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MODELING USING DRYNESS INDEX TO PREDICT EVAPOTRANSPIRATION IN A SUB-SAHARAN ENVIRONMENT

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ABSTRACT
There is a growing concern especially in Africa, about the consequences of climate change for food systems and food security. There is also concern that meeting the rising demand for food is leading to environmental degradation thereby exacerbating factors in part responsible for climate change, and further undermining the food systems upon which food security is based. Based on crop-climate studies from the viewpoint of modeling and predictability, this paper presents a new dryness index (DI), the ratio of rainfall over reference evapotranspiration (ET), for Ilorin (8.48^o N) in the transition zone between humid and semi-arid climatic belts in Nigeria. The ET values were computed using the Blanney-Criddle and Hargreaves equations using the maximum and minimum temperatures as input. The number of days with DI more than unity was better represented by the Hargreaves equation at the study site. The daily rainfall analysis showed signs of a possible climate change. The implication of this in developing a sustainable crop plan for Nigeria and in crop-climate studies towards boosting the food production system in a changing climate is emphasized.
Keywords: *evapotranspiration; sustainable; food; Nigeria; water; agriculture*

INTRODUCTION
Evapotranspiration is a significant water loss from a watershed and the types of vegetation and land use significantly affect evapotranspiration, and therefore the amount of water leaving a watershed. What should we do in situation like in Sub-Saharan Africa where the trees or the evapotranspirators that should contribute to evapotranspiration are gradually disappearing through unsustainable modulation of our ecosystem? The landscape is changing due to urbanization accentuated by increasing population. Food shortages are common. Africa, where agriculture plays a dominant role in supporting rural livelihoods, is thought to be the region most vulnerable to the impacts of climate variability and change (Salinger *et. al.*, 2005; Challinor *et. al.*, 2007).

Weather and climate variability is the largest source of uncertainty to prediction of agricultural yields and crop models (Peterson & Keller, 1990). These models typically ingest weather data at daily time intervals to simulated progress toward biomass production, phenological development, and final grain yield. Recent reports point to agricultural practices as contributing factors to regional weather (Giorgi *et. al.*, 1993) characteristics that have adverse human impact. Farmers, governments and policy makers have downplayed the importance of agroecosystem sustainability. Sparks *et. al.* (2002) suggested that extensive plantings of corn and soybeans in the Midwest of United States are contributing to higher dew point temperatures, which exacerbate heat waves (Kunkel *et. al.*, 1996). These and other reports suggest a need for more direct coupling of time-dependent land processes into weather and climate models for more accurate simulation of crop impacts on local weather.

The influence of the climate on crop water needs is given by the reference crop evapotranspiration (ET) which is usually expressed in millimeters per unit of time, e.g. mm/day, mm/month, or mm/season. Grass has been taken as the reference crop. The major climatic factors which influence the crop water needs are sunshine, temperature, rainfall, humidity and wind speed. ET is important to irrigation management because crop yield relates directly to it. Irrigators who are working to achieve maximum yields need to apply water to meet the crop's ET demand (Ramakrishnan, 1998). The effects of climate change induced by increased atmospheric carbon dioxide depends on the counteracting effects among higher daily evapotranspiration rates, shortening of crop growth duration, and changes in precipitation patterns, as well as the effects of carbon dioxide on crop growth and water-use efficiency (Iglesias *et. al.*, 1996). Increased water vapour in the atmosphere not only has a greenhouse effect, but also can change precipitation patterns causing flooding and monsoons in some regions, while others face drought therefore causing some stress on the food production system.

In this work, the reference evapotranspiration data were calculated by the Blanney-Criddle (Palutikof *e.t al.*, 1994) and Hargreaves (2003) methods, whose details are listed in the following section. Our aim is to use it in conjunction with the daily rainfall amount to develop crop plans using a new dryness index that will be invaluable in our crop-climate interaction studies and predictability from the viewpoint of mitigating climate change through sustainable food production systems.

METHODS AND MATERIALS

The site studied in this work is Ilorin in Nigeria located on longitude 4^{o} $34^{'}$ East and latitude 8^{o} $32^{'}$ North. Like most locations in West Africa, there are two seasons; the wet and dry seasons, which differ by the levels of precipitation, temperature and humidity, with the wet season recording higher precipitation, higher humidity and lower temperature than the dry season. The wet season usually spans from April to September while the dry season lasts from October to March of the succeeding year. The temperature data used for computing the reference evapotranspiration (ET) was collected from the meteorological department of the Federal Ministry of Aviation located at the Ilorin airport.

