain yield of maize varieties did not vary between wet and dry seasons, except in Batac and Ubay.

Grain yield response to SR was significant among varieties and seasons. Positive correlations between grain yield and CSR were observed in all varieties. The variety, 30B80, had maximum grain yield response to CSR and higher SRUE than other two varieties. Higher variations in SRUE were apparent during wet seasons. On the other hand, SRUE was stable (among varieties and across locations) during dry season. SRUE was relatively higher during dry seasons.

Grain yields were correlated with GDD in all varieties during wet and dry seasons. The variety, 30B80, had the maximum grain yield to the same range of GDD during wet and dry seasons. In addition, the yielding performance of 30B80 were increased with CSR. USM Var10, on the other hand, increased with GDD, while IPB Var11 yield was not correlated with CSR.

Grain yield of 30B80 varied with growing location and climatic factors. Specifically, SR and T_{min} had positive affect on grain yield, while T_{max} and RH reduced grain yield. SR in different growing sites (locations) was the major yield-limiting factors. In terms of varietal interaction with environment, solar radiation increased grain yield of IPB Var11, while RH and T_{max} had negative affect. Generally, the major yield-limiting factor for IPB Var11 was RH. Grain yield of USM Var10 was increased with SR but decreased with RH and T_{max}. It appeared that the major yield-limiting factor for USM Var10 is RH. Significant seasonal climate variation can be observed in major maize growing areas resulting in different seasonal productivity, and solar radiation and relative humidity are the major yield-limiting climatic factors. Moreover, the hybrid variety, 30B80, can be recommended for dry season in Batac, Tupi, and Baybay; wet season in Ubay; and both wet and dry season in Maramag, Kabacan, and Ilagan as a high-yielding maize variety.

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