# Estimating Crop Evapotranspiration Rates for Spinach in Minna, Niger State

**Kuti, I. Abayomi[1], Musa, J. J[1]., Ibraheem Ishola[1], Abdullahi, Suleiman[2], [3]Adabembe, B. A. Aroboinosen, Hillary[3]**

[1]Department of Agricultural &Bioresources Engineering, Federal University of Technology, Minna, Nigeria.

[2]Centre for Disaster Risk Management & Development Studies, Federal University of Technology, Minna, Nigeria

[3]Department of Water Resources Management and Agro meteorology, Federal University Oye -Ekiti State, Nigeria

[4]Department of Agricultural &Bioresources Engineering, Federal University of Agriculture, Abeokuta, Ogun State,Nigeria.

abykuti6@futminna.edu.ng

## Abstract

*Crop evapotranspiration differs in each region depending on crop type, soil and climate conditions. In view of this, this study assessed crop evapotranspiration rates for spinach in Minna, Niger State with the aim of determining the optimum evapotranspiration loss on spinach field in Minna. The study took one soil sample randomly on the plot to compute total depth of water in the root zone and irrigation interval in the month of March and June. The study installed pan evaporation in the crop field (4.17m by 1.70m) and water loss after 24 hours was estimated and multiplied by crop factor ($K_C$) to obtain crop evapotranspiration. The study obtained daily rainfall and temperature data from Nigerian Meteorological Agency (Mimet) between March and June, 2016 to compute evapotranspiration ($ET_C$) for Blaney-Criddle and Thornthwaite. The computed $ET_0$ pan evaporation, $ET_0$ Blaney-Criddle and ($ET_C$) Thornthwaite were subjected to analysis of variance (ANOVA) and Duncan test. The evapotranspiration losses on spinach field through pan evaporation were 2.8mm/day and 2.38mm/day respectively. The study shows that there was a significant differences between the three methods* ($p > 0.05$, F= 0.0001073). *The study concluded that the evapotranspiration losses on spinach field in the month of March were higher than the month of June with the same depth of irrigation. Also, pan evaporation gives optimum evapotranspiration results followed by Blaney-Criddle and Thornthwaite method. The study recommended that there is need to take soil sample of the study area at different growth stages of spinach so as to determine their irrigation intervals.*

***Keywords:*** *Crop Evapotranspiration, Spinach, Class A Pan Evaporation*

## Introduction

Over 90% of water used in agriculture is lost through land evaporation and crop transpiration (Ding *et al.*, 2013). Evapotranspiration refers to the total amount of water loss through evaporation and transpiration. In irrigation, evaporation is the water loss from the land surface while transpiration is the process by which plant lost water from their bodies i.e. the root, vascular tissue, stomata and leaves (Maina *et al.*, 2012). According to Abubaker (2009), the amount of water that plants transpire varies greatly geographically and over time, and the factors that determine transpiration rates are temperature, relative humidity, wind and air movement, soil-moisture availability and type of plants. Crop evapotranspiration is an important components used in the planning, design, construction, operation, and maintenance of irrigation systems (Ertek, 2011). Several studies have shown different methods of determining evapotranspiration and these include Penman-Monteith, Pan evaporation, modified Penman formula, Thornthwaite and Blaney-Criddle method. Among these method of evapotranspiration, pan evaporation was found most suitable followed by Blaney-Criddle and Thornthwaite in determining potential evapotranspiration whereas both Penman-

Montieth and modified Penman neither overestimated nor underestimated the evapotranspiration values (Maina *et al.,* 2012; Ertek, 2011). Although, studies have shown that pan evaporation inherent uncertainties such as improper calibration of the pan, improper positioning of the pan, installation of bird-guards and mammals drinking the water were found to reduce measured evaporation by 7% (Fu *et al.*, 2009). This study required to correct the uncertainties tied to the pan evaporation in determining evapotranspiration. Furthermore, understanding evapotranspiration dynamics on crop land will help to determine optimum crop water requirement in dry season (March) and raining season (June), predict surface runoff, groundwater and irrigation scheduling. In view of these, the study aimed at determining evapotranspiration rate of spinach using pan evaporation and compared their results with Blaney-Criddle and Thornthwaite equations so as to know the best evapotranspiration methods in Minna, Niger State.

