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RESPONSE OF MAIZE (ZEA MAYS L) TO INTERMITTENT WATER APPLICATION UNDER TROPICAL SAVANNA CONDITION

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ABSTRACT

Tropical regions usually experience intermittent rainfall and this affects maize production in most tropical countries where irrigation facilities are inadequate. The pot experiment was conducted at the School of agriculture Teaching and research Farm, University of cape Coast, to investigate the effect of intermittent water application on maize growth and yield parameters. A randomized complete block design was used with three replications. Four different water amounts of correspondingly different frequency intervals were used as treatments: 300 cm3 water at 3-day intervals (T1); 490 cm^3 water at 5-day intervals (T2); 770 cm^3 water at 7-day intervals (T3); and 1150 cm^3 water at 9-day intervals. The results showed no significant ($p \leq 5\%$) difference among the treatments on the germination rate. However, the effect of the treatments on all the other maize growth and yield parameters determined showed significant ($p \leq 5\%$) differences and followed similar trend in the order of T3 > T2 > T4> T. In conclusion, even though maize production in the study area increased with increasing water amount at long application intervals, prolonged interval of 9-days reduced the maize performance even with increased water amount.

Keywords: coastal savanna, frequency interval, intermittent rainfall, maize production, tropical region.

INTRODUCTION

Maize is grown in climates ranging from temperate to tropics regions so long as sufficient soil moisture is available and the temperatures are above 15°C and frost-free (FAO, 2015). Adaptability of maize varieties in different climates varies widely (FAO, 2012a). According to FAO (2012b), maize is an efficient user of water for total dry matter production, and among cereals it is potentially the highest yielding grain crop. For maximum production, maize water requirement ranges between 500 and 800 mm depending on the climate (FAO, 2015).

In most developing countries in the tropics including Ghana, there are inadequate or non-existence irrigation facilities and therefore rainfall is the main determinant of soil moisture content. Tweneboah (2000) noted that the success of maize production on any appreciable scale depends on the total amount, the distribution and the reliability of the rain during the growing period of maize. Ge *et al* (2012) observed that maize development and yield responses to water stress depend on the intensity and duration of the stress as well as on the maize developmental stage. Alami-Milani et al. (2013) observed that water deficit generally affects morphological features and physiological processes associated with plant growth and development. Fageira *et al*. (2006) also noted that maize is water demanding crop at all stages of its physiological development and higher yield can be achieved when water and nutrients are not limiting. Roygard *et al.* (2002) observed that maize exhibits yield reductions in response to soil water deficits at any growth phase. Water stress during the vegetative stage limits cell division and expansion (Reymond *et al*., 2003) and this reduces stem elongation and leaf area growth (Stone *et al*., 2001). According to Khan et al (2001), water stress reduces crop leaf area and therefore photosynthesis, leaf chlorophyll content and consequently grain yield. Çakir (2004) noted that maize grain is sensitive to moisture stress at the beginning of tasseling and continue to grain filling, and drought when coincides with tasseling to grain filling stage causes serious yield instability. According to Mansouri-Far *et al*. (2010), grain yield reduction caused by drought ranges from 10 to 76 % depending on the severity of the drought and the growth stage at which it occurs. Bruce *et al*. (2002) observed that moisture stress causes average annual yield losses in maize of about 17 % in the tropics but the losses in individual season approaches 60 %.

Rainfall is intermittent and even unreliable in the tropics even though it is the main source of soil moisture for maize production in many developing countries in the region. The degree of rainfall uncertainty in these countries is not known a priori before planting. Forecasting of seasonal rainfall based on rainfall data from the previous years is usually unreliable due to continuous changing of the climate and therefore an area expected to have some appreciable level of rain within the year often experiences less than the anticipated amount (Tweneboah, 2000). It is therefore often possible for an area considered as high rainfall area goes through the season with rainfall below the minimum crop requirement, hence serious crop failure. The results are that maize always suffers from seasonal soil moisture deficit. The chances of increasing maize production seem to lie in irrigation since rainfall has become a major limitation to crop production Harris and Orr (2014). However, the high cost and sometimes irrigation water shortage due to competition of water between agriculture and other sectors inhibit the efficient use of irrigation (Costa *et al*., 2007). Therefore, the objective is to assess and identify water use strategy for optimum maize growth under tropical condition.

