**American Journal of Agricultural Research
(ISSN:2475-2002)**

Statistical Analysis Of Impact Of Climate Change On Crop Potentials Productivity On A Regional Scale

K.O. Rauff[1*], A.A. IsmaiID[2]

[1]Federal University of Kashere, Gombe State Nigeria.
[2]School of Physics, Universiti Sains Malaysia, 11800 USM, Penang.

ABSTRACT

Yield improvement is the main aim of all agricultural activities. Therefore, it is important to have an idea about the yield that can be produced from a piece of land before investing in it. This work is aimed at analysing the impact of climate change on crop yield potential and predicting the crop yield potential in six geo political zones in Nigeria using global solar radiation as the only limiting factors of production. Climatic data were obtained from Nigeria Meteorological Agency (NIMET), Oshodi, Nigeria. Results of impact of climate change on the photosynthetic, light-temperature, and climatic potential productivities of maize and their gap differences are presented using a crop growth dynamics statistical method. The results showed that photosynthetic potential productivity decreased from north to south, with the largest values in two maize-growing zones due to higher average growing season radiation and a longer maize growing season. The light-temperature potential productivity of maize was higher than photosynthetic potential productivity, which varied from 3223.99 to 4425.79 kg ha−1, with a mean of 3821.402 kg ha−1 and climatic potential productivity varied from 11279.92 to 29263.75 kg ha−1, with a similar distribution pattern to light-temperature potential productivity with a mean of 23817.32 kg ha−1. The gap between light temperature and climatic potential productivity varied from 6884.07 to 33506.92

*Correspondence to Author:
K.O. Rauff
Federal University of Kashere, Gombe State Nigeria.

kg ha $^{-1}$, with the high value areas centered in Southern Nigeria.

Keyword: Climate Change; Crop yield Potential; Global Solar Radiation; Dynamics Statistical Method; Climatic Potential Productivity; Light-Temperature Potential Productivity

1. INTRODUCTION

The relation between the atmosphere and the soil cannot be overemphasized. Food production is being influenced by weather and climate variations therefore, studying the impact of climate change is important in order to cater for people as the population of the world is expected to be around 10 billion people by 2100 (Keyzer *et al.,* 2002, Boogaard *et al.,* 2014)). The key parameter that determines the food production is crop potential productivity (Wang *et al.,* 2011). Grassini *et al.,* (2009) reported that when a crop is grown under favorable conditions unlike in 2016 that the earth's surface experienced the warmest climate for the past 135 years (NASA GISS, 2017), it is referred to as potential yield. Yang *et al.,* (2010) and Zheng-Hong Tan *et al.,* (2017) defined the photosynthetic light-temperature and climatic potential productivity as when there is maximum crop output determined by radiation, light-temperature,and light-temperature-precipitation conditions, respectively. Crop growth models which we use to estimate agriculture potential and to forecast crop yield are important tools of interdisciplinary research (Zunfu *et al.,* 2017). The essential input variable to estimate potential productivity and actual evapotranspiration is global solar radiation (H_0) but has been a significant challenge. Despite the fact that remote sensing technique makes H_0 data available to users, the use of empirical models to estimate H_0 from measured meteorological variables is still relevant in many applications (Chen *et al.,* 2013). Many formulas were developed so as to choose the best selection method to tackle these challenges and some of these formulas have been incorporated into crop models as part of the software package (Donatelli *et al.,* 2003), so as to facilitate the preparation of the necessary weather data. The concerns of the general community is our climate variation and its impact on our food production. There is need to develop a statistical tool that can assist the farmers (Keating *et al.,* 2003) to forecast the production even before going to the farm. Some studies (Chen *et al.,* 2013) have estimated the spatiotemporal changes in crop potential productivity using various approaches. The generally acceptable method (Supit *et al.,* 1994) to calculate evapotranspiration is the Penman approach. Penman (1948) was the first to describe evapotranspiration in physical mathematical terms. He calculated evaporation from free-water surfaces, wet bare soil and low grass swards for 10-day periods (Foken, 2008).

2. METHODOLOGY

2.1 Theoretical Background

Penman Eq. 1 consists of two parts: the radiative that calculates the net absorbed radiation and the aerodynamic that calculates the evaporative demand of the atmosphere and the resulting equations are used to calculate the potential evaporation.

$$ET = WH_n + (1-W)E_a \qquad (1)$$

Where, ET = the evapo(transpi)ration [mm d^{-1}]; H_n = the net absorbed radiation in equivalent evaporation [mm d^{-1}]; $W =$ the temperature related weighing factor; and E_a = the evaporative demand in equivalent evaporation [mm d^{-1}].

2.2 Preparatory Calculations

The average temperature is equal to the air temperature (T) which is calculated as.

$$T = \frac{T_{max} - T_{min}}{2} \qquad (2)$$

Where, T_{max} = the maximum temperature [^{o}C];

T_{min} = the minimum temperature [^{o}C]; and T = the average daily air temperature [^{o}C].

The difference between maximum and minimum temperature is used to calculate the empiric constant of the wind function in the Penman equation.

$$\Delta T = T_{max} - T_{min} \qquad (3)$$

Where, ΔT = the temperature difference [^{o}C]

The wind-speed dependency is incorporated in the evaporative demand as the wind speed measured at a height of two meters, and multiplied by an empirical coefficient which is temperature dependent and it is calculated as.

$$BU = 0.54 + 0.35 \frac{\Delta T - 12}{4}, \quad \Delta T \geq 12^0 C \qquad (4)$$

$$BU = 0.54 , \Delta T \leq 12^0 C \qquad (5)$$

Where, BU = the empirical coefficient in the wind function.