## Materials and Methods

### Description of the Study Area

The study lies on the geographical coordinates of Latitude 9⁰36'50" North of the equator and Longitude 6⁰33'24" East of the Greenwich Meridian. The average elevation of Minna is 272m and altitude 1007 feet. The mean annual rainfall and temperature were 1284 mm and 33.5 °C respectively (Afolabi *et al.,* 2014). The study was conducted at Dutsen Kura irrigation farm, Minna, Niger State to determine evapotranspiration rate of spinach under an irrigated and rain- fed conditions in the month of March and June respectively. The plot used for the study has an area of 7.1 m$^2$. The spinach seeds were planted between 3$^{rd}$ of March, 2016 and 25$^{th}$ of May 2016 under irrigated and rain fed condition. Also, harvesting was done between the 7$^{th}$ of April and 29th of June, 2016 respectively.


**Fig. 1: Map of Minna**

Source: Olaxxy consult (2016)

**Soil Analysis**

One soil sample was taken (up to 50cm) randomly on the plot to determine irrigation parameters of the scheme as shown in Appendix 2-10. The soil and water parameters determined include moisture content on dry basis, specific gravity of the soil, water holding capacity of the soil, total depth of water, water in the root zone, soil moisture deficit, quantity of water applied to the crop field and irrigation interval as follows:

(i) Moisture content (dry basis) in the month of March and June. Moisture content on dry basis was estimated at different soil depth in the month of March and June as shown in equation 1 below.

$$M.C_{dry\ basis} = \frac{Weight\ of\ water\ removed\ from\ soil\ after\ oven\ dry}{Weight\ of\ oven\ dry\ soil} \times 100 \qquad (1)$$

(ii) Specific gravity of soil in the month of March and June

Specific gravity of the soil was estimated in the month of March and June as shown in equation 2 below.

$$\text{Specific gravity of the soil (G)} = \frac{W_2 - W_1}{W_3 - W_1} \qquad (2)$$

Where,

$W_1$ = Weight of the volumetric flask (g)

$W_2$ = weight of the volumetric flask and oven dried soil (g)

$W_3$= weight of the volumetric flask and distilled water (g)

(iii) Water holding capacity of the soil

Water holding capacity was estimated in the month of March and June using equation 3 below.

$$\text{Water holding capacity of the soil} = \frac{Total\ water\ in\ the\ wet\ soil}{Oven\ dry\ weight\ of\ the\ total\ soil} \times 100 \qquad (3)$$

(iv) Total depth of water in the root zone

The depth of water in the root zone from $0 - 0.25m$ and $0.25 - 0.5m$ were estimated in the month of March and June using equation 4 below.

$$D = (A_s) \times (D) \times (P) \qquad (4)$$

Where,

$A_s$ = apparent specific gravity

$D$ = difference in soil depths (0 to 0.5m and 0.25 to 0.5m)

$P$ = moisture content value (0 to 0.5m and 0.25 to 0.5m)

Therefore, the total depth of water in the root zone equals the water retained at different soil depths in the month of March and June respectively.

(v) Water in the root zone

The study estimated water in the root zone using the equation 5 below.

$$\text{Water in the root zone} = \frac{water\ holding\ capacity\ of\ the\ soil}{100} \times \text{root zone depth of spinach} \qquad (5)$$

(vi) Soil moisture deficit/ irrigation depth

Soil moisture deficit or depth of irrigation was calculated using equation 6 below.

$$\text{soil moisture deficit} = \text{water in the root zone} - \text{total depth of water in the root zone} \qquad (6)$$

(vi) Quantity of water applied to the crop field

The study estimated the quantity of water using equation 7 below.

$$\text{The quantity of water applied} = Area\ of\ the\ field \times total\ depth\ of\ water\ in\ the\ root\ zone \qquad (7)$$

(vii) Irrigation interval

The study determined irrigation interval of spinach using equation 8 below.

$$\text{Irrigation interval} = \frac{Depth\ of irrigation}{Peak\ Evapotranspiration} \qquad (8)$$

### Evapotranspiration measurement and Data Collections

The evaporation pan used for this study was calibrated at the Department of Agricultural and Bioresources Engineering, Federal university of Technology Minna. This pan was made of stainless steel with a dimension of 25mm in height and 290mm in diameter. The study obtained daily evapotranspiration rates of spinach in the month of March and June 2016 after 24 hours by subtracting the depth of water left in the evaporation pan from the initial depth of water in the pan. In addition, the study obtained daily minimum and maximum temperature data from the Nigerian Meteorological Agency (NIMET) between the month of March and June, 2016.