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MATERIALS AND METHODS

Study site

The study was carried out at the School of Agriculture Teaching and Research Farm, University of Cape Coast. The site lies within the coastal savanna zone of Ghana and falls within latitude 5.1° N and longitude 1.4° W. The site experiences a mean annual rainfall of about 950 mm, the temperature ranges between 23.2°C - 33.2°C and the relative humidity is between 81.3-84.4% (Asare, 2004). The soils at the site belong to Benya series and could be classified as Haplic Acrisol (FAO) and are moderately acidic with a pH of about 5.2 (Asamoa, 1973). The soils have a low nutrient status; phosphorus is about 1.2 ppm; nitrogen is 0.1%; organic matter is 2% and low moisture retention capacity (Adu, 1995).

Experimental design and treatment allocation

The study was pot experiment and was carried out in an open shed. The pots were cylindrical-shaped plastic containers with each measuring 25 cm in diameter and 25 cm deep. The base of each pot was perforated to facilitate drainage. The pots were then filled with soil from the study site to a bulk density of 1.25 gcm^{-3} and this was to reflect the field situation at the site. Four increasing water amounts which were correspondingly applied at increasing length of application frequency intervals were used as treatments. The treatments were 300 cm^3 water applied at 3-day frequency intervals (T1), 490 cm^3 water at 5-day frequency intervals (T2), 770 cm^3 water at 7-day frequency intervals (T3) and 1150 cm^3 water at 9-day frequency intervals (T4). The treatments were laid out in a complete randomized block design (CRBD) with three replications giving a total of 12 pots. Using watering-can, the water application started on the day of sowing with the view of obtaining a good stand and rapid root development of the maize seedlings (FAO, 2012b). The maize used was a local variety called 'Obatanpa' which had early maturity period. Four maize seeds per pot were sowed at 5 cm deep and after germination thinned to 2 when at two leaf stage. The cultural practice adopted was regular hand picking of weeds to ensure that moisture lost from the pot was mainly through the maize evapotranspiration.

Soil sampling and analysis

The soil for the experiment was characterized by sampling both disturbed and undisturbed soil across the study field to a depth of 15 cm (Gao *et al*., 2010). The disturbed soil samples were bulked and together with the undisturbed soil samples sent to the Department of Soil Science laboratory, University of Cape Coast, for the analysis of particle size distribution, bulk density, total porosity, moisture content, soil pH, organic carbon, total nitrogen, available phosphorus and exchangeable potassium. In the laboratory, the bulked soil samples were air-dried, sieved through 2 mm mesh and then used for the analysis.

The particle size distribution was determined based on the hydrometer method (Bouyoucos, 1951). The bulk density was determined using the core method (Blake and Hartge, 1986). The soil moisture content was determined on mass basis using gravimetric method and then converted to volume basis by multiplying the gravimetric moisture content and the bulk density (Kutilek and Nielsen, 1994). The total porosity was calculated using the bulk density and the particle density of 2.65 g cm^{-3}. The soil organic carbon was determined using the Walkley-Black method (Nelson and Sommers, 1982). The total nitrogen was determined by Kjeldahl digestion method (Bremner and Mulvaney, 1982) and the available phosphorus was determined using the Bray-1 method (Olsen and Sommers, 1982). The exchangeable potassium (K) was determined using the flame photometer (Rhoades, 1982). Table-1 shows the soil characterization of the study site.

Table-1. Some physico-chemical properties of the experimental soil.