Saturated vapor pressure is related to mean daily air temperature (Goudriaan, 1977) and it given as.

$$e_s = 0.61078 \cdot \exp\left(\frac{17.2693882 \cdot T}{T - 35.86 + 273.16} \right) \qquad (6)$$

Where, e_s = the saturated vapor pressure [hPa]; and T = the air temperature [°C].

2.3 Terms in the Penman Formula
The temperature related weighing factor W in Eq. 1 is defined (Penman, 1948).

$$W = \frac{\Delta}{\Delta + \gamma} \qquad (7)$$

Where, Δ = slope of the saturation vapor pressure curve $\left(hPa^oC^{-1} \right)$, γ = the psychometric constant $\left(hPa^oC^{-1} \right)$.

The evaporative demand of the atmosphere depends on the difference between saturated and actual vapor pressure and on the wind function.

$$E_a = 0.26\left[\left(e_s - e_a \right)\left(f_c - BU \cdot u(2) \right) \right] \qquad (8)$$

Where, E_a = the evaporative demand [mm d^{-1}]; e_s = the saturated vapour pressure [hPa]; e_a = the actual vapour pressure [hPa]; f_c = the empirical constant; BU = the coefficient in wind function; and u = the mean wind-speed [m s^{-1}].

For crop canopies f_c = 1.0 and for a free water surface f_c = 0.5 are assumed, Eq. 1 becomes.

$$ET = \frac{\Delta H_n + \gamma E_a}{\Delta + \gamma} \qquad (9)$$

Where: ET = the pan evaporation in $\left(mmd^{-1} \right)$; H_n = the net absorbed radiation $\left(mmd^{-1} \right)$; Δ : the slope of the saturation vapor pressure versus air temperature $\left(hPa^oC^{-1} \right)$; γ = the psychometric constant $0.49 \, mm$ of $Hg \, /^o C$ or $0.667 kPa / K$; and E_a = the evaporative demand [mm d^{-1}].

Methods to Estimate Global Radiation
Solar radiation is one of the meteorological factors determining potential productivity (Boisvert *et al.*, 1990). This can be estimated (Ångström,

1924) from other climatic variables for example from sunshine duration; air temperature range (De Jong & Stewart, 1993), precipitation (De Jong & Stewart, 1993) and cloud-cover (Barker, 1992). We used the equation postulated by (Ångström, 1924) and modified by (Prescott, 1940).

$$\frac{H_h}{H_0} = a + b\frac{n}{N} \qquad (10)$$

Where, H_h = the monthly average daily global radiation on a horizontal surface $\left(MJ \cdot m^{-2} \cdot day^{-1}\right)$; H_0 = the monthly average daily extraterrestrial radiation on a horizontal surface $\left(MJ \cdot m^{-2} \cdot day^{-1}\right)$; n = the monthly average daily number of hours of bright sunshine; N = the monthly average daily maximum number of hours of possible sunshine (or day length); and a and b = the regression constants.

This above named equation is the most widely used empirical equation which estimates global solar radiation from sunshine hour duration.

Daily climate data from sixteen (16) stations of the Nigeria Meteorological Agency (NIMET) Oshodi, Nigeria were obtained from. The climate data are of high quality. The data include Sunshine Hours (h), Average Temperature (ᵒC), Maximum Temperature (ᵒC), Minimum Temperature (ᵒC), Precipitation (mm), Relative Humidity (%), and Wind Speed (ms⁻¹) over the period 30 years (1985–2014). In estimating crop yield potential, the study areas were divided into three maize-growing districts based on different sowing dates and growth periods. Observed maize phenology from the Institute of Agricultural Research and Training (IAR&T) meteorological station was used to calibrate the maize-growing districts.

2.4 Calculation of Maize Potential Productivity

Crop Potential Productivity is calculated according to the crop growth dynamics statistical method, which divides the Potential Production into three levels: Photosynthetic, Light-Temperature, and Climatic Potential Productivity (Yuan *et al.,* 2012). The photosynthetic potential productivity (PPP; 10^3 kg ha⁻¹) is calculated.

$$PPP = \sum_{j=1}^{4}\left(\sum_{i=1}^{dl_i}\left(0.219 \times C \times H_h\right)\right) \qquad (11)$$

Where, 0.219 = the Huang Bingwei coefficient in unit of $10^{-5}\, kgkJ^{-1}$; C = the crop economic coefficient, taking the value of 0.4 (Li *et al.,* 2009); j represents each maize development stage; dl_i = the length of each crop development stage; H_h = the daily shortwave radiation during the crop growing season in unit of $kJ \cdot cm^{-2} \cdot day^{-1}$.

