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WATER REQUIREMENT OF SUNFLOWER (*Helianthus annuus* L.) IN A TROPICAL HUMID-COASTAL SAVANNA ZONE

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ABSTRACT

Productivity of sunflower (*Helianthus annuus* L.) is strongly regulated by the availability of water and greatest yield losses occur when water shortage occurs at flowering. Field experiment was carried out to study the water requirement of sunflower in a tropical humid-coastal savanna environment in Ghana to evaluate the response of sunflower to discretionary supplementary irrigation. Randomised Complete Block Design (RCBD) was used with 5 treatments and 3 replicates. Can-irrigation system was used to irrigate the crop at different levels and time intervals. The results show that all the plant parameters measured (plant height, leaf area index, head diameter and seed yield) increased consistently with an increase in water input until T4 beyond which any increase occurred at a decreasing rate. The field estimate of water requirement of sunflower was determined as the optimum level of water required to reach maximum head diameter. Water requirement of sunflower (by the field method) was estimated at 672.4 mm/season or 7.1 mm/day. The consumptive use of sunflower estimated using the Blaney-Criddle method was 4.3 mm/day. The Blaney-Criddle method estimated the water requirement of sunflower at 361.2 mm/season. The field value was considered the water requirement of sunflower since this includes both soil losses and losses in the soil-plant-atmosphere continuum. It was concluded that even though sunflower is considered to be tolerant to water deficit to some extent, in areas of low rainfall, supplementary irrigation can boost the productivity of the crop.

Keywords: sunflower, crop water requirement, supplementary irrigation, humid coastal savanna, blaney-criddle.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the four most important oil crops in the world (Demir *et al.*, 2006; Richard *et al.*, 1984). Because of its moderate cultivation requirements and high oil quality, its acreage has increased in both developed and developing countries (Skoric, 1992). Sunflower oil is highly demanded not only for human consumption, but also for chemical and cosmetic industries. In respect of total yield produced, water requirements of sunflower are relatively high compared to most crops. Despite its high water use, the crop has the ability to withstand short periods of severe soil water deficit of up to 15 atmosphere tensions. Long periods of severe soil water deficit, particularly at water-sensitive growth stages cause significant reduction in seed yield (Beyazgul *et al*, 2000) by limiting evapotranspiration (ET) through stomata closure, reduced assimilation of carbon and decreased biomass production (Demir *et al.*, 2006).

It has been shown that, sometimes, periods of reduced growth may trigger physiological processes that actually increase yield (Smith *et al.*, 2002). Severe water deficits during the early vegetative growth result in reduced plant height but may increase root depth. Adequate water during the late vegetative period is required for proper bud development. The flowering period is the most sensitive to water deficits which cause considerable yield decrease since fewer flower come to full development (Beyazgul *et al.*, 2000; Ali and Shui, 2009). Seed formation is the next most sensitive period to water deficit, causing severe reduction in both yield and oil content (Doorenbos and Kassam, 1979). According to Casadebaig *et al.*, (2008), minimization of water loss in response to water deficit is a major aspect of drought tolerance and can be achieved through the lowering of either leaf area expansion rate or transpiration per unit leaf area (stomatal conductance). Although sunflower is known to be a drought tolerant crop or grown under dry land conditions, substantial yield increases can be achieved by supplementary irrigation, which is one of the most effective strategies to mitigate the effects of dry spells in crop production (Fox and Rockstrom, 2000; Xiao *et al.*, 2007).

Even though sunflower cultivation is expanding in the Central Region of Ghana, there is paucity of information on the effect of supplementary irrigation on the field performance of sunflower. More so, farmers apply water using their discretion and by observing the rainfall pattern (amount and frequency) without concerning themselves with the antecedent moisture content of the soil and/or the atmospheric demand (ET). This situation can lead to over-irrigation or under-irrigation and consequently affect crop performance and yield. A greater part of the Central Region (largely the southern part) is situated in the humid coastal savanna climatic zone where annual rainfall is low and exhibits high spatial and temporal variability. Therefore, supplementary irrigation is vital for some periods during the growing season. The objective of this study was therefore to use simple discretionary supplementary irrigation method (the common practice of sunflower farmers in the Central Region), and the Blaney-Criddle consumptive use method, to determine the water requirement of sunflower and to evaluate its response to water deficit in a tropical humid coastal savanna environment.