### Determination of reference Evapotranspiration using Class A pan

The evaporation Pan equation is as follows:

$$ET_c = K_{pan} \times E_{pan} \quad (9)$$

Where $ET_o$ = crop evapotranspiration

$K_{pan}$ = pan coefficient

$E_{pan}$ = pan evaporation

The crop Evapotranspiration computed using evaporation Pan was compared with Blaney-Criddle and Thorntwaite equations so as to examine the variation between the selected methods of Evapotranspiration. The Blaney-Criddle and Thornthwaite equations used to compute evapotranspiration (Grace and Quick, 1988) were shown in equation 10 – 13.

$$ET_o(\text{Blaney-Criddle}) = p\,(0.46T_{mean} + 8) \quad (10)$$

Where $T_{mean}$= mean monthly temperature in °C

$ET_c$= crop Evapotranspiration

$P$= mean monthly percentage of maximum possible day time hours of the year

$$ET_c\ (\text{Thornthwaite}) = 16.0 \times (\frac{10t}{I})^a \quad (11)$$

Where $ET_c$= crop evapotranspiration in mm/day

$t$= mean monthly temperature in °C

I is the "heat index" for the 12 months in a year, given by

$$I = \sum i = \sum(\frac{t}{5})^{1.514} \quad (12)$$

$$a = (6.75\times 10^{-7} \times I^3) - (7.71\times 10^{-5} \times I^2) + (1.792 \times 10^{-2} \times I^1) + (0.49239) \quad (13)$$

### Data Analysis

The computed $ET_c$ pan evaporation, $ET_c$ Blaney-Criddle and $ET_c$ Thornthwaite were subjected to descriptive statistics and analysis of variance and Duncan test. The results of the analysis were presented in Tables and charts.

## Result and Discussion

### Determination of irrigation interval

Table 1 shows the irrigation interval of spinach in the month of March and June. Before irrigation, the irrigation depth in the month of March and June were estimated to be 10.84mm and 10.78 mm respectively. The quantities of water estimated and applied throughout the month of March and June were 1200 litres and 800 litres respectively. The irrigation intervals in the month of March and June were estimated to be 3 days and 4 days respectively. This work concurs with the Asia farming (2015). This implies that both months (i.e. March and June) had the same depth of irrigation and the rate of evapotranspiration was higher in the month of March as compared to June. This was attributed to higher temperature and relative humidity. However, the month of June had delay in rainfall. This simply means that the amount of water required to bring the soil moisture content to field capacity in the month of March was slightly different from that of June.

**Table 1: Irrigation Interval of Spinach during the Month of March and June**

| Month | Quantity of water applied to the Spinach plot (litre) | Depth of irrigation (mm) | Irrigation interval (days) |
|---|---|---|---|
| March | 1200 | 10.84 | 3 |
| June | 800 | 10.78 | 4 |

**Comparison of $ET_c$ between Different Methods in the month of March**

Table 2 shows statistical comparison of the evapotranspiration rate of spinach in the month of March. Thornthwaite had the highest $ET_c$ in the month of March followed by Pan evaporation while Blaney-Criddle had the least value. There was no close relationship in terms of pattern between the Thornthwaite $ET_c$ and temperature values as shown in Fig. 4. Also, Fig. 4 show that the higher the temperature values, the higher the Thornthwaite $ET_c$ and vice versa. This finding agrees with the work of Maina *et al*., (2012). Also, there exist a close relationship between pan evapotranspiration and Blaney-Criddle evapotranspiration as shown Fig. 2 which implies that apart from pan evaporation method, Blaney-Criddle could be used in the study area. This finding disagrees with the work of Maina *et al*., (2012). The daily Pan evapotranspiration, Blaney-Criddle evapotranspiration and Thornthwaite evapotranspiration obtained were analyzed in a randomized complete block design where each method stands as treatments and the days as blocks. Based on analysis of variance (ANOVA) results, there was a significant difference between the methods as the calculated F value (0.001073) tested significant at 95% confidence level. According to the Duncan Alpha test (at 95% confidence level), the three methods were statistically different as shown in Table 2.