The Light-Temperature Potential Productivity (LTPP; 10^3 kg ha⁻¹) is calculated by correcting the Photosynthetic Potential Productivity with the Temperature Stress Coefficient.

$$LTPP = \sum_{i=1}^{4}\left(\sum_{i=1}^{dl_i}\left(0.219 \times C \times H_h \times f(T)\right)\right) \qquad (12)$$

Where, $f(t_i)$ = the temperature stress coefficient that can be calculated as follows.

$$f(T) = \begin{cases} 0 & T \leq T_{\min} \\[1mm] & T \geq T_{\min} \\[1mm] \dfrac{T - T_{\min,}}{T_0 - T_{\min,}} & T_{\min} \leq T \leq T_0 \\[2mm] \dfrac{T_{\max} - T}{T_{\max} - T_0} & T_0 \leq T \leq T_{MAX} \end{cases} \qquad (13)$$

Where, T = the daily average temperature in (^{O}C); T_{min}, T_{max}, and T_o = the minimum, maximum, and optimum temperatures (^{O}C) for each crop development stage, respectively.

$$LTPP = \sum_{i=1}^{4}\left(\sum_{i=1}^{dl_i} \left(0.219 \times C \times H_h \times f(T) \times f(w_j) \right) \right)$$

(14)

Here, $f(w_j)$ = the water stress coefficient, calculated as

$$f(w_j) = \begin{cases} \dfrac{P_j}{ET} & 0 \leq P_j \leq ET \\ \\ 1 & P_j \geq ET \end{cases}$$

(15)

Where, P_j = the total precipitation (mm) during each maize development stage. ET = the total crop water requirement (mm) during each crop development stage, which can be calculated as shown in Eq.1.

3. RESULTS

The results of Photosynthetic Potential Productivity (PPP); Light-Temperature Potential Productivity (LTPP); Climatic Potential Productivity (CPP) and Gap differences for the Six Geo Political Zones in Nigeria are presented in

The Climatic Potential Productivity (CPP; 10^3 kg ha^{-1}) is calculated by correcting the Light Temperature Potential Productivity with the Water Stress Coefficient.

Table 1 while the geographical map of the area of study is presented in Fig. 1.

The geographical information of Photosynthetic Potential Productivity (PPP); Light-Temperature Potential Productivity (LTPP) and Climatic Potential Productivity (CPP) are presented in the figures 2,4 and 6 while their values are presented in the figures 3,5 and 7 respectively, figure 8 showed the trend pattern of their gap difference.