Soil property	Value
pH	5.22
Bulk density (gcm^{-3})	1.25
Total porosity (%)	52.82
Moisture content (%)	7.21
Organic carbon (%)	1.35
Total N (%)	0.11
Avail. P (ppm)	1.24
Exch. K ($cmol_c kg^{-1}$)	0.62
Sand (%)	51.0
Silt (%)	16.6
Clay (%)	32.4
Textural class	Sandy clay loam

Plant growth and yield parameter measurements

The maize growth and yield parameters measured included seed germination rate, plant height, stem girth, leaf area index (LAI), dry matter weight and water use efficiency (WUE). The seed germination rate was determined after maize seed emergence (4 days after planting) had ceased, by counting the number of germinated seeds on each treatment pots and expressed as a percentage of total number of seeds sown. The plant heights, the stem girth and the leaf area index (LAI) were taken weekly from 2 weeks after planting (WAP) to 8 WAP. The plant height above ground was measured using a measuring tape. The stem girth was determined by measuring the circumference of the maize stem with a thread and transferring the thread to a meter rule to determine the length. The lengths and widths of the leaves of the maize crops were measured and the leaf area index (LAI) was then calculated using the formula mentioned by Babiker (1999) as:

$$\text{LAI} = \text{LL x LW x } \frac{\text{no. of leaves}}{\text{plant}} \text{ x } 0.75 \text{ x } \frac{\text{no. of plants}}{\text{m}^2} \qquad (1)$$

where, LL is leaf length (cm), LW is leaf width (cm), and 0.75 is correction factor.

The dry matter weight and the water use efficiency (WUE) were determined after 8 WAP. The maize plants in each pot were cut at ground level, the above-ground plant shoot (wet matter) was oven dried at 102^oC overnight and then measured to get dry matter weight. The average dry matter weight per pot for each treatment was then determined. The water use efficiency (WUE) was determined as the ratio of dry matter (kg ha^{-1}) to the amount of water applied as outlined by Sinclair *et al* (2007).

Data analysis

The data were statistically analyzed using Analysis of variance (ANOVA) component of Genstat discovery 4.10.5(win32) edition and the means were compared using least significant difference (LSD) at 5 % probability level.

RESULTS AND DISCUSSIONS

Physico-chemical properties of the soil used for the study

The soil used for the study was sandy clay loam (sand = 51.0 %; silt = 16.6 %; clay = 32.4 %) and was moderately acidic with pH of 5.2 (Table-1). The soil pH was within the range for optimum solubility of most important plant nutrients (Brady and Weil, 2007). This suggested that the soil was good enough to support plant growth. The soil bulk density of 1.25 g cm^{-3} and a total porosity of over 50 % indicated that the soil had enough aeration and high drainage capacity. The soil had organic carbon content of 1.35 % and this was low (John et al., 2010). Even though the organic carbon content was low, it could support plant growth because it was higher than 0.75 % (Sheoran *et al.*, 2010). The total nitrogen (0.11 %) was low and this could be attributed to the low organic carbon in the soil which was typical of many tropical savanna soils (Blanchart *et al.*, 2005). Generally, the soils were low in P (< 2 ppm) and slightly moderate in K (> 0.30 $cmol_c$ kg^{-1}) (Adu, 1995).

Effect of intermittent water application on maize growth

The maize seed germination rate, the maize height, the stem girth and the maize LAI are all important growth parameters that indicate the maize ability to make efficient use of soil water coupled with solar energy which are critical in crop growth and also the yield. The amount of water stored in the soil depends on how much water was received through irrigation and/or rainfall, and how much was lost through evaporation, transpiration and percolation (Acquaah, 2002). Hillel (2004) noted that the stage of evaporation process is important in soil moisture conservation for plant growth. According to him high irrigation frequency may cause the soil surface to remain wet and the first stage of evaporation to persist, resulting in a maximum rate of water loss.

