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# Effect of Planting Season on Phenology and Accumulated Heat Units in Relation to Yield of White Yam in the Tropical Wet- and-Dry Climate

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## ABSTRACT

Field experiment was carried out to study the effect of phenology and accumulated heat units of white yam (*Dioscorea rotundata*) in different seasons. White yam was cultivated during early ($T_1$) and late ($T_2$) cropping seasons of 2011 and 2012. Rainfall-potential evapotranspiration (P-PE) model according to Cocheme and Franquin (1967) was followed to determine planting dates. The observations on days required for attainment of different phenological stages viz., establishment, vine elongation, vegetative, bulking and senescence were recorded. Heat units such as Growing Degree Days (GDD), Photo Thermal Units (PTU), Helio Thermal Units (HTU), Relative Temperature Disparity (RTD), Heat Unit Efficiency (HUE), Photo Thermal Index (PTI) and seasonal efficiency were worked for different seasons of white yam and related to different phenological stages of growth and yield. The results revealed that among the different indices, GDD, HTU, PTU and RTD does not influence the phenolgical stages of growth whereas HUE, PTI and seasonal efficiency had great influence on yield of white yam. Thus, the indices such as HUE, PTI and seasonal efficiency are seem to be effective in taking into account and expressing the effect of varying ambient temperature on the duration between the phenological events for comparing the white yam response to the ambient temperature between different phenological stages.

**Keywords**: White Yam, Planting Season, Tropical Wet-Dry Climate.

## INTRODUCTION

The major climatic parameters involved in crop production are rainfall, temperature, light, and photoperiod (Orkwor *et al.*, 1998; Ekaputa, 2004). However, temperature plays a critical role in almost all biological processes of yam production (Girijesh *et al.*, 2011). It is one of the most important climatic events affecting the growth, phenology, development and yield of yam in the tropical wet- and – dry climate (Maduakor *et al.*, 1984; Okoh, 2004, Inyang, 2005). Yam (*Dioscorea rotundata*) apart from being important as a source of energy in the diets of millions of people and some livestock (Scott *et al.*, 2000), it also has cultural and socio-economic significance (Hahn *et al.*, 1988). Though there are ample evidences that tuber yields are better when the crop is sown during dry season (Okoh, 2004 and Inyang, 2005), excessive heat which may arise from dry spells following occasional wet days during the period from planting until emergence causes partial drought which usually lead to loss of setts and disparity in emergence. Influence of different time of sowing as well as temperature on phenology and yield of crop plants can be

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studied under field conditions through the accumulated heat units system (Bishnoi *et al*., 1995, Girijesh *et al*., 2011 and Thavaprakaash, *et al*., 2007). Crop model can be developed for large areas to forecast the phenology and crop production attributes (Thavaprakaash, *et al*., 2007). The accuracy in prediction depends on the assessment of rate of plant development at each growth stage during the growing season. The influence of high temperature stress on the heat unit requirement of crops should be assessed in a larger area as the temperature of farms in a zone varies considerably. The relationship of phenological development of white yam with thermal units under different seasons was studied in the present investigation.

## MATERIALS AND METHODS

The field experiments were conducted at the Teaching and Research farm of University of Agriculture along Alabata road, Abeokuta (7$^{o}$ 15'N, 3$^{o}$25'E) in Odeda Local Government Area of Ogun State, South Western Nigeria (fig. 1) during the 2011 and 2012 cropping seasons. The study area is characterized by a tropical climate with distinct wet and dry seasons with bimodal rainfall pattern and mean annual air temperature of about 30$^{o}$C. The actual rainfall totals during the 2011 and 2012 cropping season were 1177.2 and 1201.6mm, respectively. The soil at the experimental site was categorized as a well-drained tropical ferruginous soil. The A horizon of the soil is an Oxic Paleudulf of the Iwo series with 83% sand, 5% silt and 12 % clay with a pH of 6 considered tolerable by yam cultivation (Olasantan, 2007).