Table 1: The six Geo-Political zones of Nigeria

| District	GEO-POLITICAL ZONES	PPP; kg ha^{-1}	LTPP;kg ha^{-1}	CPP; kg ha^{-1}	Gap Diff
I	North Central States	1400.07	4116.20	18390.89	14274.60
II	North-Eastern States	1495.19	4395.85	11279.92	6884.07
III	North-Western States	1505.37	4425.79	20986.05	16560.26
IV	South-Eastern States	1180.43	3470.48	29263.75	25793.27
V	South-Southern States	1096.59	3223.99	36730.91	33506.92
VI	South-Western States	1091.03	3296.10	26252.41	22956.31
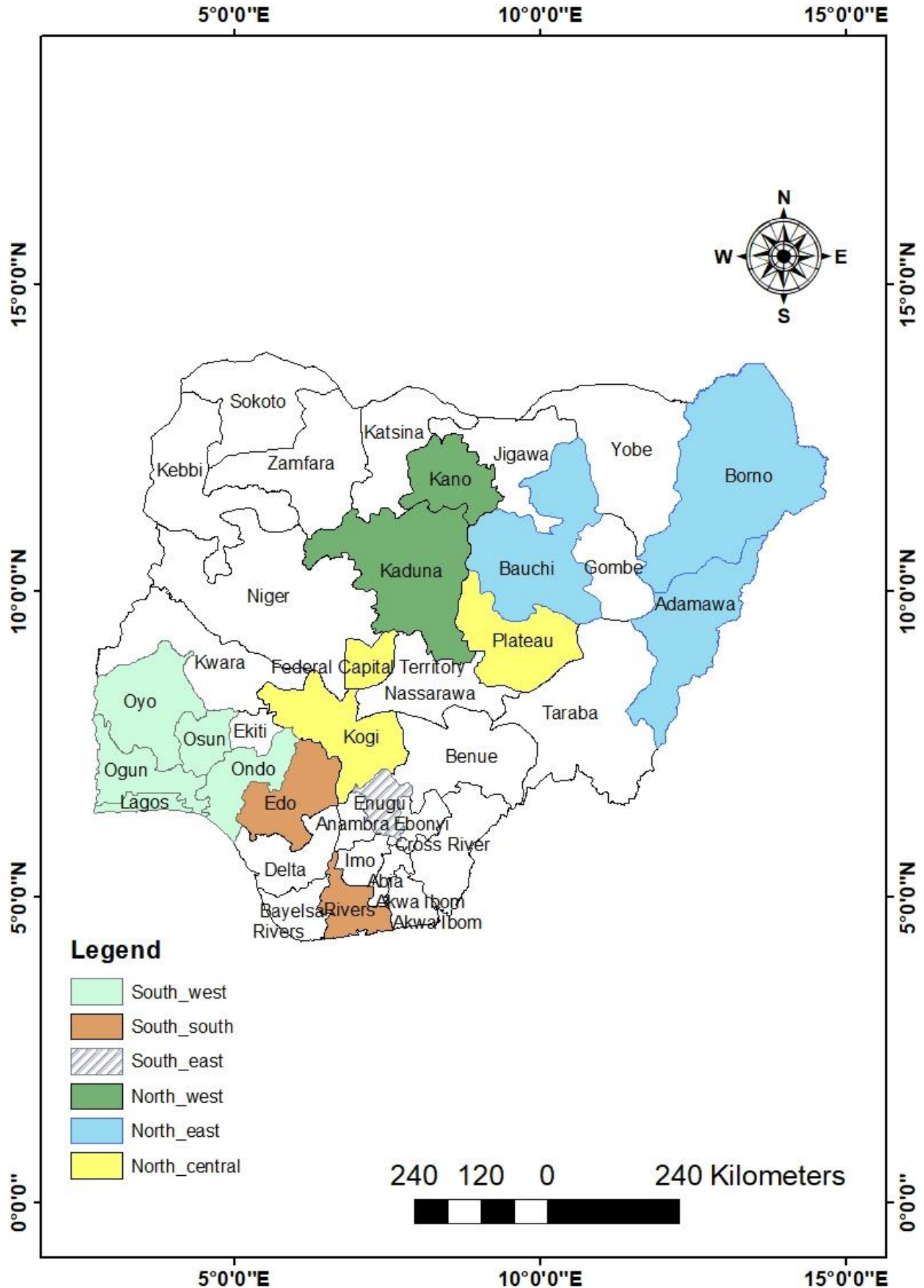
Fig. 1: The map of Nigeria showing the six geopolitical zones of area of study.
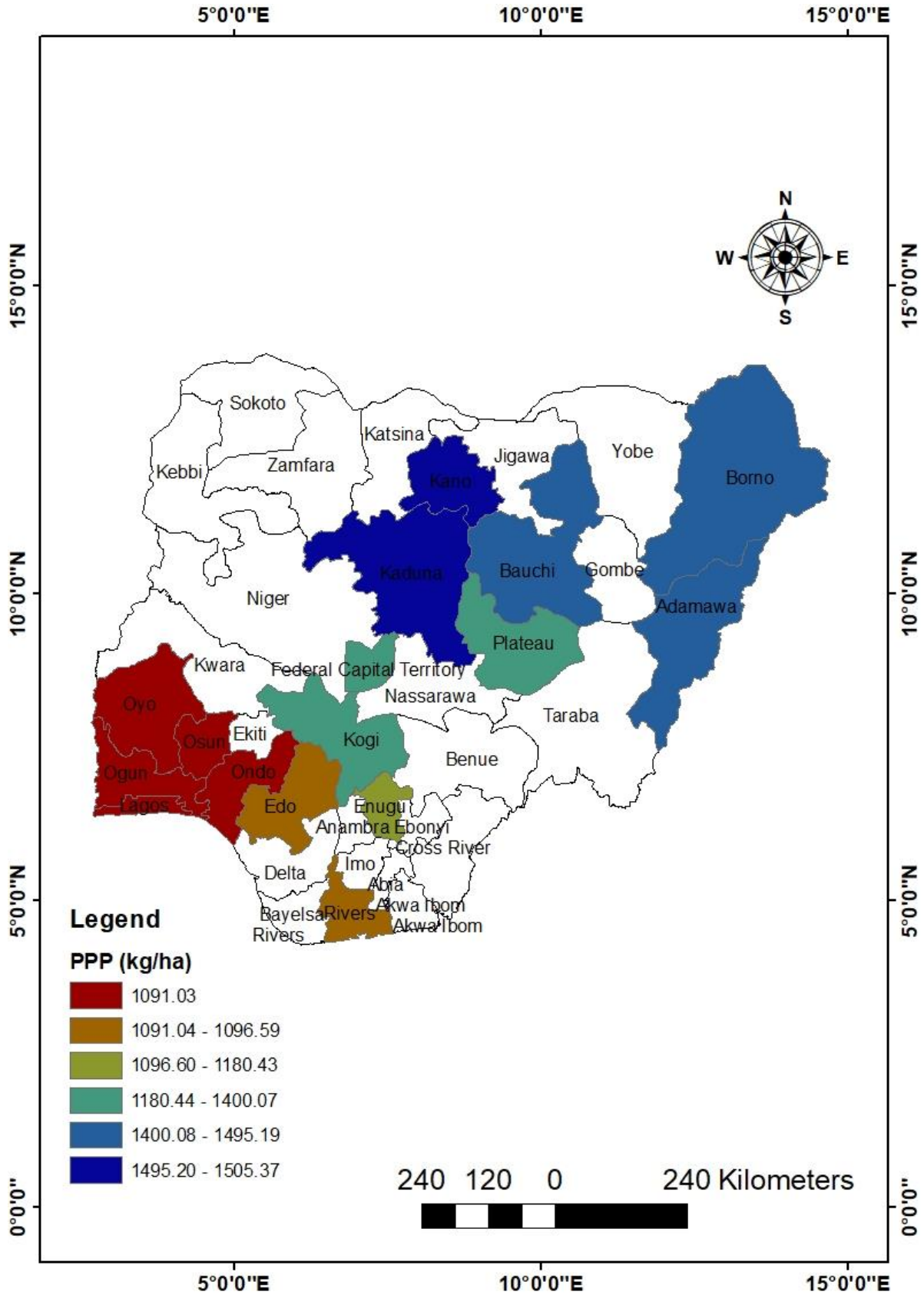
Fig. 2: The geographical information of Photosynthetic Potential Productivity (PPP) of the six geopolit-
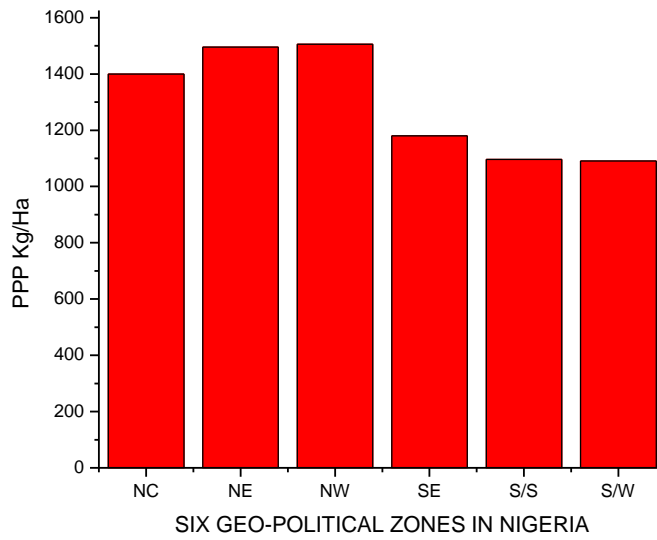
ical zones of area of study