**Table 2: Statistical Comparison of the Evapotranspiration Rate of Spinach in the Month of March**

| | | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean Lower Bound | 95% Confidence Interval for Mean Upper Bound | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| March A | Pan | 11 | $2.23^{a}$ | 0.283 | 0.085 | 2.04 | 2.42 | 2 | 3 |
| | Blaney –Criddle | 11 | $0.39^{b}$ | 0.131 | 0.040 | 0.31 | 0.48 | 0 | 0 |
| | Thornthwaite | 11 | $6.11^{c}$ | 0.198 | 0.060 | 5.97 | 6.24 | 6 | 6 |
| | Total | 33 | 2.91 | 2.428 | 0.423 | 2.05 | 3.77 | 0 | 6 |
| March B | Pan | 11 | $1.40^{a}$ | 0.000 | 0.000 | 1.40 | 1.40 | 1 | 1 |
| | Blaney-Criddle | 11 | $0.44^{b}$ | 0.008 | 0.002 | 0.43 | 0.44 | 0 | 0 |
| | Thornthwaite | 11 | $6.21^{c}$ | 0.077 | 0.023 | 6.15 | 6.26 | 6 | 6 |
| | Total | 33 | 2.68 | 2.563 | 0.446 | 1.77 | 3.59 | 0 | 6 |
| March C | Pan | 11 | $0.83^{a}$ | 0.526 | 0.158 | 0.47 | 1.18 | 0 | 1 |
| | Blaney-Criddle | 11 | $0.43^{b}$ | 0.017 | 0.005 | 0.41 | 0.44 | 0 | 0 |
| | Thornthwaite | 11 | $6.08^{c}$ | 0.173 | 0.052 | 5.97 | 6.20 | 6 | 6 |
| | Total | 33 | 2.45 | 2.635 | 0.459 | 1.51 | 3.38 | 0 | 6 |

Mean value with same superscript are significantly different

**Comparison of $ET_c$ between Different Methods in the Month of June**

Table 3 shows statistical comparison of the evapotranspiration rate of spinach in the month of June. Thornthwaite had the highest $ET_c$ in the month of June followed by Blaney-Criddle and Pan evaporation. There was no close relationship in terms of pattern between the Thornthwaite $ET_c$ and temperature values as shown in Fig. 5. Also, Figure 5 show that the higher the temperature values, the higher the Thornthwaite $ET_c$ and vice versa. This finding agrees with the work of Maina *et al.*, (2012). Also, there exist a close relationship between Pan evapotranspiration and Blaney-Criddle evapotranspiration as shown in Fig. 3 which implies that apart from Pan evaporation method, Blaney-Criddle could be used in the study area. This finding disagrees with the work of Maina *et al.*, (2012). The daily Pan evapotranspiration, Blaney-Criddle evapotranspiration and Thornthwaite evapotranspiration obtained were analyzed in a randomized complete block design where each method stands as treatments and the days as blocks. Based on ANOVA results, there was significant difference between the methods as the calculated F value (0.002803) tested significant at 95% confidence level. According to the Duncan Alpha test (at 95% confidence level), the three methods were statistically different as shown in Table 3.

**Table 3: Statistical Comparison of $ET_c$ Means between Different Methods in the month of June**

| | | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound | | |
| June A | Pan | 11 | $0.13^a$ | 0.283 | 0.085 | -0.06 | 0.32 | 0 | 1 |
| | Blaney-Criddle | 11 | $0.37^b$ | 0.008 | 0.002 | 0.37 | 0.38 | 0 | 0 |
| | Thornthwaite | 11 | $5.35^c$ | 0.124 | 0.037 | 5.26 | 5.43 | 5 | 5 |
| | Total | 33 | 1.95 | 2.447 | 0.426 | 1.08 | 2.82 | 0 | 5 |
| June B | Pan | 11 | $1.27^a$ | 0.283 | 0.085 | 1.08 | 1.46 | 1 | 1 |
| | Blaney-Criddle | 11 | $0.39^b$ | 0.004 | 0.001 | 0.39 | 0.39 | 0 | 0 |
| | Thornthwaite | 11 | $5.56^c$ | 0.053 | 0.016 | 5.52 | 5.59 | 5 | 6 |
| | Total | 33 | 2.41 | 2.297 | 0.400 | 1.59 | 3.22 | 0 | 6 |
| June C | Pan | 11 | $1.97^a$ | 0.283 | 0.085 | 1.78 | 2.16 | 1 | 2 |
| | Blaney-Criddle | 11 | $0.40^b$ | 0.007 | 0.002 | 0.40 | 0.40 | 0 | 0 |
| | Thornthwaite | 11 | $5.73^c$ | 0.090 | 0.027 | 5.67 | 5.79 | 6 | 6 |
| | Total | 33 | 2.70 | 2.278 | 0.396 | 1.89 | 3.51 | 0 | 6 |