Figure-1 shows the seeds germinated rate under different amounts and frequencies of water application. Even though T1 had 85 % germination, T2 had 88 % germination, whilst T3 and T4 had 80 % and 90 % germination respectively, there was no significant difference ($p \leq 5\%$) in the germination rates among the treatments. This showed that maize germination appeared not to be seriously affected by the amount and frequency of water, provided there was adequate amount of conserved water in the soil for the seed germination. This suggested that after breaking of dormancy, all the treatments provided sufficient water that afforded the seeds the greater opportunity to utilize soil moisture, an effect that is vital during germination and establishment of crop growth phases.

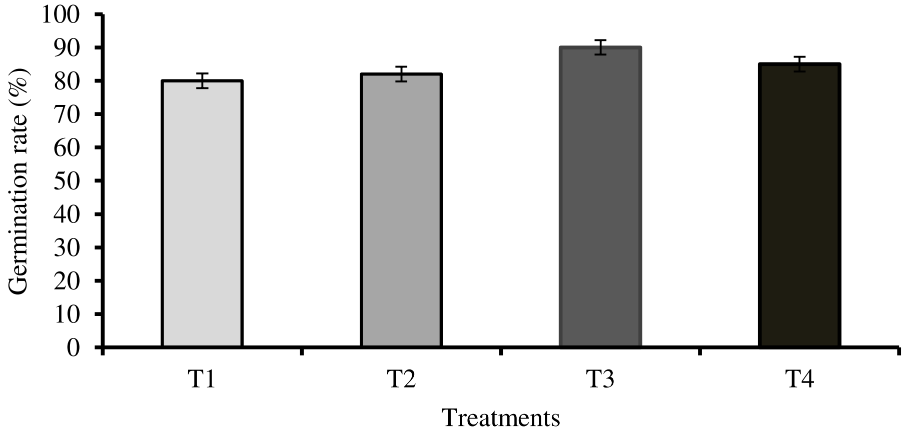

Figure-1. Maize germination rate under intermittent water application.

Figure-2 shows maize height as affected by the intermittent water application. At 2 WAP, the plants on T3 plots were higher than those on the other treatments plots that showed similar heights till 3 WAP before clear differences started showing. By 8 WAP, a maximum height of maize (128 cm) was found under T3 and was closely followed by plants under T2 (119 cm) then T4 (112 cm) and T1 (104 cm) followed. The plant height increased with increasing amount of water application and corresponding long application frequency intervals. However, the plant height reduced by 12.5 % from 7-day frequency intervals to 9-day frequency intervals even though the water application amount was higher. This corroborated with Mina *et al*. (1998) who observed appropriate irrigation frequency for maize as 7-day frequency intervals. Statistical analysis showed that there was a significant ($p \leq 5$ %) difference between T3 on one hand and T4 and T1 on the other, but not between T3 and T2. Similarly, significant difference existed between T2 and T1 but not between T1 and T4. The shortest plant height recorded at T1 could be that the shorter water application frequency intervals caused the soil surface wet that enhanced high evaporation thereby resulting in maximum rate of water loss (Hillel, 2004) which inhibited the maize growth.

The stem girth of maize was significantly affected by intermittent water application (Figure-3). The stem girth of maize plant increased from 2.3 cm at 2 WAP to 6.0 cm at 8 WAP for T3. The least stem girth after 8 WAP was recorded as 4.7 cm for T1. There was no significant difference on the stem girth from 2 WAP to 4 WAP among the treatments, but significant differences showed from week 5 WAP to 8WAP under T3 against T1, T4 and T2. There were no significant differences among T1, T2 and T4 at 8 WAP.