The reference crop evapotranspiration (ET) is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water. Evaporation pans provide a measurement of the combined effect of temperature, humidity, windspeed and sunshine on the reference crop evapotranspiration ET. If no measured data on pan evaporation are available locally, a theoretical method to calculate the reference crop evapotranspiration ET has to be used. There are a large number of theoretical methods to determine the ET (Mbagwu, 1988; Jensen *et. al.,* 1990; Lemuer and Zhang, 1990; Fennessey and Kirshen, 1994; Xu and Chen, 2005; Cai *et al.*, 2007; Rim, 2008). The Penman-Monteith method (Allen *et. al.,* 1998) is the benchmark but requires many climatic parameters that may not be available most of the time like the vapour pressure, relative humidity, net and global radiation amongst others. The methods used to compute the reference evapotranspiration data are described below.

The modified Blanney – Criddle method

This is the modification of the original Blanney – Criddle method (Dorenboos & Pruitt, 1977; Palutikof *et. al.,* 1994, Allen *et. al.*, 1998). The equation for calculating reference evapotranspiration with this method is:

$$ET\ (mm/day) = p\ (0.46Ta + 8) \qquad \text{------- (1)}$$

where Ta is the mean air temperature (maximum + minimum)/2 and p is a local constant (0.27).

Hargreaves Equation

The equation is written by Hargreaves and has been tested over tropical Africa (Chineke, 1993). It is a simple equation that requires temperature values to compute the reference evapotranspiration estimate. It is found to be favourable or gives better results in drier regions. The equation is (Hargreaves, 2003)

$$ET\ (mm/day) = 0.0021Ra\ [Ta + 17.8]\ Td^{1/2} \qquad \text{-------- (2)}$$

where Td is the temperature difference (maximum-minimum). Ra is the extraterrestrial solar radiation which was computed with a computer routine requiring as the only input, the latitude of a location (Chineke, 2008). We computed what we called a dryness index (DI) using the method by Kulandaivelu and Jayachandran (1994) which had been used by Kassam (1976) in Nigeria who demonstrated that crop-water requirements are usually met when rainfall is only half the value of the evapotranspiration. The equation is

$$DI = Rainfall/ET \qquad \text{---------- (3)}$$

where rainfall is the daily amount of precipitation (mm/day) and ET the evapotranspiration (mm/day). Three sets of index were used; (i) $DI \leq 0.5$), (ii) $0.5 > DI < 1.0$ and (iii) $DI \geq 1.0$.

RESULTS AND DISCUSSION

A month is assumed to be humid if our dryness index (DI) equals or exceeds 1.0. The Hargreaves method therefore captures more humid days for the 2002-2004 period than the Blanney-Criddle method. It should be noted that the former formulation includes the temperature difference which definitely tells something about the cloudiness of a place. The Blanney-Criddle method on the other hand is based on the mean air temperature and is preferable since it uses mean air temperature and therefore averages the noise that may be inherent due to instrument errors, for example on days with maximum and minimum temperatures having a marginal difference, for example 3 degrees Celsius.

The combination of the main elements used in the Blanney-Criddle and Hargreaves models for the Ilorin analysis is very germane and suitable, especially for the drier sections of the middle and Northern parts of Nigeria, where wind, solar-radiation and temperature play a significant role in the determination of evapotranspiration and reference evapotranspiration rates. Again, the choice of Ilorin, which is located between the transitional wetter Guinea Savannah belt and the drier Sudan Savannah belt of Nigeria, is very ideal, because a suitable and very workable "crop plan index" can be developed simultaneously for the two zones, using the data from Ilorin. Using the Hargreaves and Blanney models, the 2002 to 2004 (daily weather variables) reference evapotranspiration (mm) rates indicated that there are significantly fewer days of "poor DI", and more for "good DI" rates. The results are listed in Table 1.

Table 1: Distribution of DI ratios for 2002-2004 at Ilorin for the Hargreaves (HARG) and Blanney-Criddle (BLAC) methods

Classification		DI ≤ 0.5	0.5 > DI < 1.0	DI ≥ 1.0
2002	HARG	297	15	53
	BLAC	299	24	42
2003	HARG	298	14	53
	BLAC	305	10	50
2004	HARG	297	12	57
	BLAC	303	13	50

Legend: Number of days for 2002 and 2003 is 365 and 366 for 2004

Observations from the 3 year Rainfall/ET data indicate that there are about 148 "poor DI" days and 217 "good DI" days in 2002. The observed values for 2003 are 126 for "poor DI" days and 239 for "good DI" days (Table 1). The 2004 values indicate that there are 91 "poor DI" days and 275 "good DI" days. Deducing from the above information, it can be observed that there is a minimum of 3 drier months and a maximum of 4 drier months, between year 2002 and 2004, coupled with a steady but gradual increase in rainfall. However, it is pertinent to suggest here, that caution should be exercised, so as not to adopt with error any rainfall data for this decade alone without making provisions for comparisons with data from other decades, which may either be wetter or drier than the present decade 2000 to 2009.