Mean value with same superscript are significantly different

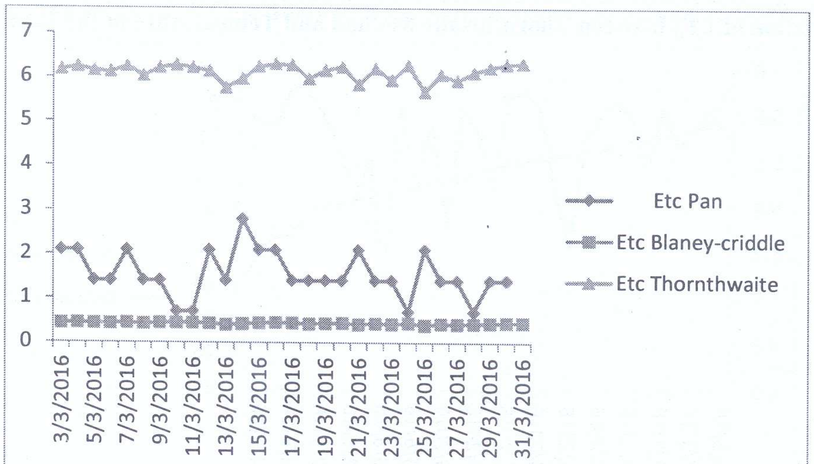


**Fig. 2: $ET_o$ of Various Methods in the Month of March.**

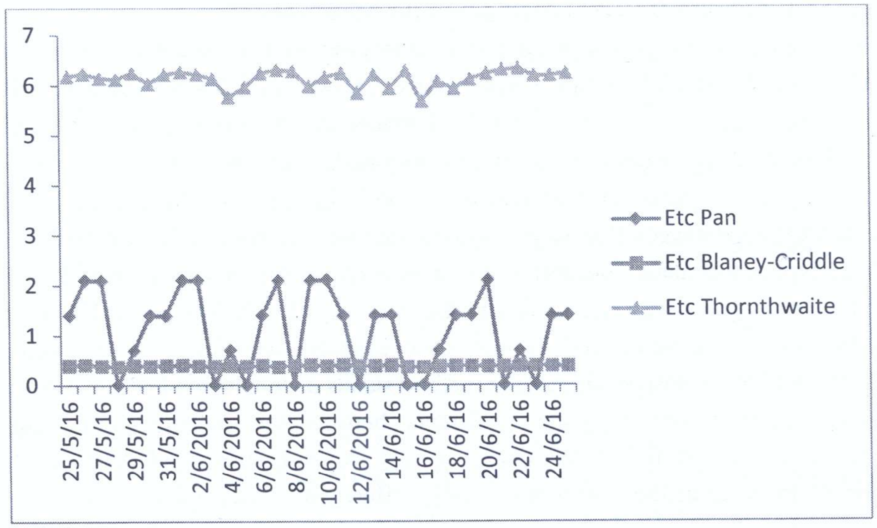


**Fig. 3: $ET_o$ of Various Methods in the Month of June.**

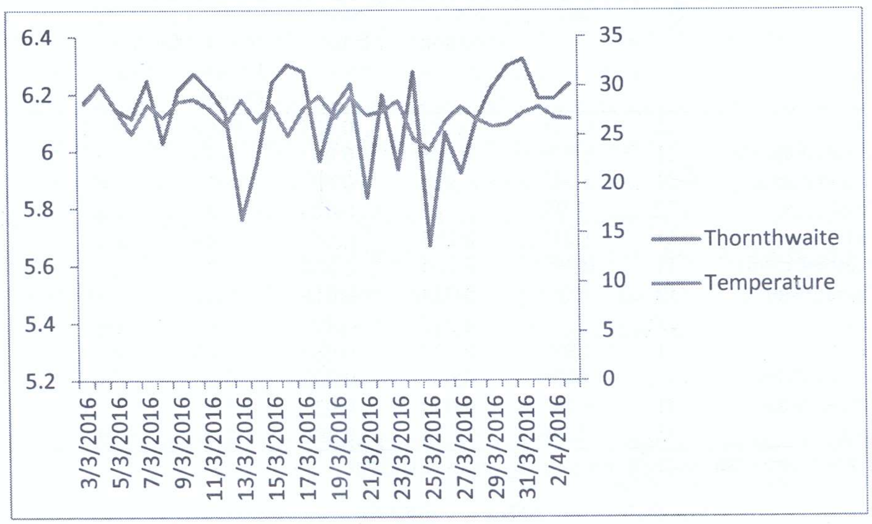


**Fig. 4: Variation of $ET_o$ between Thornthwaite Method and Temperature in the Month of March**

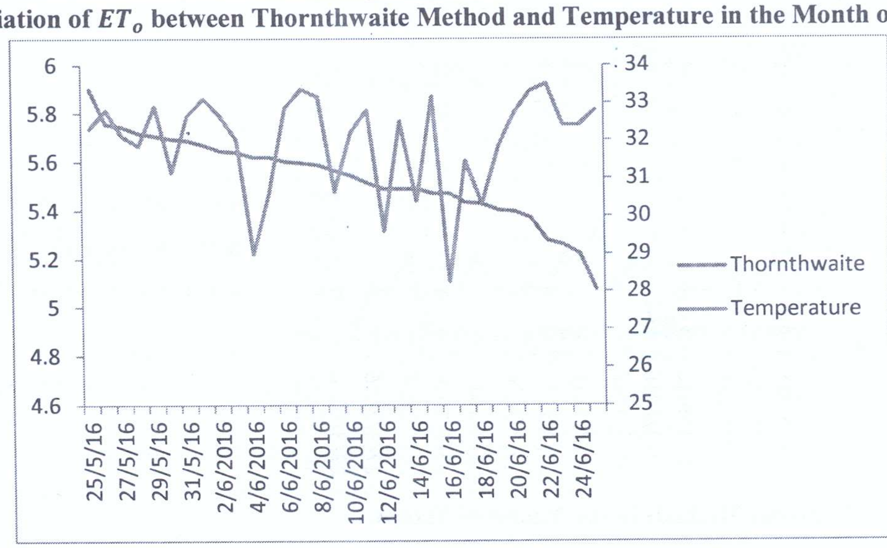


**Fig. 5: Variation of $ET_o$ between Thornthwaite Method and Temperature in Month of June**

## Conclusion

Crop evapotranspiration rates for spinach in Minna, Niger State was assessed using pan evaporation with the aim of determining the optimum evapotranspiration loss on spinach field in Minna, and also to compare the estimated Pan evapotranspiration with Blaney-Criddle and Thornthwaite evapotranspiration methods. The evapotranspiration losses on spinach field in the month of March and June were 2.8mm/day and 2.38mm/day respectively. The study concluded that the evapotranspiration loss on spinach field in the month of March was higher than the month of June with the same depth of irrigation. Also, pan evaporation gives optimum evapotranspiration results followed by Blaney-Criddle and Thornthwaite method.

## Reference

Abubaker, J. (2009). Irrigation scheduling for efficient water use in dry climates. Master's thesis submitted to Swedish University of Agricultural Sciences. Retrieved from http://stud.epsilon.slu