The maize LAI was affected by intermittent water applications (Figure-4), and the effect was exponential from 2 WAP to 6 WAP and then changed to linear up to 8 WAP. Even though the effect of the treatments on the LAI was of the order T3 >T2>T4>T1, there was no significant difference among the treatments from 2 WAP to 5 WAP. However, at 6 WAP, there was significant ($p \leq$ 5 %) difference between T3 and the rest of the treatments, and also between T2 and T4 on one hand and T1 on the other. At 7 WAP and 8 WAP, the significant ($p \leq 5$ %) difference only existed between T3 and the other treatments but there was no significant differences among the rest. The results indicated that large water amount at long water application interval increased maize LAI. This could be that the large volume of water application with long frequency interval allowed for quick evaporation from soil surface and the subsequent formation of dry soil surface layer served as mulching to reduce the rate of any further evaporation from the soil (Hillel, 2004). This LAI results corroborated with the assertion by Robert (2006) that evaporation is inversely related to the leaf area index. Even though the LAI increased with increasing amount of water at long frequency interval, the LAI started to reduce on T4 plots. This suggested that maize photosynthetic ability decreased beyond 7-day frequency intervals even though the applied water could be increasing. The results were in agreement with that of Ibrahim and Kadil (2007) who observed that extreme long water application frequency interval was detrimental to maize production.

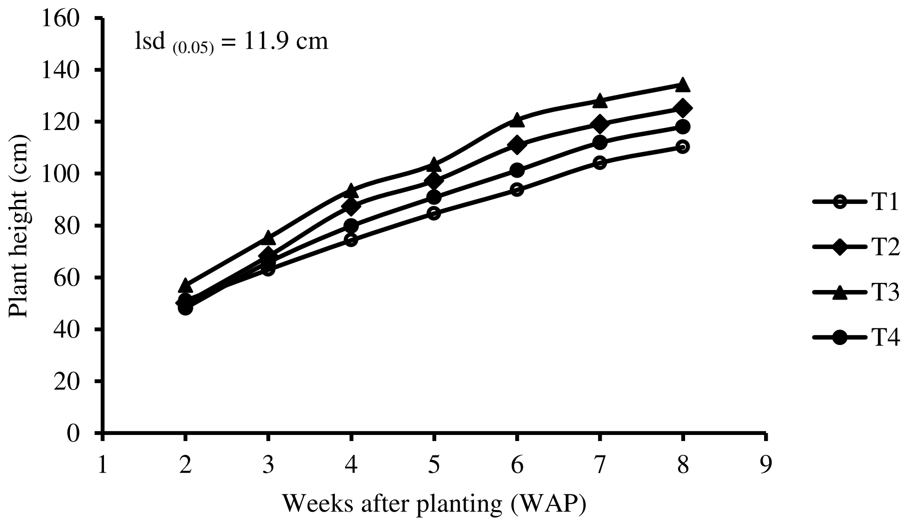

Figure-2. Plant height as affected by intermittent water application.

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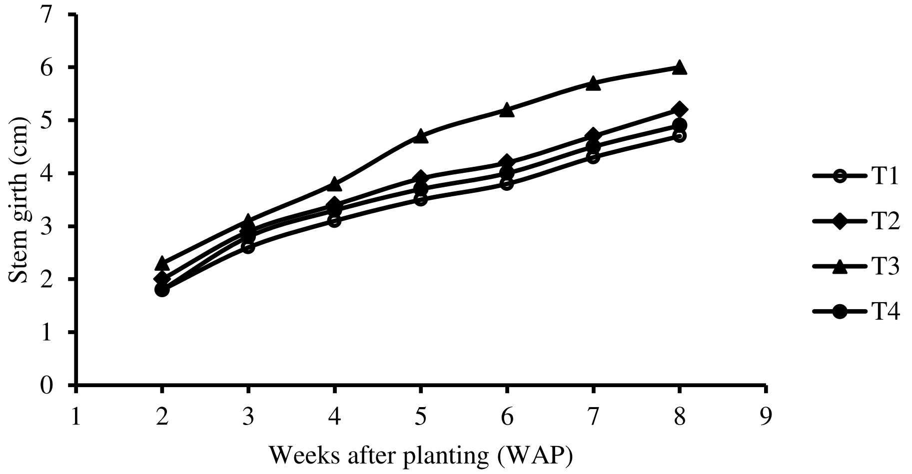

Figure-3. Effect of intermittent water application on maize stem girth.