Daily evapotranspiration at Ilorin

The estimated ET levels for the site are plotted in Figures 1-3 for the three years (2002-2004). In Fig. 1, we see the Blanney-Criddle method having signatures that have the similitude of expected patterns at a subtropical site. The values ranged from 4.95 mm on day 357 (December 23) to 6.13mm on day 91 (April 1). The Hargreaves temperature-difference method had ET values that were consistently lower than the Blanney-Criddle estimates ranging from 2.65 mm on day 184 (July 3) to 6.09 mm on day 69 (March 10) as can be seen from Fig. 1.

The scenario is not far-fetched for the year 2003 as is listed in Fig. 2. The Blanney-Criddle values ranged from 4.95 mm on day 184 (July 3) to 6.26 mm on day 78 (March 19). The Hargreaves ET surrogates ranged from 2.63 mm on day 263 (September 20) to 6.13 mm on day

84 (March 25). For the year 2004, whose result is shown in Fig. 3, we also see patterns that are similar to those of other years (Figs 1-2). The Blanney-Criddle ET values ranged from 5.02 mm on day 176 (June 26) to 6.2 mm on day 86 while the Hargreaves ET ranged from 2.65 mm on day 235 (August 22) to 6.16 mm on day 172 (June 20) as can be seen in Fig. 3. In Fig. 4 is listed the monthly mean climatology of the ET values for the 36 study months (2002-2004). The Hargreaves ET estimates had its minimum as 3.51 mm/day in August 2002 and 5.48 mm/day in March 2003 which is expected since the months of March to April is the peak of the dry season in Nigeria. The situation is similar with the Blanney-Criddle equation that computed ET values with a range of 5.27 mm in August 2004 to 5.97 mm in March 2002.

One key difference between the Hargreaves and Blanney-Criddle methods is that the former takes care of the diurnal variation in the temperature. The temperature difference should be less when cloud cover is greater. This is because the day temperatures remain high and the heat is conserved so that the night temperature is also high, resulting in less temperature range during the day. The Td takes into account changes in radiation due to proximity to oceans, mountains, and the altitude of the location (Chineke, 2008). We also plotted the monthly rainfall climatology which is shown in Fig. 5. For the year 2002, the peak rainfall was recorded in August which dropped in September increasing in October. In 2003, we see the months of June and September recording the maximum amounts of 370.8 mm and 400.1 mm of rainfall respectively which we may attribute to the local phenomenon of “little dry season” or the August break (Adeniyi and Oladiran, 2006; Adejuwon and Odekunle, 2006; Salako, 2008) which associates a clear and distinct bimodal rainfall pattern in Nigeria. In 2004, it is obvious that the bimodal pattern in rainfall (see Fig. 5) may be vacillating with the extreme rainfall amount of 210.3 mm recorded in May. If the rainfall amount decreases, the agricultural system that depends to a large extent on rainfall may have unpleasant feedbacks like reduced crop yield, stress on groundwater resources and food shortage.

IMPLICATION OF THE RESULTS

With the utilization of the effective growth energy of crops (Oshodi, 1966; Kowal and Kassam, 1976) which we have modified to be in line with present climate patterns in Nigeria, suitable soil type, favourable Rainfall/ET ratio, sustainable food production systems (like reduced tillage, multi-cropping, optimal fertilizer and pesticide use, forest conservation), the basis for the development of crop plans with suitable varieties that are often drought-resistant and with shorter periods of maturity can be established across the Sub-Saharan environments of Africa. For grains such as millet, sorghum, beans, rice, wheat, maize and Soya-beans, all locations in Nigeria are suitable, with the exception of the wetter Niger Delta areas, where millet, sorghum, wheat and Soya-beans which are dry weather crops cannot perform optimally (Bello, 1997).