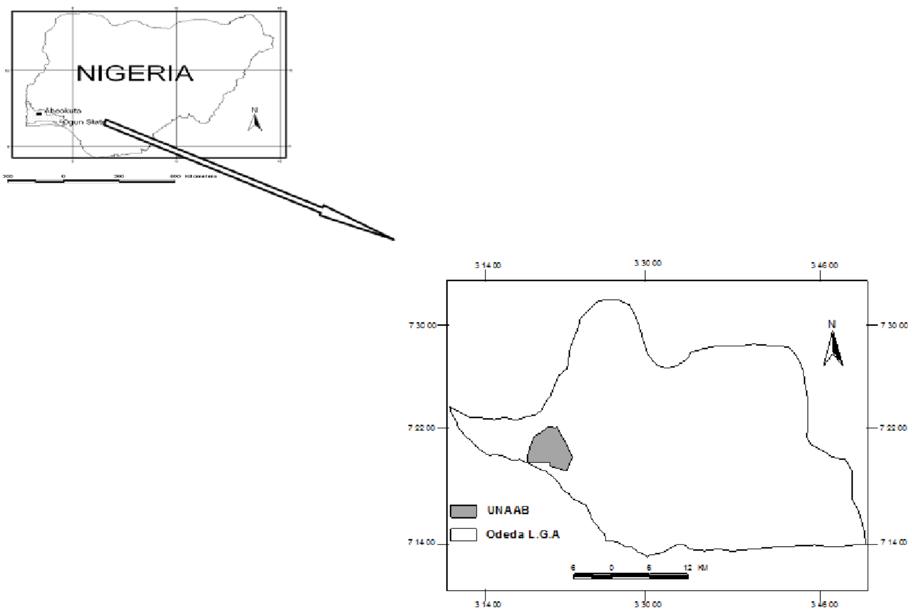



**Fig. 1: Location of University of Agriculture, Abeokuta within Odeda Local Government Area in Ogun State, Southwestern Nigeria.**

### *Experimental design and field measurement*

The experimental site had previously carried beans and groundnut intercrop but had been fallowed for over 3 years (from 2008-2010). The site was cleared manually using cutlass in November 2010, in preparation for the 2011 cropping following the popular practice by the farmers in the study area. This period marks the preparatory period for the cultivation of early yam planting in the study area. The experimental design was a split-plot within a randomized complete block design with three replicates. The mainplots were planting dates with subplots being varieties. Yam mounds were made manually using African hoe during the two experimental years. The mounds were of height 60cm and spaced 1.5 x 1.5m$^2$ with a walk way of 1m between adjacent rows. The mound tillage system was selected for the study not only because it is the most widely used method in the study area, but also because it improves soil aeration and hydrothermal conditions for crop emergence, root development, crop growth and yield (Kutugi, 2002).

During each year of study, rainfall-potential evapotranspiration (P-PE) model according to the procedure of Cocheme and Franquin (1967) was followed to determine planting date. The model used in this study was formulated to incorporate farmer's conventional calendar for yam cultivation. Consequently, planting date was selected based on the following general model:

$0.1PE < P < 0.5PE$

where

PE = Potential evapotranspiration

P = Rainfall

0.1PE = One tenth of the potential evapotranspiration

0.5PE = Half the potential evapotranspiration

Two specific planting dates ($T_1$ & $T_2$) generated from the general model above is as below:

$\Sigma(P-0.1PE) \leq 0$ ………….. $T_1$

$\Sigma(P-0.5PE) \leq 0$ …………… $T_2$

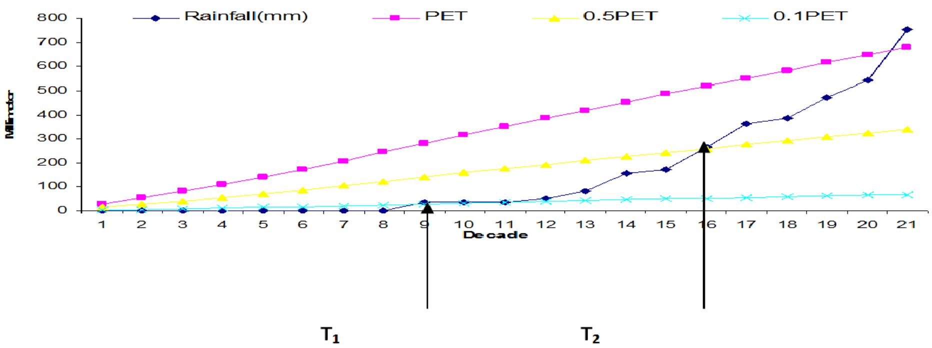
Where

$\Sigma(P-0.1PE) \leq 0$ = accumulated difference between rainfall (P) and one tenth of the potential evapotranspiration (PE) is zero

$\Sigma(P-0.5PE) \leq 0$ = accumulated difference between P and half PE records zero

The terms P, PE, 0.1PE and 0.5PE are as previously defined.

It follows that the two planting dates ($T_1$ & $T_2$) in each experimental years were determined from the model as shown in Fig. 2 & 3.