Fig. 3: The photosynthetic potential productivity in the six geopolitical zones, Nigeria
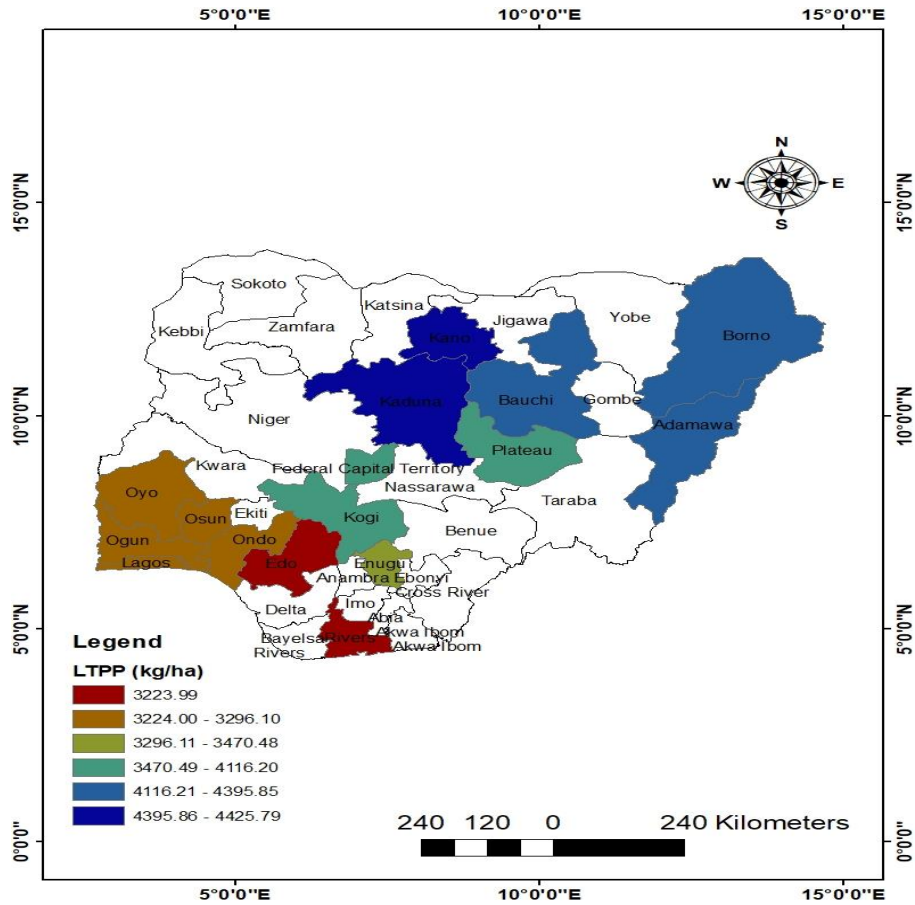

Fig. 4: The geographical information of Light Temperature Potential Productivity (LTPP) of the six ge-

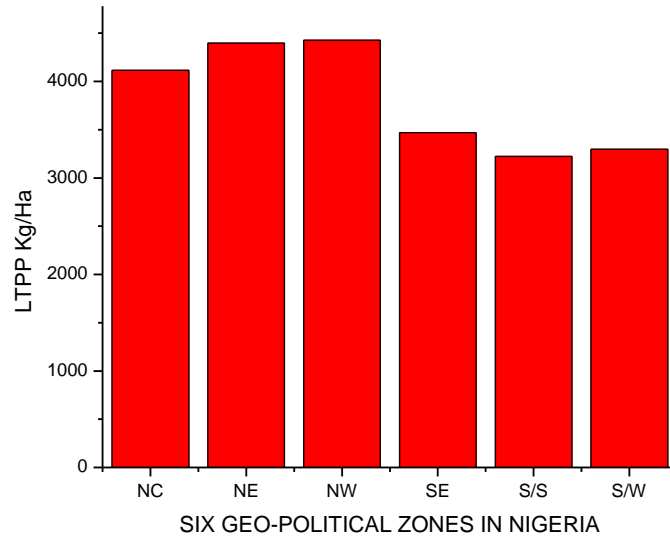opolitical zones of area of study.