Soil type, rainfall/evapotranspiration ratio, and other types of information can provide the basis for developing crop plans with suitable varieties that are drought tolerant and mature in a shorter period. Although extensive areas of Ilorin have sufficient moisture for only three to four months per year, three varieties of rice are grown each year with the aid of irrigation. Seventy-five percent of the total water available in Ilorin is used for rice production only. By adopting improved technology, it should not be difficult to marginally cut the rice growing areas without reducing total production. Water saved could be profitably used for growing other crops. Ilorin therefore has ample justification to increase cultivation of other crops, such as millets, oil seeds, pulses, vegetables, and so forth. Pulses can be grown successfully in these areas. In places that are prone to moderate to severe drought, millets such as sorghum and pearl millets are recommended (Bello, 1997).

A good crop plan to reduce the risk of crop failure includes cereals mixed with pulses or oil seeds. Suitable crops and varieties should be selected based on the degree of drought tolerance in relation to soil types. In a changing ecosystem like in sub-Saharan Africa due to many factors like overgrazing, indiscriminate felling of trees, unsustainable food production systems, desert encroachment, inappropriate management of land and water resources, new crop plans and varieties must be adopted to boost food production for an ever-increasing population faced with other problems like wars and ethnic conflicts.

CONCLUSIONS

The Food and Agriculture Organization (FAO) Land and Water Development Division has played an active role during the past three decades in developing and promoting guidelines and methodologies on crop water management at the field level. These methodologies have become widely-used standards. This particularly applies to the methodologies for the calculation of crop water requirement and crop water productivity in irrigated and rainfed agriculture (Kassam & Smith, 2001). From our results, we suggest that the wetter months between May and October, particularly in the drier northern parts of Nigeria, can be dedicated for the growing of the following crops alone crops: yams, cassava, cocoyam, potato, maize and rice. It is believed that the growing of these crops within the wetter months would not require irrigation water which will add stress to the “lean” water ecosystem. However, the drier Sahelian areas of Northern Nigeria, such as Borno, Kano, Bauchi, and Sokoto, where the duration of rainfall days are often less than 80 days, should not be included except under irrigated agriculture.

In order to protect the public from anthropogenic climate change, collective effort is required to carefully monitor physical and natural systems in Africa. A long-term monitoring system for climate change should be developed using existing technologies (satellites and surface measurements) and investing/replacing infrastructure where needed. A good step will be to include the analysis of climate model simulation to investigate if the disappearance of this interruption in rainfall patterns at Ilorin and in other sub-Saharan environments can be linked to anthropogenic forcing. At the Atmospheric Physics Group and Department of Geography and Environmental Management of Imo State University, we collaborate on Regional Climate Change with emphasis on anthropogenic effects and future climate scenarios, and natural climate variability in addition to agroecosystem sustainability, environmental management and awareness creation on the links between climate change, pollution, energy and environment and food production.