Where PET = Potential Evapotranspiration

$T_1$ = date of 1st planting according to P-PE model

$T_2$ = date of 2nd planting according to P-PE model

**Fig. 2: Planting dates as determined by using decadal cumulative rainfall– potential evapotranspiration (P-PE) model in 2011 growing season.**

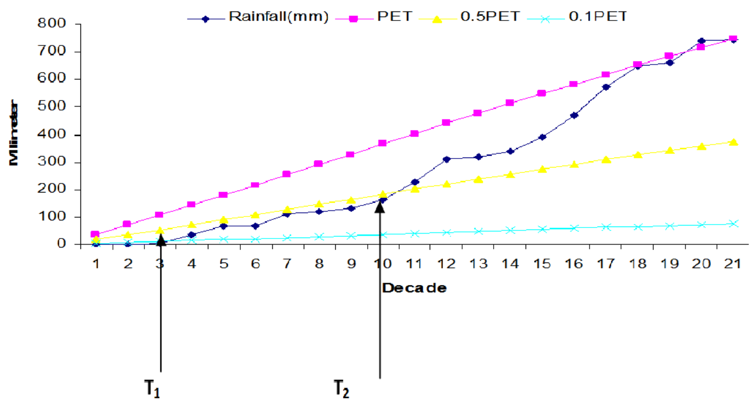



**Fig. 3: Planting dates as determined by using decadal cumulative rainfall – potential evapotranspiration (P-PE) model in 2012 growing season.**

For instance, the planting dates for the 2010-2011 experimental year are as below

$T_1 = \Sigma(P\text{-}0.1PE) \leq 24$ = March 22 which fell in the 9th decade of 2011

$T_2 = \Sigma(P\text{-}0.5PE) \leq 259$ = June 5 which fell in the 16th decade of 2011

Whereas the planting dates for the 2011-2012 experimental year happened to be:

$T_1 = \Sigma(P\text{-}0.1PE) \leq 10$ = January 21 which fell in the 3rd decade of 2012

$T_2 = \Sigma(P\text{-}0.5PE) \leq 182$ = April 6, 2012 which fell in the 10th decade of 2012

Using a new knife, tubers of each yam cultivar were cut into setts weighing an average of 550grams, and planted at an average depth of 15cm on mounds. After sprouting, the yams were staked to about 3m high and the vines were trained regularly. No fertilizer or insecticide was applied and all plots were regularly hand weeded. Bush rat was controlled by regular clearing of the surroundings of the project site. The climatic requirements of yam from planting to harvesting were measured according to phenological stages of the crop. In this study, the date of occurrences of different phenological events viz., establishment, vine elongation, vegetative, bulking and senescence were recorded when more than 50% of the plants in each replication reached the respective stages. The daily data on temperature (maximum and minimum) and bright sunshine hours during the crop season were obtained from meteorological enclosure adjacent to the experimental field. The day length details were obtained from FAO (1977). Yam development and yield components recorded during early seasons (T1) and late season (T2) for each trial were used for calculations. The heat units were calculated as follows:

$$GDD = \sum_{i=1}^{n} \frac{(\mathrm{Tmax} + \mathrm{Tmin})}{2} - \mathrm{Tb}$$

$$HTU = \sum_{i=1}^{n} \mathrm{GDD \times SSH}$$

$$PTU = \sum_{i=1}^{n} \mathrm{GDD \times Daylength}$$

$$RTD = \sum_{i=1}^{n} \frac{(\mathrm{Tmax} - \mathrm{Tmin})}{\mathrm{Tmax}} \times 100$$

HUE = Yield ÷ GDD (Haider et al., 2003)

PTI = GDD ÷ Growingdays (Haider et al., 2003

Seasonal Efficiency = (Yield of a season ÷ Mean yield of all season) x100

Where,

GDD= Growing Degree Days

HTU= Helio Thermal Units

PTU = Photo Thermal Units

RTD = Relative Temperature Disparity

HUE= Heat Use Efficiency

PTI = Photo Thermal Index

Tmax= Maximum temperature (°C)

Tmin= Minimum temperature (°C)

Tb = Base temperature (°C) = 10°C

SSH = Bright sunshine hours

Data collected were subjected to analysis of variance (ANOVA) using GenStat Release 7.2 statistical software (Discovery Edition 3) to evaluate the effects of "planting season" on the phenophases and yield of yam. The significant difference of treatment means were determined using least significance difference (LSD) 5% level of probability. The strength of relationship between the heat units and phenophases of yam were determined using simple linear regression model of Steel and Torries (1988) to calculate the correlation coefficient of determination. Based on these analyses, the extent to which each of the thermal units parameter could significantly predict the growth and yield of yam was assessed.