Fig. 5: The light-temperature potential productivity in the six geopolitical zones, Nigeria.
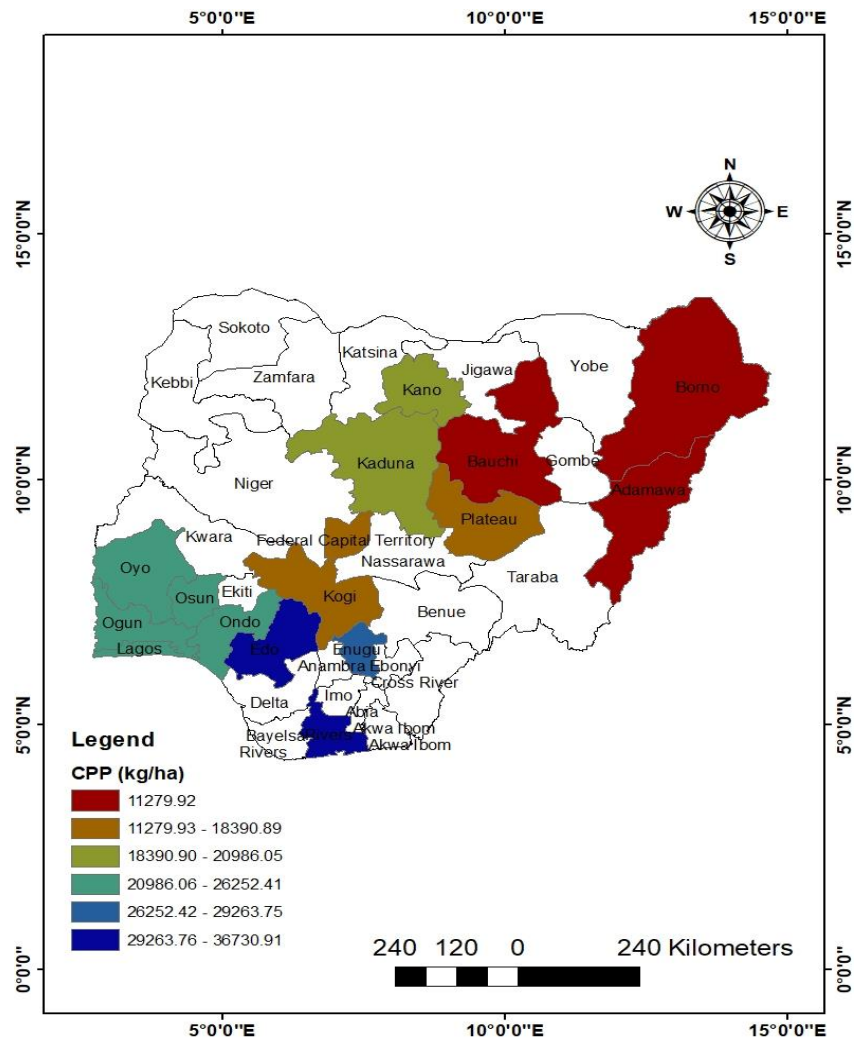
Fig. 6: The geographical information of Climatic Potential Productivity (CPP) of the six geopolitical zones of area of study.
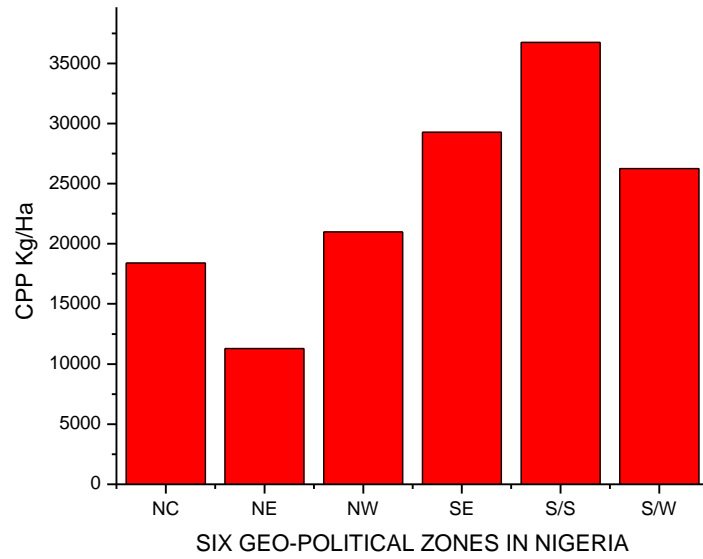
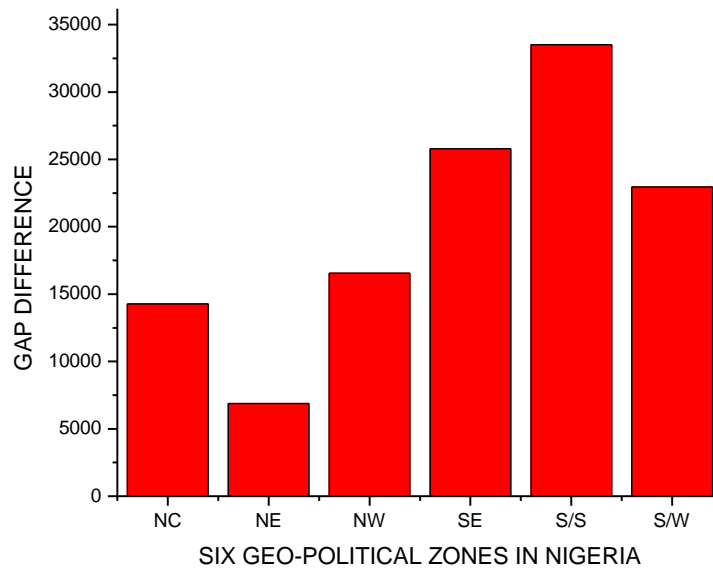Fig. 7: The climatic potential productivity in the six geopolitical zones, Nigeria

Fig. 8: The gap difference in the six geopolitical zones, Nigeria.