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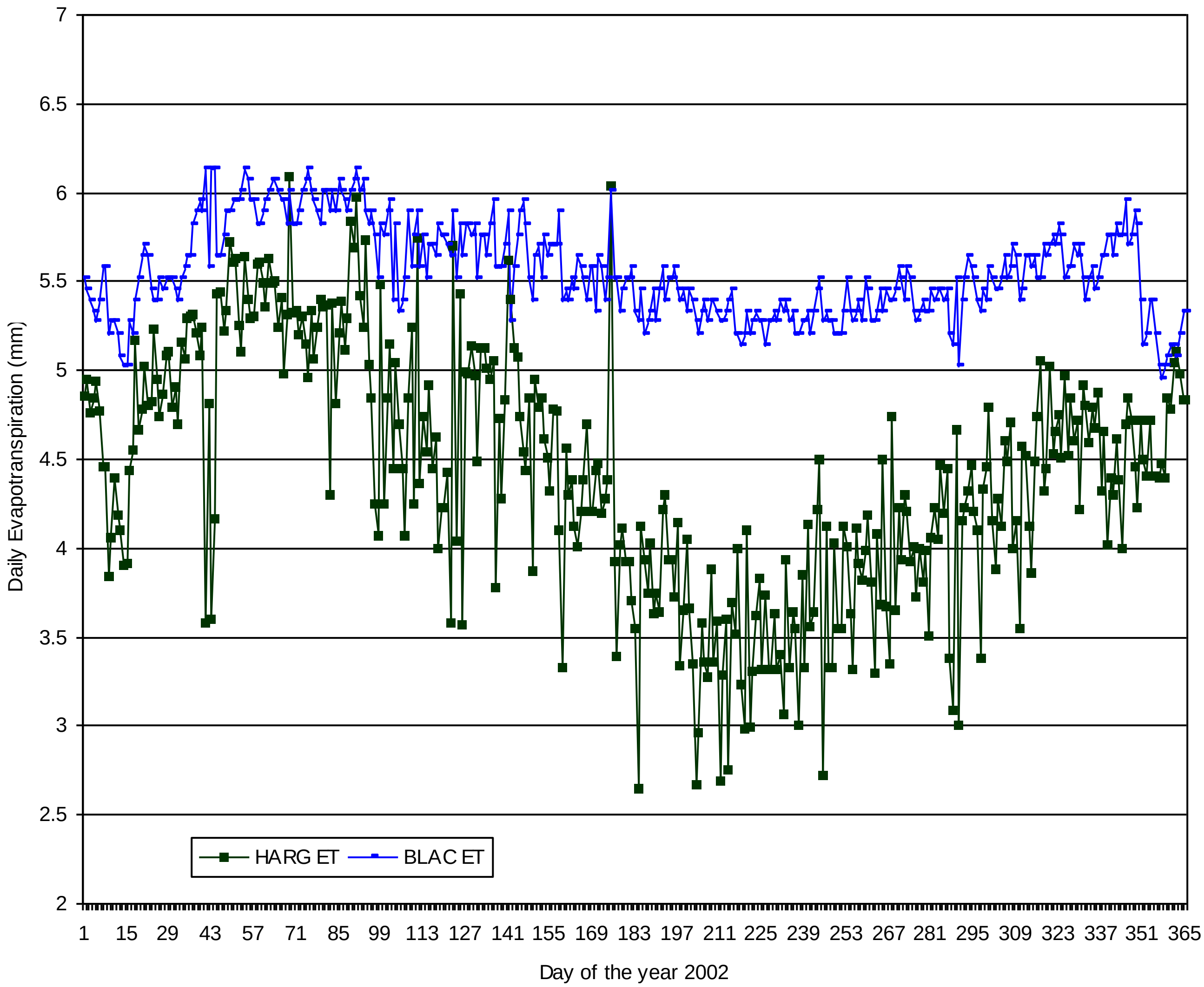