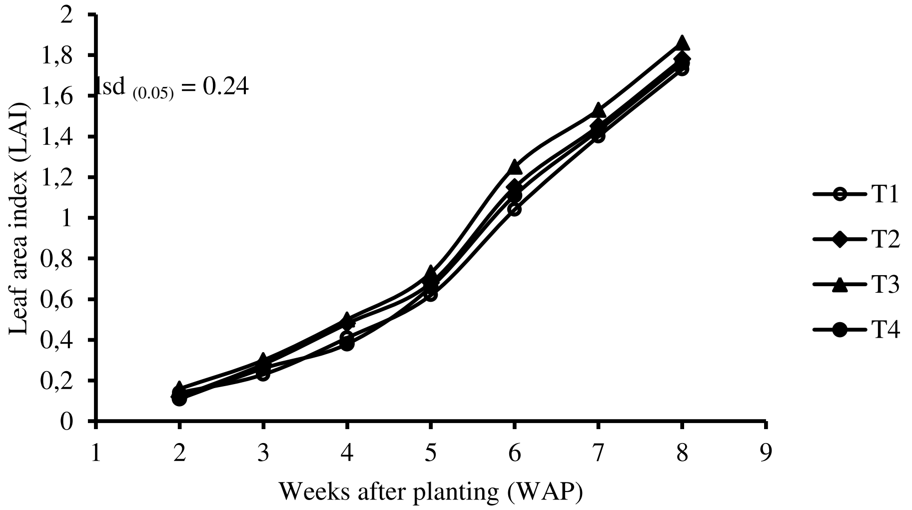

Figure-4. Maize LAI as affected by intermittent water application.

Intermittent water application on maize dry matter and water use efficiency

Table-2 shows the average maize dry matter weight and water use efficiency (WUE) as affected by intermittent water application at 8 WAP. The average dry matter weight ranged from 224 kgha^{-1} for T1 to 312 kgha^{-1} for T3 and the order was T1 (224.5 kgha^{-1}) < T2 (285.7 kgha^{-1}) < T4 (306.1 kgha^{-1}) < T3 (312.2 kgha^{-1}). There was significant ($p \leq 5$ %) differences among the treatments except between T3 and T4. The results indicated dry matter weight of maize increased with increasing water application at long frequency intervals but started to reduce at 9-day frequency intervals even though the water applied continued to increase.

Table-2. Effect of intermittent water application on maize dry matter and water use efficiency.

Treatment	Dry Matter (kgha^{-1})	Water Use Efficiency (kgm^{-3})
T1	224.5	2.0
T2	285.7	2.9
T3	312.2	2.8
T4	306.1	2.4
LSD(0.05)	26.5	0.28

From Table-2, the water use efficiency (WUE) of maize under the intermittent water application was in the order of T2 (2.9 kgm^{-3}) >T3 (2.8 kgm^{-3}) > T4 (2.4 kgm^{-3}) > T1 (2.0 kgm^{-3}). Statistically, there was significant ($p \leq 5$ %) differences among the treatments except between T2 and T3. The least WUE for T1 suggested that small amount (330 cm^3) of water application at short frequency

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intervals (3 days) could lead to low retention of soil moisture for plant physiological processes due to higher evaporative loss from the several shallow water applications (Hillel, 2004). Like the other measured parameters, there was increase in WUE with increasing amount of water supply at longer frequency intervals but at prolonged frequency interval (9-days) the WUE began to reduce though the applied water amount increased.

CONCLUSIONS

From the results of this study, intermittent water application had effect on maize production under tropical coastal savanna condition. Although there was no significant ($p \leq 5\%$) differences among the treatments on the germination rate, the effect of the treatments on all the maize growth and yield parameters determined except the WUE followed similar trend and the order was T3 > T2 > T4> T1. The effect on the WUE was in the order of T2 > T3 > T4> T1. It can be concluded that maize growth under the study area conditions increased with increasing water amount and long frequency intervals but prolonged frequency interval of 9-days reduced the maize performance even if the water amount was increased. Field trials under similar conditions are recommended for further studies.

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