3.1 The six Geo-Political Zones of Nigeria where the data were obtained

1. North Central States: Kogi, Plateau and Federal Capital Territory.
2. North-Eastern States: Borno, Bauchi and Adamawa.
3. North-Western States: Kaduna and Kano.
4. South-Eastern States: Enugu.
5. South-Southern States: Edo and Rivers.
6. South-Western States: Oyo, Ogun, Lagos, Ondo and Osun.

4. DISCUSSIONS

The potential productivity and potential productivity gap evaluation are important in order to understand the effect of temperature, rainfall and light resources on crop production. In this study, we analyzed the variations in climate factors and their impact on crop (maize) potential productivities (photosynthetic, light-temperature, and climatic) in six geo-political zones of Nigeria for 30 years between 1985 and 2014, and then quantified the spatial and temporal variations in the gap between light temperature and Climatic Potential Productivity. The highest values of maize potential productivity occurred in North-Eastern and North-Western states. In general, PPP decreases from North to South, with the largest values in maize-growing zones II and III (Bauchi, Yola, Kaduna and Kano states) due to higher average growing season radiation and a longer maize growing season as shown in Fig.2. The spatial change in maize potential productivity did not follow a decreasing trend with latitude due to the complex topographic conditions in these regions. The distribution of areas with high values of Photosynthetic Potential Productivity was different to that with high values of light-temperature productivity due to change in altitude. Areas with high values of Photosynthetic Productivity were mainly located in the North-Eastern and North-Western regions; however, those with low values of Light-Temperature Potential Productivity were mainly located in Southern region of Nigeria. Fig. 3 depicts the Photosynthetic Potential Productivity (PPP) of maize that varied from 1091.03 kg ha^{-1} to 1505.37 kg ha^{-1}, with a mean of 1294.78 kg ha^{-1} and the highest values of PPP occurred both in the northwest and northeast whereas the lowest values occurred in the south-south and south-east of the six geopolitical zones in Nigeria. It was noticed that both the PPP and LTP productivities followed the same patterns where the lowest values were recorded in both the south east and south-south of Nigeria as presented in Fig.4. Light-temperature potential productivity of maize was noticeably higher than photosynthetic potential productivity, which varied from 3223.99 to 4425.79 kg ha^{-1}, with a mean of 3821.402 kg ha^{-1} as it has been shown in Fig. 5. Fig. 6 presents the geographical information of climatic potential productivity (CPP) of the six geopolitical zones of area of study. Climatic potential productivity varied from 11279.92 to 29263.75 kg ha^{-1}, with a mean of 23817.32 kg ha^{-1}. Fig. 6 exhibits the climatic potential productivity variations which decrease in the Northeast of Nigeria, whereas it increases in the Southwest of Nigeria. The gap between Light Temperature and Climatic Potential Productivity varied from 6884.07 to 33506.92 kg ha $^{-1}$, with the high value areas centered in Southern Nigeria as shown in Table 1 and Fig.8 respectively. The gap between light-temperature and climatic potential productivity varied considerably with location (between 6884.07 to 33506.92 kg ha $^{-1}$) from 1985 to 2014 in Nigeria. Climatic Potential Productivity was about 10% – 24% of Light-Temperature Potential Productivity in these regions, which implies that precipitation is a strong limiting factor for maize potential productivity.

In general, the simulated potential yield decreases generally from north to south due to the latitudinal distribution of solar radiation and growing season temperature which corresponds to the work of (Wu *et al.,* 2006). Precipitation during the maize growing season ranges from 412 to 608 mm in different maize-growing districts, which in theory can meet the water requirements of maize. The Climatic Potential Productivity decreases in the northeast of Nigeria, whereas they increase in the southwest of Nigeria. However, a distinct gap between Light Temperature and Climatic Potential Productivity exists, varying from 6884.07 to 33506.92 kg ha $^{-1}$, with the high value areas centered in Southern Nigeria, which presents a

maize potential productivity loss due to water stress caused by uneven precipitation distribution during the maize growing season. As presented in Table 1, the largest yield gap was located in sout-south and south-east zones.

5. CONCLUSIONS

The major advantage of potential productivity gap analysis is that, it is used to know crop yield improvement when there is information about the solar radiation, evapotranspiration, photosynthetic potential productivity (PPP), light-temperature potential productivity (LTPP) and climatic potential productivity (CPP) of the area. Generally, it is a known fact that increase in temperature caused a reduction in climatic potential productivity in the high temperature category, whereas it contributed to an increase in climatic potential productivity at stations in the low temperature category. However, in Northeast, a simulated increase in maximum temperature generally caused a reduction in yield potential, while an increase in minimum temperature produced no significant impact on yield potential. It is noticed that potential productivity is not completely consistent with actual yield. In conclusion, we have demonstrated that a distinct gap between light-temperature and climatic potential productivity exists where annual and growing season precipitation is sufficient when analyzing the impact of climate change on the spatial and temporal variations of maize photosynthetic, light-temperature, and climatic potential productivity from 1985 to 2014 in Nigeria. It is also worthy of concluding that the geographic information helps to gather actionable intelligence from all types of data.