Fig 1: Daily reference evapotranspiration at Ilorin for 2002

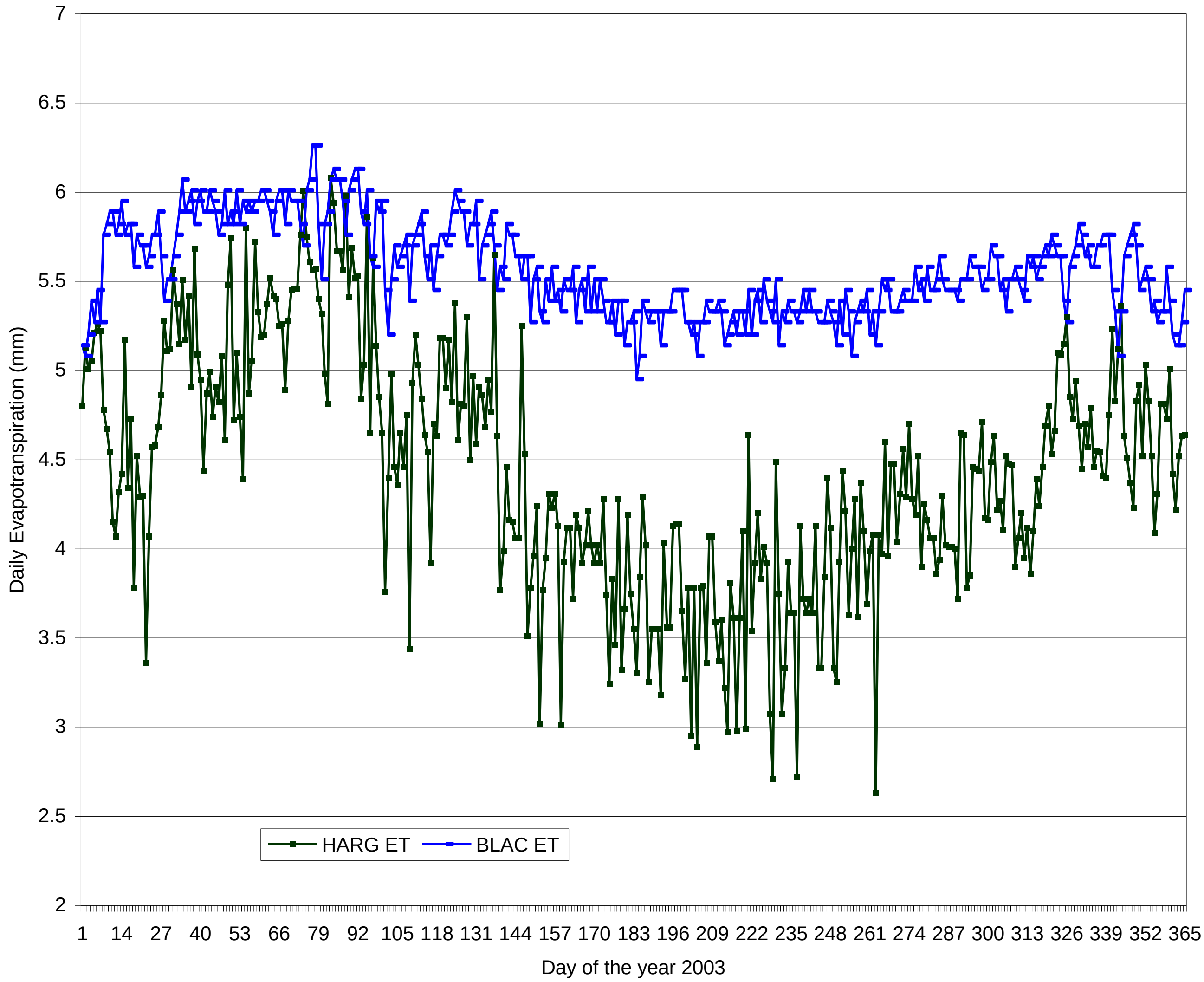

Fig 2: Daily reference evapotranspiration at Ilorin for 2003

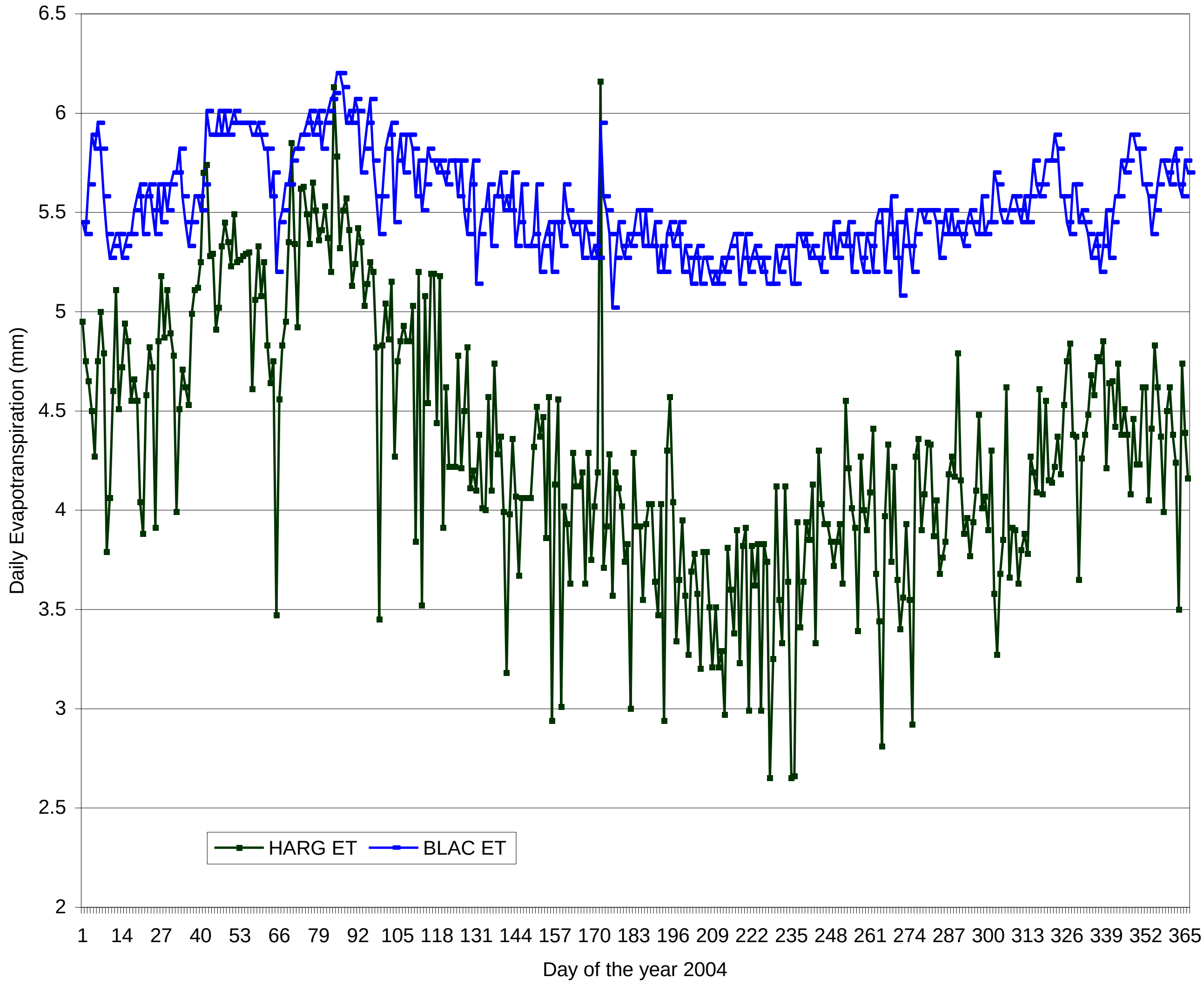