MATERIALS AND METHODS

Study area

The study was conducted from December 2006 to February 2007 at the Teaching and Research Farm of the University of Cape Coast (5.07^0 N, 1.14^{0}W). The experimental site lies within the tropical humid coastal savanna zone of Ghana (Agyarko *et al.*, 2006) or the dry equatorial climate. The area has a bimodal rainfall regime. The major season lies between March and July with a peak in June, while the minor season occurs from September to December with a peak in October; thus, leaving December to February as essentially the dry season. The mean annual rainfall is 800 mm and relative humidity ranges between 70-90%. During the experimental period the total rainfall recorded was 72.4 mm for 9 rainy days (December recorded 43.3 mm, January recorded 28.5 mm and February recorded 0.6 mm of rain). Like most parts of the country, temperature is uniformly high throughout the year with an annual mean temperature of 24.5 ^{o} C (Asamoah, 1973). The mean temperatures for the study period were approximately 26^{o}C and 27^{o}C for December-January and February respectively. The coolest and hottest months are August and February respectively. The soil of the site falls within the Benya series, classified as a Haplic Acrisol (FAO-UNESCO, 1998) with a soil pH between 6.4-6.9. It is part of the Edina-Ataabadzi Benya-Udu compound association. The colour of the series is yellowish brown and has clay-loam texture with fine granular and friable structure and medium internal drainage. The site has a uniformly flat surface.

Experimental design and data collection

The experimental field covered an area of 196 m^2, which was divided into 15 plots, each measuring 8 m^2 with a path of 1m between adjacent plots. There were 5 treatments of water application and each was replicated three times in a Randomized Complete Block Design (RCBD). Early maturing sunflower seed (PAN 7353) was used as the planting material. Water was applied to the plots using an improvised irrigation system. The improvised irrigation system consisted of a calibrated watering can connected to a tap through a rubber hose. The field was irrigated using the improvised irrigation system throughout the experiment. The amount of water used to irrigate the field and crops is shown in Table-1.

Table-1. Water application.

Treatment	**Amount of irrigation** (mm) **/season**	**Total amount of water input** (mm/season)	**Log scale**
T1	50	122.4	2.1
T2	150	222.4	2.3
T3	300	372.4	2.6
T4	600	672.4	2.8
T5	1000	1072.4	3.0

Total amount of water input is the sum of irrigation water and rainfall amount during the experiment. The log scale represents the logarithm of the total water input. Watering was done by observing the frequency and amount of rainfall events during the growing season. That is, when there was higher amount of rainfall, minimal watering was done. Consequently, for each treatment, 20% of the total amount of water was applied in December, 35% in January and 45% in February. It was assumed that soil water content (from rainfall input) was uniform in the experimental field; and that differences in water content were due to the difference in the amount of water applied through supplementary irrigation. This simplistic approach was done with the view to simulating the prevailing farmer practice in the Central Region where farmers apply water by observing rainfall patterns (amount and frequency) without worrying about the moisture balance of the soil. As a result, even though soil moisture was determined, it is not reported here.

Refilling was carried out ten days after planting to replace seeds that failed to germinate. The first and second weeding were done 3 and 8 weeks after planting, respectively. Compound fertilizer (NPK 15:15:15) was applied four weeks subsequent to planting at a rate of 10 kg/120 m^2. Six plants were randomly selected from the two middle rows of each plot and tagged for the height measurement using a tape measure. The mean height of the plants for each plot was taken at 21, 42 and 54 days after planting (DAP). The length and width of three randomly selected leaves were measured every week for each of the experiment fields. Individual leaf area (S) was estimated from leaf length (L) and maximum width (W), using a break-linear model (R^2 = 0.992, RMSE = 5.886 and n = 250):

$$\text{If } (L \times W) < \frac{c}{a-b} \text{ then } S = a \times (L \times W) \text{ else } S = b \times (L \times W) + c;$$

Where $a = 0.684$, $b = 0.736$, $c = -8.860$

Measured leaf area (MLA) was obtained by taking the average of the individual leaf area values (S). Plant leaf area (LA) was estimated from measured leaf area (MLA) using a linear relation:
$\mathrm{LA}_j = 1.91\mathrm{MLA}_j + 14.17$; where R^2 = 0.993, RMSE = 246.8 and n = 50).

The plant leaf area (LA) was then multiplied by 0.7 to obtain the leaf area index (LAI) (Rawson and Turner, 1983).