## RESULTS AND DISCUSSION

### Days required for phenological stages of development

Quicker attainment of phenological stages was noticed during late planting season whereas it was delayed during early planting season of 2011 and 2012 trials as shown in Figure 4, though the attainment of phenological stages during the early growing season was associated with the late season planting having coefficient of variability of $R^2 = 0.99$ indicating that this parameter reflects no significant variation as observed in Table 1. Higher amount of solar radiation and higher daily mean temperature recorded during dry (early planting) growing season which increases the evaporation rate and consequently reducing soil moisture might have induced the late attainment of phenological stages of yam (Thavaprakaash, *et al*., 2007). On the other hand, during late planting (wet) 2011 and- 2012 season, the crop was sown during the early establishment of rain in April month, the days were about 10 -20 decades shorter during most of its crop growth in the early planting and the daily mean temperature was very low (average of 26°C). Both high mean temperature and short day length during the early planting delayed all phenological stages of development including crop establishment. Variation of phenological stages during different time of sowing was reported earlier (Olasantan, 2007).

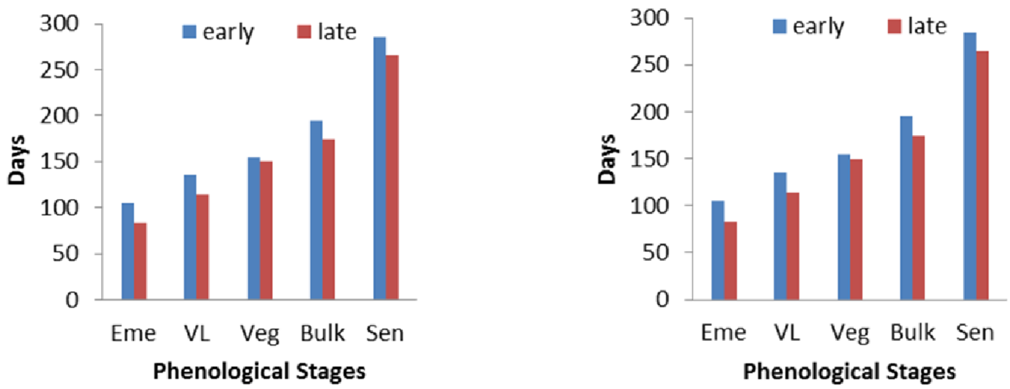
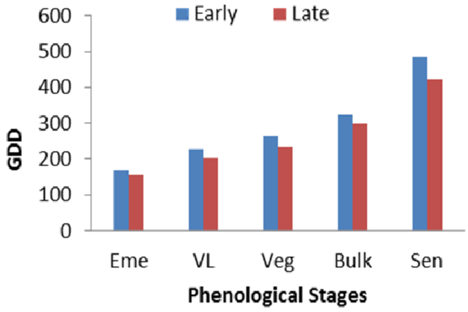


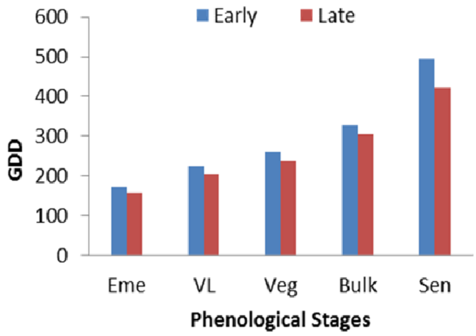

**Fig. 4:Days taken for different phenological stages of yam as influenced by different growing seasons during 2011 and 2012 trials**

**Growing Degree Days (GDD)**

Heat units required to attain individual stages varied with different seasons (Fig.5). The required degree days during early 2011 and 2012 seasons were higher than those of late seasons in all stages of growth. However, for both seasons, all the stages required only minimum heat units to attain the stages except for the senescence. High temperature during the early stage of yam phenology at both early and late season might have influenced for shorter GDD in these stages. This implies that during early stages of growth of both years, the climatic requirements might be optimum and hence GDD requirements were low. However, the GDD and yam phenological stages during the early growing season has a stronger correlation than the late season although they both had very low coefficient of variability of $R^2 \leq 0.20$ as shown in tables 1.




2011




2012

**Fig. 5:Accumulated growing degree days (GDD) of yam as influenced by different seasons at different phenological stages during 2011 and 2012 trials**

**Table 1. Linear regression between dominant Accumulated Heat Units and the Phenological stages of yam at different seasons.**

| **Dominant Accumulated Heat Units** | | **Coefficient of determination ($r^2$)(%)** | | **Coefficient of determination ($r^2$)(%)** |
|---|---|---|---|---|
| | **2011** $T_1$ | $T_2$ | **2012** $T_1$ | $T_2$ |
| Days to Phenology | 0.98 | 0.99 | 0.99 | 0.99 |
| GDD | 0.18 | 0.03 | 0.20 | 0.05 |
| HTU | 0.01 | 0.12 | 0.14 | 0.28 |
| PTU | 0.19 | 0.06 | 0.13 | 0.03 |
| RTD | 0.48 | 0.28 | 0.02 | 0.05 |
| PTI | 0.65 | 0.36 | 0.24 | 0.17 |