Fig 3: Daily reference evapotranspiration at Ilorin for 2004

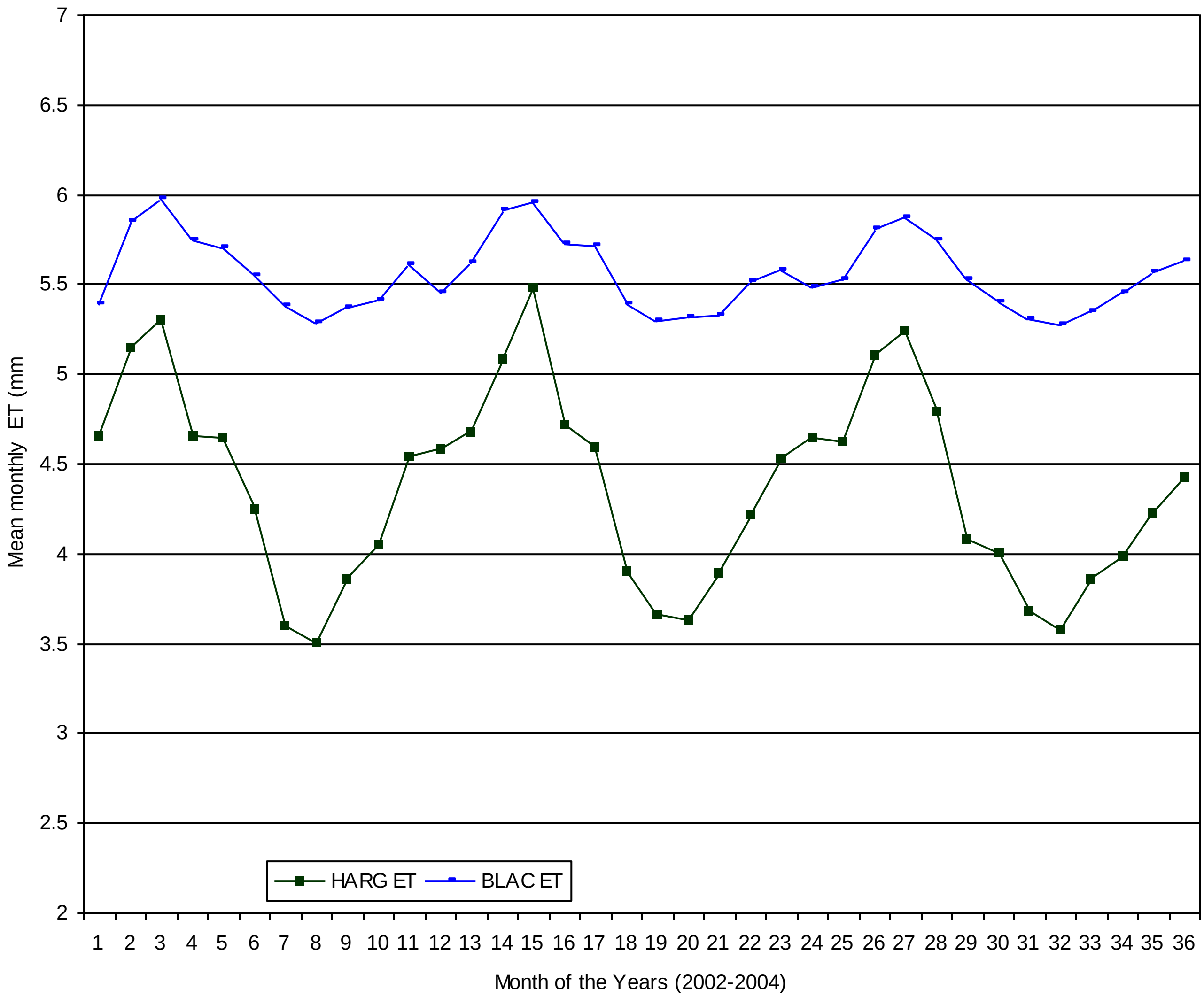

Fig 4: Seasonal variation of reference evapotranspiration at Ilorin for 2002-2004