The average diameter of the head of eight randomly selected plants was calculated. The eight plants were oven-dried at 60^0C for 72 hours. The seeds were then shelled and counted as the number of seeds per head. The number of seeds obtained from each head was weighed and the mean seeds per plant determined and converted to tons ha^{-1}.

Calculation of ET with Blaney-Criddle method

The Blaney-Criddle method is well known and still in common use. It is a simple temperature-based method that can be used where meteorological data is limiting, and it is selected for these reasons. In its most modern complex form (Allen and Pruitt, 1986; Doorenbos and Pruitt, 1977; Frevert *et al.*, 1983), it contains much empiricism, and now it is hard to consider it merely as a temperature-based method. The currently preferred form of the equation is:

$E = a_{BC} + b_{BC}f$

With $f = p\ (0.46T + 8.13)$; $a_{BC} = 0.0043RH_{min}-(n/N)-1.41$;

$b_{BC} = 0.82-1.41(RH_{min}) + 1.07\ (n/N) + 0.066\ (U_2) - 0.006\ (RH_{min})\ (n/N)-0.0006(RH_{min})\ (U_2)$

where E is the potential evapotranspiration (mm day^{-1}); p is the ratio of actual daily daytime hours to annual daytime hours expressed as a percent; RHmin is the minimum daily relative humidity in percentage; U_2 is the daytime wind speed at 2m height (m s^{-1}); and the units of n and N are (h day^{-1}).

However, owing to limited data, the more simplified form of the Blaney-Criddle method was used in the determination of the water requirement for sunflower. The simplified form is expressed as:

$ET\ crop = ET_0 \times K_c$

$ET_0 = P\ (0.46T_{mean} + 8)$

Where ET crop refers to the water requirement of sunflower in mm per unit of time (mmday^{-1}, mm $month^{-1}$, mm $season^{-1}$)

K_c refers to crop coefficient (0.79 for sunflower)

P is the mean daily percentage of annual day time hours

ET_0 refers to reference crop evapotranspiration in mm per unit time

The number of days the plants spent in each month is then multiplied by ET_0 to obtain the Total ET_0.

December: $ET_0 = [0.27\ (0.46x\ 26.1) +8] \times 29$

January: $ET_0 = [0.27\ (0.46x\ 26.1) +8] \times 31$

February: $ET_0 = [0.27\ (0.46x\ 27.3) +8] \times 24$

Where 29, 31 and 24 are the number of days the plants spent in December, January and February, respectively.

Total $ET_0 = 457.3$

$ET\ crop = ET_0 \times K_c$

$= 457.3 \times 0.79 = 361.2$ mm $season^{-1}$

RESULTS

Seed germination and seedling emergence were generally good; germination was about 80% in all plots by the 7th day after planting. Pest and disease attack on the plants was minimal. Figure-1(a-c) shows the relationship between leaf area index (LAI) and plant height for the five treatments at 21, 42 and 54 days after planting (DAP), respectively.

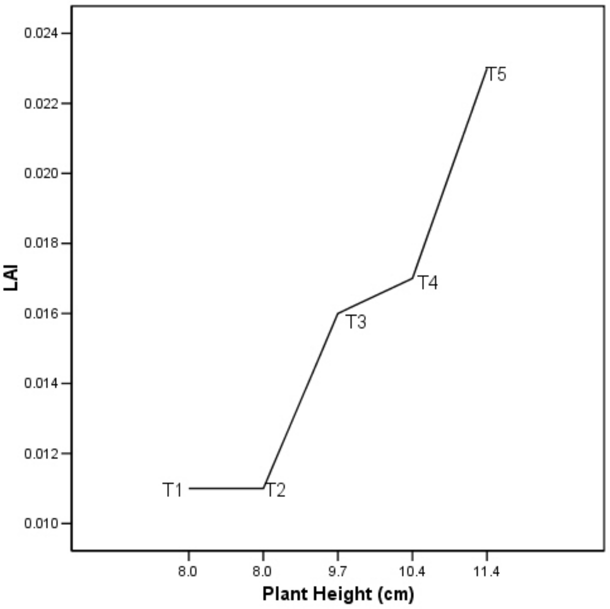

Figure-1(a). 21 DAP.