**Helio Thermal Units (HTU)**

Figure 6 shows that there is seasonal variation in HTU required for attaining different phenological stages. Table 1 showed that late planting has higher correlation between HTU and phenological stages than early season in both trials. Late planting favored the emergence, vine elongation and vegetative stages while early planting favored bulking and senescence stages in particular during the 2011 cropping season that witness high rate of heat (Tables 2 & 3) despite the application of mulch as required for yam cultivation. The high rate of heat stress significantly ($P < 0.05$) increased emergence rate of yam by 46% and tuber yield by about 6-8 tonnes $ha^{-1}$ $season^{-1}$. This finding agreed with previous report that the emergence and growth rate of yam seedling were observed to be significantly higher in mulched plots (high rate of heat conserved) than the un-mulched plot by Olasantan 1999 and Odjugo,2008. Increased emergence and more rapid development of setts in yams could be attributed to an increase in soil moisture content and the consequent modification of soil temperature by the use of mulch (Maduakor et al.,1984; Okoh, 2004; Inyang, 2005).

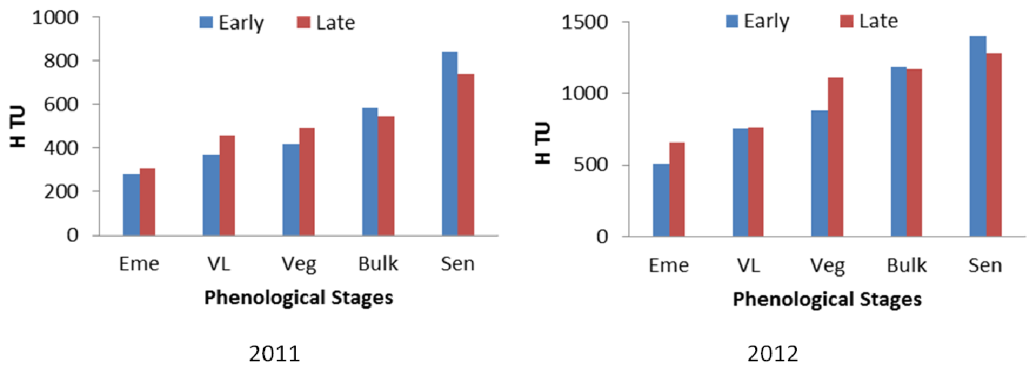



**Fig. 6: Accumulated Helio thermal units (HTU) of yam as influenced by different seasons at different phenological stages during 2011 and 2012 trials**

**Table 2. Effect of planting date on growth of three white yams grown at Abeokuta during 2011 cropping season**

| Factor | Emer. % | Vine length (cm ) | No. branch | No. leaves | No. roots | Vine Ø (cm ) | Branch length (cm ) | Root length (cm) | LAI |
|---|---|---|---|---|---|---|---|---|---|
| Planting season | | | | | | | | | |
| $T_1$ | 54.6±5.57 | 137.6±22.9 | 21.8±2.04 | 776.3±98.74 | 24.3±2.33 | 1.424±0.06 | 68.7±5.66 | 32.8±2.58 | 1.396±0.32 |
| $T_2$ | 31.7±4.83 | 15.3±4.38 | 15.2±1.92 | 191.6±29.76 | 16.2±1.67 | 1.352±0.05 | 59.6±5.60 | 24.5±1.94 | 0.141±004 |
| P | <0.001* | <0.001* | 0.017** | <0.001* | 0.009* | 0.266 | 0.217 | 0.016** | <0.001* |

*Significant at P< 0.01 **Significant at P< 0.05

**Table 3.Effect of planting date on growth of three white yams grown at Abeokuta during 2012 cropping season**

| Factor | Emer % | Vine length (cm ) | No. branch | No. leaves | No. roots | Vine Ø (cm ) | Branch length (cm ) | Root length (cm) | LAI |
|---|---|---|---|---|---|---|---|---|---|
| Planting Date | | | | | | | | | |
| $T_1$ | 74.0+4.13 | 381+40.29 | 25.1+2.97 | 568.1+57.22 | 29.4+2.82 | 1.465+0.05 | 94+9.13 | 35.5+2.60 | 1.230+0.17 |
| $T_2$ | 68.5±4.6 | 357±28.03 | 19.4±2.58 | 332.6±28.65 | 21.5±2.19 | 1.348±0.06 | 62.7±5.92 | 28.2±2.02 | 0.628±0.10 |
| P | 0.205 | 0.424 | 0.121 | <0.001* | 0.05** | 0.109 | 0.008* | 0.044** | <0.001* |

*Significant at P< 0.01 **Significant at P< 0.05

The crop required more days to pass each phenological stage, increased the day hours and in turn HTU. The HTU requirement was lower to attain different stages during early and late planting of 2011 than 2012 growing seasons. The days taken to complete each stage is minimum and lower values of degree days which in turn reduced the HTU. This reflected in the yield levels as shown in tables 4 and 5 with early and late 2012 significantly (p< 0.01) higher values than 2011 seasons.