REFERENCE

1. Ångström A.; (1924). Solar and atmospheric radiation. Quarterly J. of the Royal Meteor. Soc. 50: 121-126 (7 pages).

2. Barker H.W.; (1992). Solar radiative transfer through clouds possessing isotropic variable extinction coefficient. Quarterly J. of the Royal Meteor. Soc., 118(3):1145-1162 (17 pages)

3. Boisvert J.B.; Hayhoe H.N.; Dubé P.A.; (1990). Improving the estimation of global radiation across canada. Agricultural and Forest Meteor., 52(3-4): 275-286 (11 pages).

4. Boogaard H.L.; De Wit A.J.W.; te Roller J.A; Van Diepen C.A.; (2014). Wofost control centre 2.1; User's guide for the wofost control centre 2.1 and the crop growth simulation model wofost 7.1.7. Wageningen (Netherlands), Alterra, Wageningen University & Research Centre (133 pages).

5. Chen C.; Baethgen W.E.; Robertson A.; (2013). Contributions of individual variation in temperature, solar radiation and precipitation to crop yield in the north china plain, 1961–2003. Climatic Change., 116(3-4): 767–788 (21 pages).

6. De Jong R.; Stewart D.W.; (1993). Estimating global radiation from common meteorological variables in Western Canada. Canadian J of Plant Sci., 73(2): 509-518 (9 pages).

7. Donatelli M.; Bellochi G.; Fontana F.; (2003). RadEst300: Software to estimate daily radiation data from commonly available meteorological variables. Eur. J. of Agronomy., 18(3-4): 363-367 (4).

8. Foken T.; (2008). Micrometeorology. Springer-Verlag Berlin Heidelberg., (306 pages).

9. Goudriaan J.; (1977). Crop micrometeorology: a simulation study. simulation monographs. pudoc, wageningen, Netherland. (262 pages).

10. Grassini P.; Yang H.; Cassman K.G.; (2009). Limits to maize productivity in western corn-belt: a simulation analysis for fully irrigated and rainfed conditions. Agri. Forest Meteor., 149(8): 1254–1265 (9 pages).

11. Keating B. A.; Carberry P.S.; Hammer G.L.; (2003). An overview of apsim, a model designed for farming systems simulation. Eur. J. of Agronomy., 18(3-4), 267–288 (21 pages).

12. Keyzer M.; Merbis M.; Pavel F.; (2002). Can we feed the animals? origins and implications of rising meat demand. Paper presented at 2002 International Congress, Eur. Assoc. of Agric. Econ., Zaragoza, Spain, 28–31 Aug.

13. National Aeronautics and Space Administration, Goddard Institute for Space Studies (NASA, GISS). 2015. NASA, NOAA Finds 2015 Warmest Year in Modern Record. 18 January. http://www.giss.nasa.gov/research/news/20150116/ (accessed 18 January 2017).

14. Penman H.L.; (1948). Natural evaporation from open water, bare soil and grass. Proceedings Royal Soc. Series A., 193(1032): 120-146 (26 pages).

15. Prescott J.A.; (1940). Evaporation from a water surface in relation to solar radiation.Transactions of the Royal Society of South Australia., 64: 114-480 (366 pages).

16. Supit I.; Hooijer A.A.; van Diepen C.A.; (1994). System description of the wofost 60 crop simulation model implemented in CGMS. Volume 1 theory and algorithms, Joint Research Centre Commission of the European Communities EUR 15956 EN: Luxembourg, 1994, (146 pages).

17. Wang T.; Lu C.; Yu B.; (2011). Production potential and yield gaps of summer maize in the Beijing-Tianjin-Hebei Region. J. Geograph. Sci., 21(4): 677–688 (11 pages).

18. Yang J.; Peter M. V.; Jian Y.; Michael E. G.; (2010). A Commentary on 'Common SNPs Explain a Large Proportion of the Heritability for Human Height. Twin Research and Human Genetics., 13(6): 517-524 (8 pages)

19. Yuan Z.; Li J.; Zhang L.; Gao X.; Gao H.J.; Xu S.; (2012). Investigation on brca1 snps and its effects on mastitis in chinese commercial cattle. Elsevier., 505: 190-194 (5 pages)

20. Zheng-Hong Tan, Jiye Zeng, Yong-Jiang Zhang, Martijn Slot, Minoru Gamo, Takashi Hirano, Yoshiko Kosugi, Humberto R da Rocha, Scott R Saleska, Michael L Goulden (2017). Optimum air temperature for tropical forest photosynthesis: mechanisms involved and implications for climate warming2017 Environ. Res. Lett.12: 054022

21. Zunfu Lv, Xiaojun Liu, Weixing Cao and Yan Zhu (2017). A Model-Based Estimate of Regional Wheat Yield Gaps and Water Use Efficiency in Main Winter Wheat Production Regions of China. *Scientific Reports* volume 7, Article number: 6081