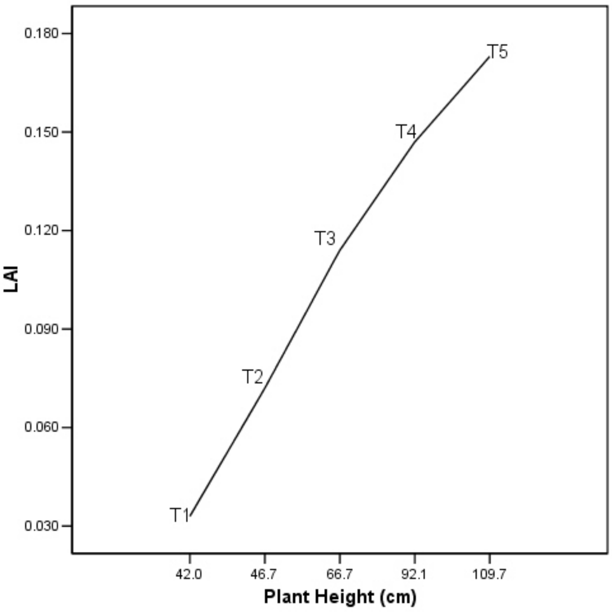

Figure-1(b). 42 DAP.

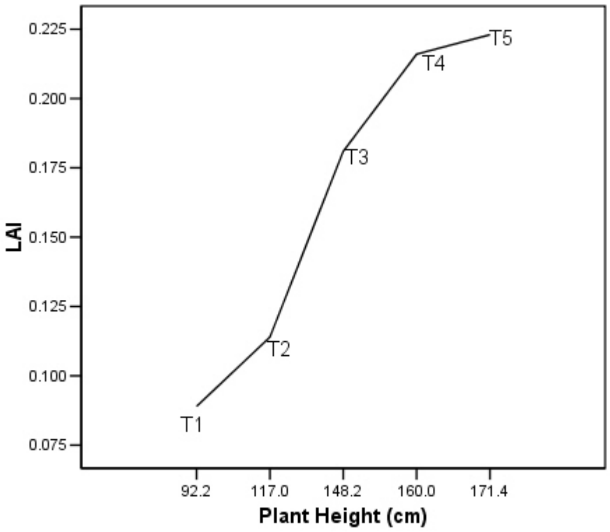

Figure-1(c). 54 DAP.

In Figure-1a (the initial stage), there was no difference in plant height and consequently in LAI between T1 and T2. There was a steep rise in plant height and LAI between T2 and T3, and between T4 and T5. However, it can be said that water use did not significantly influence plant height as the heights ranged between 8 and 11.4 cm. During the plant development stage (between 21 and 42 DAP), water use to a great extent affected the plant height, while increased water use corresponded with increased LAI (Figure-1b). The differences in plant height and LAI among the treatments were high, giving almost a linear relationship. This linear relationship suggests that, during the crop development stage, higher amount of water is required for rapid canopy expansion. It is significant to note that between T2 and T3, the difference in plant height was as high as 20 cm; and between T3 and T4 was 25.4 cm. However, between T4 and T5, the difference in plant height was 17.6 cm. This decline in the rate of increase in plant height suggests that, perhaps, the soil had reached saturation and that any further addition of water was unlikely to positively affect plant growth.

There was also rapid increase in LAI from 0.03 to 0.18. Between 42 and 54 DAP (the final stage of vegetative growth, Figure-1c), plant height continued to increase as well as leaf area index. However, the rate of increase was not as steep as observed in the crop development phase. The axes indicate the maximum height and LAI attained in the five treatments at 54 DAP. Thus, T1 reached a maximum height of 92.2 cm while T5 reached a maximum height of 171.4 cm. For both plant height and LAI, the difference between T2 and T3 was consistently very high in Figure-1a to 1c. This shows that, under the experimental conditions, total water input of T3 is the minimum required to ensure significant response (increase) in plant height and LAI; and beyond T3, the increase in LAI and plant height begins to slacken. Figure-2 shows the relationship between sunflower head diameter (SHD) and total water input.