**Table 4. Effect of planting date on yield and yield characteristic of white yams grown at Abeokuta during 2011 cropping season**

| Factor | Tuber length (cm) | Tuber diameter (cm ) | Tuber weight (kg) | No of tuber | Harvest yield ton/ha |
|---|---|---|---|---|---|
| Planting Date | | | | | |
| $T_1$ | 30.0±2.73 | 8.30±0.73 | 2.60±0.25 | 1.019±0.13 | 8.04±1.17 |
| $T_2$ | 9.4±2.48 | 2.59±0.67 | 0.58±0.16 | 0.370±0.95 | 1.42±0.41 |
| P | < 0.001* | < 0.001* | < 0.001* | < 0.001* | < 0.001* |

*Significant at P< 0.01 **Significant at P< 0.05

**Table 5. Effect of planting date on yield and yield characteristic of three white yams grown at Abeokuta during the 2012 cropping season**

| Factor | Tuber length (cm) | Tuber diameter (cm ) | Tuber weight (kg) | No of tuber | Harvest yield ton/ha |
|---|---|---|---|---|---|
| Planting Date | | | | | |
| $T_1$ | 37.7±2.13 | 11.49±0.644 | 3.55±0.24 | 1.133±0.06 | 12.70±1.16 |
| $T_2$ | 34.7±1.56 | 11.14±0.43 | 3.13±0.18 | 1.115±0.03 | 10.71±1.14 |
| P | 0.223 | 0.575 | 0.098 | 0.764 | 0.043** |

*Significant at P< 0.01 **Significant at P< 0.05

*Significant at P< 0.01 **Significant at P< 0.05

**Photo Thermal Units (PTU)**

Heat units in terms of bright sunshine hours varied to complete each phenological stage of yam over seasons (Fig. 7). The PTU values were maximum to attain each stage of the crop during early season of 2011 and 2012 and minimum during late seasons. The early season crop completed its life cycle early; the bright sunshine hours during February-June months were higher which increased the PTU. Whereas during late seasons, lower duration coupled with less sunshine hours ultimately reduced the PTU values.

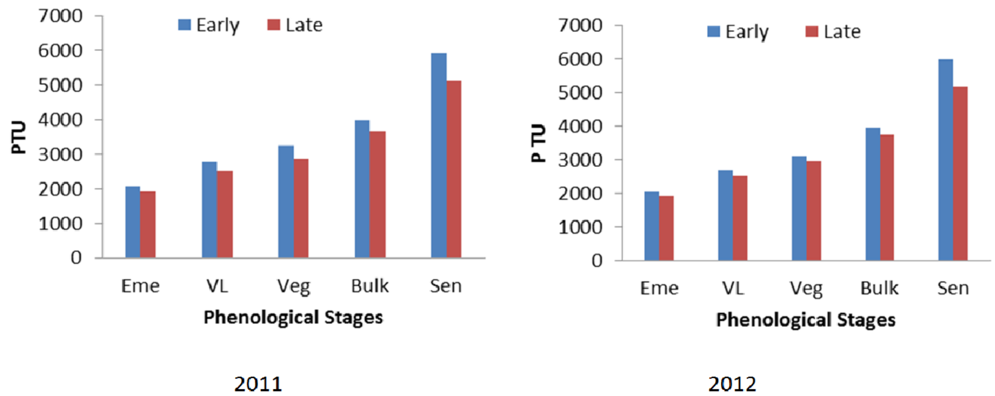



**Fig. 7: Accumulated Photo thermal units (PTU) of yam as influenced by different seasons at different phenological stages during 2011 and 2012 trials**

**Relative Temperature Disparity (RTD)**

Late 2011and 2012 seasons accumulated higher RTD values to attain each phenological stages of crop whereas lower values during early seasons for senescence (Fig. 8). Since the RTD values are dependent on maximum and minimum temperatures during different phenological stages, the late season crop took more days to pass every phenological stage in turn made more RTD values and during early season for senescence the results are different.