Afolabi, S. G., Adeboye, M. K. A., Lawal, B. A., Adekanmbi, A. A., Yusuf, A. A. &Tsado, P. A. (2014). Evaluation of some soils of minna southern Guinea Savanna of Nigeria for arable crop production. *Nigerian Journal of Agriculture, Food and Environment*, 10(4):6-9.

Asia farming (2015). Information guide. Retrieved on 25th August, 2016 from http://www.asiafarming.com

Ding, R., Kang, S., Li, F., Zhang, Y., & Tong, L. (2013). Evapotranspiration measurement and estimation using modified Priestley–Taylor model in an irrigated maize field with mulching. *Agricultural and Forest Meteorology*, *168*, 140-148.

Ertek, A. (2011). Importance of pan evaporation for irrigation scheduling and proper use of crop-pan coefficient (Kcp), crop coefficient (Kc) and pan coefficient (Kp). *African Journal of Agricultural Research*, *6*(32), 6706-6718.

Fu, G., Charles, S. P., & Yu, J. (2009). A critical overview of pan evaporation trends over the last 50 years. *Climatic Change*, *97*(1-2), 193-214.

Grace, B. & Quick, B. (1988). A Comparison of Methods for the Calculation of Potential Evapotranspiration under the Windy Semi-arid Conditions of Southern Alberta.*Canadian Water Resources Journal / Revue canadienne des ressourceshydriques*, 13:1, 9-19, doi: 10.4296/cwrj1301009

Maina, M. M., Amin, M. S. M., Aimrun, W., & Asha, T. S. (2013). Evaluation of Different ET0 Calculation Methods: A Case Study in Kano State, Nigeria. *The Philippine Agricultural Scientist*, *95*(4).