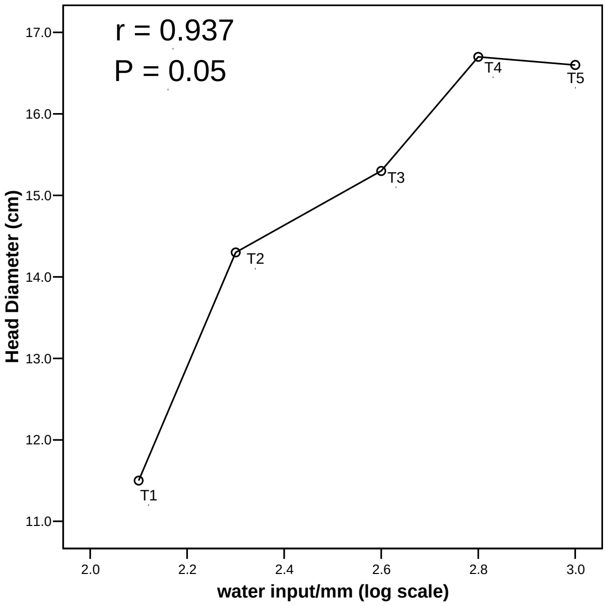

Figure-2. Plot of head diameter (cm) against water input (mm).

In Figure-2, the head diameter ranged from 11.5 to 16.7 cm. The plot of SHD against the log of water input indicates a relationship that is almost linear up to a peak at T4 (corresponding to 600 mm of irrigation water or 672.4 mm of total water input). Thereafter, there was a drop in the plot when the irrigation water supply was further increased to 1000 mm or total water input of 1072.4 mm (T5). From the plot, the point where water input gave the maximum SHD was taken to be the field water requirement of sunflower under the conditions of the experimental site. This field value corresponds to 672.4 mm season^{-1} (T4). Thus, the field value indicates the optimum water input that can satisfy ET demands and losses through drainage and deep percolation and, at the same time, give maximum SHD.

Under field conditions, soil moisture losses through drainage, runoff and evapotranspiration are inevitable; and since farmers do little (if at all) to control these losses, the field value is taken as the water requirement of sunflower under the experimental conditions. There is a positive correlation between SHD and water input (r = 0.937, P = 0.05). The Blaney-Criddle consumptive use method, on the other hand, estimated a value of 361.2 mm season^{-1}. Even though the Blaney-Criddle value is far lower than the field value, it is expected since the version of Blaney-Criddle used is essentially temperature-based; and thus the value essentially represents the losses due to ET (or satisfies the atmospheric or climatic demand) but does not consider water losses through processes other than ET. Thus, the Blaney-Criddle value was estimated to give an idea of water required to satisfy the combined demand of surface evaporation and transpiration under the experimental conditions. Figure-3 shows the relationship between seed yield and water input.

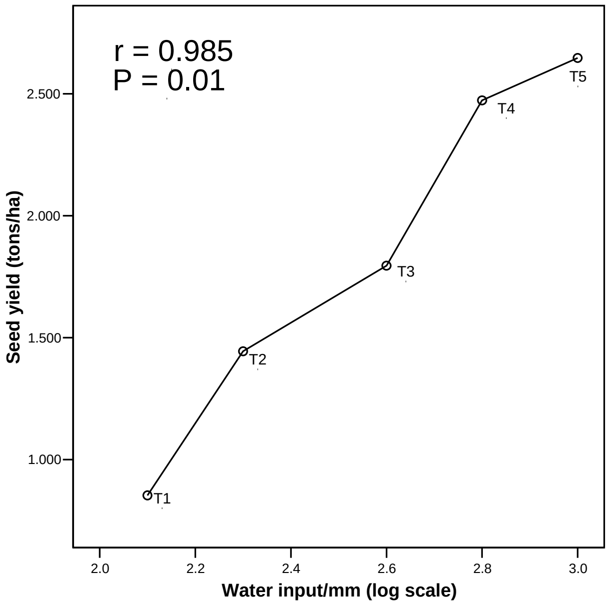

Figure-3. A plot of seed yield (tons ha^{-1}) against water input (mm).

Figure-3 looks more or less like Figure-2. In Figure-3, again, the graph indicated an increasing trend in seed yield up to T4 beyond which a decreasing rate is observable. The difference between yield of T4 and T5 was 0.174 whereas the yield difference between T3 and T4 was 0.678. However, T5 had the highest yield in response to the highest water input. A positive correlation coefficient (r) of 0.985 (P = 0.01) was observed between seed yield and water input. However, the graph indicates that an optimum yield is obtainable at T4, corresponding to total water input of 672.4 mm. Beyond this, increased water application will result in marginal increase in yield. A significant correlation was also found between seed yield and SHD (r = 0.965, P = 0.01).