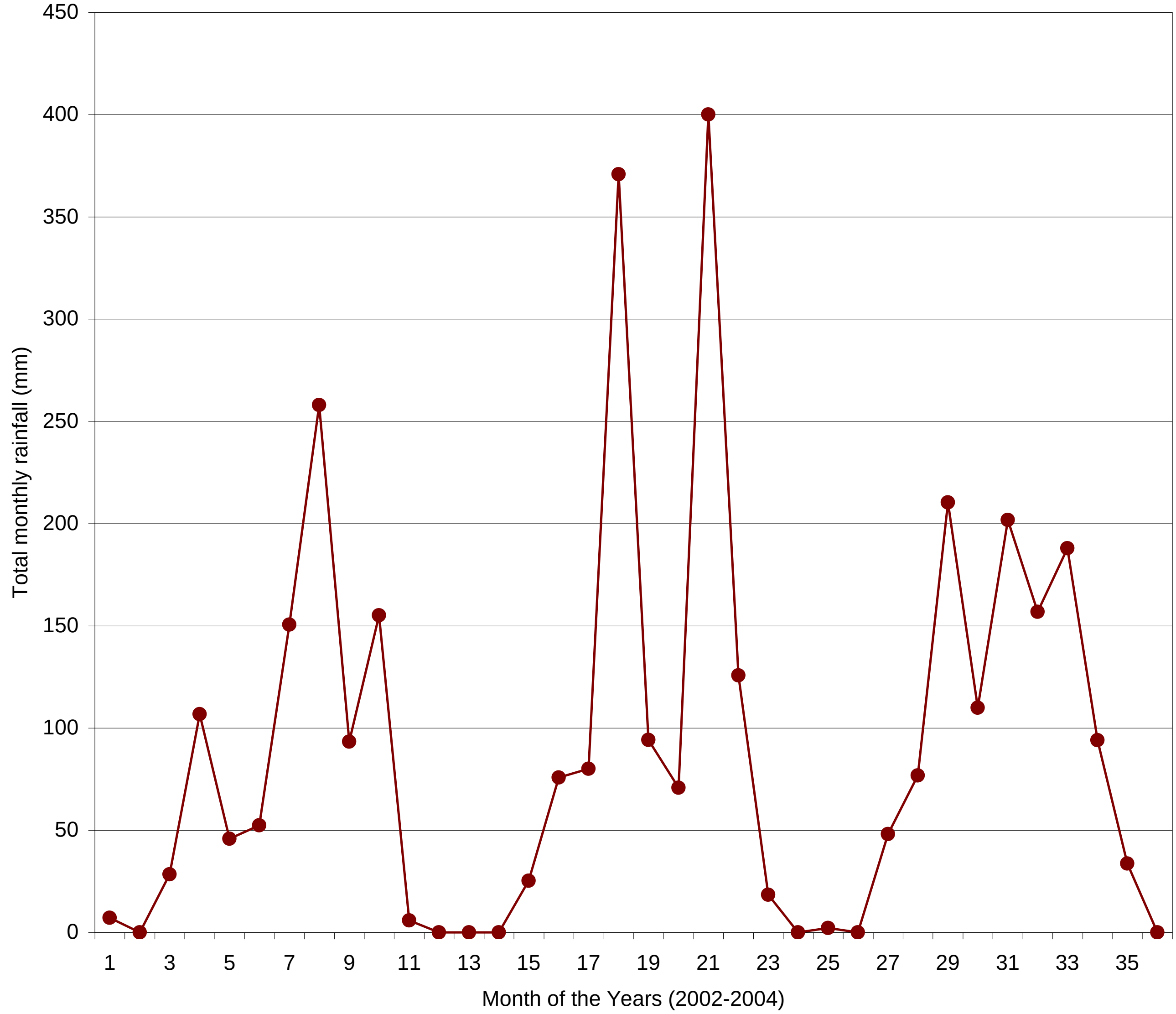

Fig 5: Seasonal variation of rainfall amount (mm/day) at Ilorin for 2002-2004

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