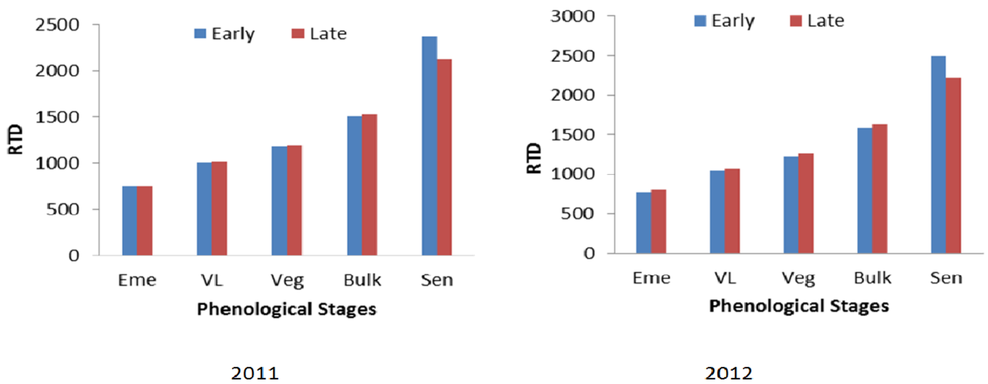



**Fig. 8: Accumulated Relative Temperature Disparity (RTD) of yam as influenced by different seasons at different phenological stages during 2011 and 2012 trials**

**Photo Thermal Index (PTI)**

Heat units required to pass from one stage to another varied among the seasons (Fig.9). The PTI values were conspicuously higher during late planting season except emergence stage during 2011 trial. Days required to attain the phenophases are lower in late season than early season planting and also relatively lower GDD values influenced higher PTI values in 2011trail and the yield determinant phenophase of bulking in 2012. Table 1 showed that the coefficient of determination R2 between PTI and the phenophases where higher in early planting season than late planting season.

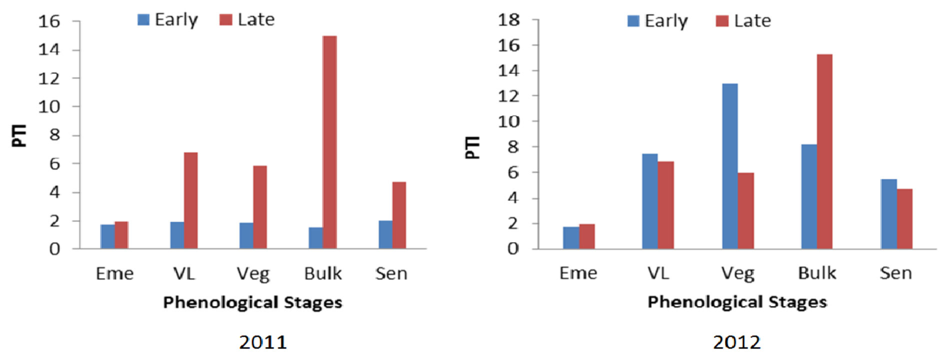



**Fig. 9: Photo Thermal Index (PTI) of yam as influenced by different seasons at different phenological stages during 2011 and 2012 trials**

**Heat Use Efficiency (HUE)**

The HUE-values (tuber yield per degree day) were calculated and presented in Fig. 10. Higher HUE values were recorded in early planting seasons than late. Higher HUE in this season could be attributed to the higher tuber yield during this period for both experimental years (Tables 4 & 5). As the temperature was optimum throughout the growing period, it utilized heat more efficiently and increased biological activity that confirms higher yield. Optimum mean temperature and short day length during early 2012 season resulted in highest tuber yield via optimum metabolic activities thereby highest HUE. In contrast, low temperature and higher duration to attain phenological stages during late planting 2011 season hampered normal biological activities resulted in lowest yield as well as lowest HUE. Similar relationship was also expressed by Paul and Sarkar (2000), Haider *et al*. (2003) and Thavaprakaash, *et al*., 2007 in different dates of sowing of crops.

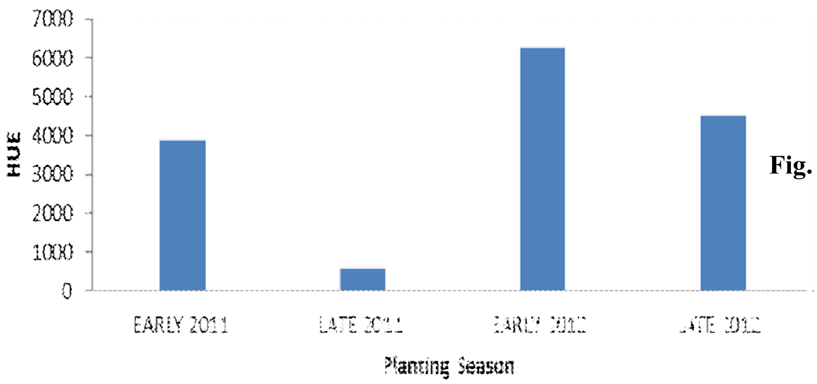



**Fig. 10: Effect of HUE of different seasons**

**Seasonal Efficiency**

Efficiency of different seasons was worked out and given in Fig. 11. The seasonal efficiency values were the highest in early 2012 planting season followed by late planting season of 2012 and early planting of 2011 seasons. All these seasons had efficiency values of more than 100 and hence suitable for raising white yam crop. However, during late planting of 2011 season, the seasonal efficiency value was <100 which expressed the non suitability of the season (Thavaprakaash, *et al*., 2007).