Effort was made to estimate a prediction equation relating SHD and water input (Figure-4) using water input (log scale) as the independent variable while SHD was used as the dependent variable. The curve fitting to estimate the prediction equations gave the following coefficients and R^2 values:

Linear: $b_0 = 0.8481$ $b_1 = 5.4812$ $R^2 = 0.878$
Quadratic: $b_0 = -43.289$; $b_1 = 40.7454$; $b_2 = -6.9278$; $R^2 = 0.965$

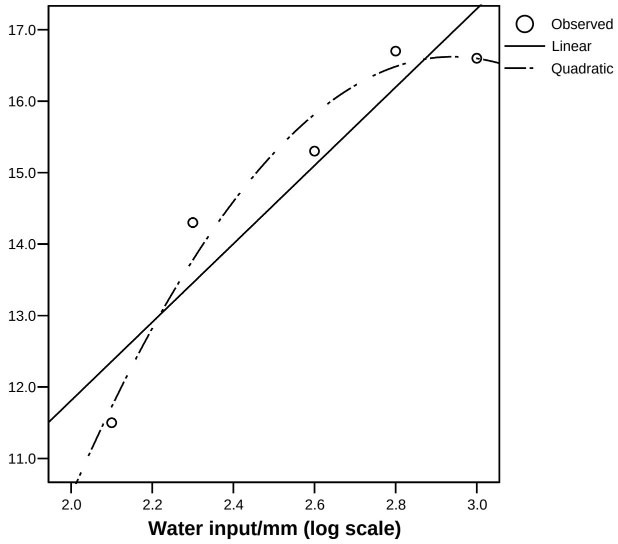

Figure-4. Curve estimation relating water input (log scale) and SHD.

DISCUSSIONS

The results show that sunflower responds positively to supplementary water application. At the initial stages of growth, differences in water application led to marginal increase in plant height and LAI. However, during the development phase, response to increased water application was high and the differences in plant height and LAI (that is biomass production) were equally high. This shows that higher water input is required for rapid canopy expansion during the development phase. Thus, short dry spells (or short periods of water deficit) during the initial phase may not significantly affect the performance of sunflower if adequate water is supplied during the development phase. During the initial growth stages (21 DAP, Figure-1a), different water applications did not significantly influence changes in plant growth. However, during the crop development stage, different water applications gave differences in plant height (Figures 1b and 1c). According to Black (1967), the walls of young cells are more plastic than those of old cells; hence any little amount of water the plant receives is efficiently utilized. At this stage, the turgor pressure exerted against the walls of cells from the inside stretches the cell walls in the plastic condition leading to enlargement of the cells. This condition does not apply to old cells, resulting in a decreased growth rate even though more water is applied.

Another interesting factor is leaf area index (LAI) which is critical to yield because photosynthesis occurs mainly through the leaves. For sunflower, maintenance of photosynthesis after anthesis is a key process for seed weight and oil content because these factors are mostly influenced by intercepted radiation of the sun during seed filling phase (Casadebaig *et al.*, 2008). During this phase, stomatal closure appears to play a very important role in the control of plant water status (Connor, 1997), suggesting that transpiration rate is controlled by the leaf area during the seed filling period of sunflower. From the results of this work, T5 which received the highest water supply registered the highest LAI, whereas T1 which received the least water supply recorded the least LAI. Thus, the incidence of drought can delay the vegetative to flowering stages of the crop (Turk and Hall, 1980). Similarly, Rauf and Sadaqat (2007) noted that water stress affected LAI of sunflower by accelerating early and abrupt senescence. Their work support the low LAI of the least water supply treatment (T1) found in this study.

Invariably, head diameter of sunflower varies in size with water input. Even though SHD increased in response to increased water input, the differences in SHD at lower levels of application between successive treatments are high while the differences between successive treatments at higher water application rates are low. For example, an additional water input of 300 mm (between T3 and T4, Table-1) increases the SHD by a margin of 1.4 cm whereas an additional water input of 400 mm (between T4 and T5) decreases head diameter by 0.1 cm. This finding is in agreement with the findings of Anderson *et al*., (2003); Omar and Mehanna (1984); Javed *et al*., (2001) and Rauf and Sadaqat (2007) who also noticed points at which the amount of water use was optimum relative to head diameter. This finding also indicates that some level of water deficit could be beneficial in sunflower production. Seed head diameter is believed to be the major yield-related indicator of sunflower performance. However, relating head diameter to seed yield has not been found to be consistent (Javed *et al*., 2001; Grassini *et al*., 2009; Scheierling et *al*., 1997). It is, therefore, not surprising that in this study T4 which had a head diameter of 16.7 cm had seed yield of 2.5 t ha^{-1}, whereas T5 with head diameter of 16.6 cm had a yield of 2.6 t ha^{-1}. Nevertheless, some positive correlations have been reported between head diameter and seed yield (Alza and Fernandez-Martinez, 1997). A simple marginal analysis indicates that optimum yield is attained at T4, with total water input corresponding to 672.4 mm. This was taken as the field water requirement of sunflower under the experimental conditions. The difference in seed yield between T3 and T4 is 0.678 t ha^{-1} (corresponding to an additional water input of 300 mm) while the difference between the yield of T4 and T5 is 0.174 t ha^{-1} (corresponding to an additional water input of 400 mm - Table-1). Consequently, higher amounts of water input beyond T4 is likely to lead to marginal increase in yield (i.e. yield will increase at a decreasing rate).

The reduction in yield in the low water supply treatments (T1 to T3) could be associated with their low capacity to tolerate low tissue water potential which influences pollination process, such as anther dehiscence, pollen shedding and viability and faulty ovary metabolism (Connor and Sadras, 1992). Other processes such as a low potential to mobilize pre-anthesis reserves towards the seed, combined with limited supply of assimilated compounds could also contribute to the reduction in yield (Hall *et al*., 1992). Though the least water supply (T1) recorded the lowest yield of sunflower, the yield for this treatment was reasonable because, according to Weiss (1983), yields well below 0.5 t ha^{-1} is normal. According to the Ministry of Food and Agriculture office in Cape Coast, maximum yield of sunflower production under rain-fed conditions in the Central Region hardly exceeds 1.0 t ha^{-1}, with an average of 0.8 t ha^{-1}. Consequently, the results of this study shows that even minimal discretionary water application (as in T1) can increase sunflower yields. Therefore, in managing water for sunflower production, it is appropriate to bear in mind that sunflower is tolerant to water deficit to some extent, but it is at the same time responsive to irrigation inputs; and that total water input between 600 mm to 650 mm can increase yields significantly in a humid tropical coastal savanna zone.

Figure-4 shows that there is a very high positive correlation between SHD and water input; and that it is possible to explore this relationship to predict SHD from total water input. The higher R^2 value of the quadratic equation points to the fact that the relationship between water input and SHD is not entirely linear and that there is the need to explore non-linear equations in predicting SHD from water input. However, even though both prediction equations give higher R^2 values, these equations will require validation to make them applicable in similar studies and useful to operational applications.

CONCLUSIONS

The growth rate and yield of sunflower are influenced by water supply. In this study, the field water requirement of sunflower was estimated at 672.4 mm season^{-1}. The field value is recommended to farmers as the water requirement of sunflower, as this is consistent with their practice and this value represents the total amount of water input required to satisfy all the partitions of soil water under field conditions. The Blaney-Criddle method estimated a value of 361.2 mm season^{-1} indicating the demand by the twin process of evapotranspiration. Attempt to estimate water requirement of sunflower using the simple temperature-based Blaney-Criddle method is very likely to produce a lower and unreliable value since the method considers only the atmospheric demand of water through ET. Even though the plant heights, LAI, head diameter and seed yield increased with increasing water input, their rate of increase was not consistent with the highest amount of water supplied. This suggests that sunflower is tolerant to water deficit to some extent, but the use of supplementary irrigation is likely to boost the productivity of sunflower.

The study shows that supplementary water application is important for increased productivity of sunflower in the study area. Discretionary supplementary water application, as practiced by farmers in the study area and adopted in this study, therefore has a potential to increase yield significantly as opposed to rain-fed production; and that a detailed study will be appropriate to deepen understanding on the intra-seasonal dry spells and their effects on sunflower performance in the coastal savanna zone in order to devise strategies for sustainable water management for higher sunflower productivity. The study also demonstrates that field methods using simple irrigation system and discretionary supplementary water application can be applied to determine the water requirement of sunflower. This is particularly useful where data and scientific instrumentation are limiting.

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