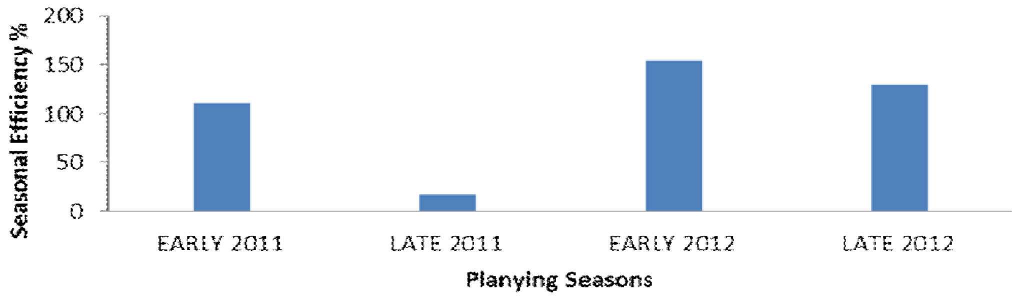



**Fig. 11: Effect of seasonal efficiency of different seasons**

**CONCLUSION**

The result of the present investigation indicates that changes in the ambient temperature for a short period reflected in all growth stages of white yam. The indices such as HUE, PTI and seasonal efficiency are seems to be effective in taking into account and expressing the effect of varying ambient temperature on the duration between the phenological events for comparing the crop response to the ambient temperature between different phenological stages. The differences in phenothermal indices for different growth stages indicated that the accumulated temperature could be utilized for studying biomass accumulation pattern at different phenological stages which ultimately influence the crop productivity.

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# تأثير موسم الزراعة على التركيب الفينولوجي ووحدات الحرارة المتراكمة في نبات اليام الأبيض وعلاقتها بالمحصول في المناطق الاستوائية ذات المناخ الرطب والجاف

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## ملخـــص

تم عمل تجارب حقلية لدراسة تأثير وحدات الحرارة المتراكمة والفينولوجيا في نبات اليام الأبيض ( Dioscorea rotundata) في الفصول المختلفة. تم زراعة نبات اليام الأبيض خلال الفصول المبكرة(T1) و المتاخرة (T2) من عامي 2011 و 2012. تم اتباع نموذج الأمطار المحتملة التبخر (P-PE) الموثق في المرجع ( Cocheme and Franquin ,1967) لتحديد موعد الزراعة. كانت المراقبة بالأيام مطلوبة لتحقيق المراحل الفيزيولوجية حيث تم أخذ القراءات لمراحل؛ الإنشاء، استطالة الساق، النمو الخضري، والإكثار و الشيخوخة في نبات اليام الأبيض. وحدات الحرارة مثل درجة النمو بالايام (GDD)، وحدات الحرارة الصورية (PTU)، وحدات الحرارة بالهيليو (HTU)، التفاوت النسبي في درجة الحرارة (RTD)، وحدة الكفاءة الحرارية (HUE)، المؤشر الحراري الصوري (PTI)، والكفاءة الفصلية تم عملها لفصول مختلفة لليام الابيض و المرتبطة بالمراحل الفينولوجية المختلفة و المتعلقه بالنمو والمردود الانتاجي. و قد تم الحصول على نتائج بأن المؤشرات المختلفة (درجة النمو بالايام (GDD)، وحدات الحرارة الصورية (PTU)، وحدات الحرارة بالهيليو (HTU)، التفاوت النسبي في درجة الحرارة (RTD)) لم تؤثر على المراحل الفينولوجية للنمو بينما (الكفاءة الحرارية (HUE)، المؤشر الحراري الصوري (PTI)) و الكفاءة الفصلية كان لها تأثير كبير على محصول اليام الأبيض. لذلك تعد المعاملات (HUE, PTI) و الكفاءة الفصلية من الأمور المهمة والفاعلة في التعبير عن تأثير تغير الحرارة المحيطة في الفترة ما بين الأحداث الفينولوجية لمقارنة استجابة اليام الابيض للحرارة المحيطة في المراحل الفينولوجية المختلفة.

**الكلمات الدالة:** اليام الأبيض، موسم الزراعة، المناخ الرطب والجاف.

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