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Effect of Partial Rootzone Drying Technique on Growth Performance of Sorghum

*Adzemi Mat Arshad[1], Ibrahim W[1,2] and Wan Zaliha W S[1]
1. Department of Agrotechnolog , Faculty of Agrotechnology and Food Science. Universiti Malaysia Terengganu, Kuala Terengganu, Malaysia
2.Department of Agricultural Technology, School of Agriculture and Food Science, Ramat Polytechnic Maiduguri, Borno State, Nigeria.
*adzemi@umt.edu.my

Abstract
A greenhouse experiments was conducted at Faculty of Agrotechnology and Food Science Research Farm, Universiti Malaysia Terengganu to evaluate the effects of partial rootzone drying (PRD) techniques on growth performance of sorghum planted on two series of soil. Partial root zone drying (PRD) consisted of a four irrigation regimes namely full irrigation (I_{100}), 75% (I_{75}), 50% (I_{50}) and 25% (I_{25}) and the two types of soil are Rhu Tapai Soil Series and Rengam soil Series. The experiment was laid out in a randomized complete block design with eight treatments. The treatments were randomly assigned to experimental polythenebags and replicated four times. A total of thirty two polythenebags were used for the study. All agronomic practices starting from preparation to harvesting were adhered to and growth and yield parameters were recorded for the experiment. The result of the study shows that, sorghum performed better under the PRD technique. The results further revealed that, irrigation regimes I_{100} and I_{75} performed better in terms of growth parameters, crop water use efficiency, under PRD compared to I_{50} and I_{25} irrigation regimes. The study also revealed that there were interaction effects of PRD irrigation and the two types of soil on some of the parameters such as leaf area index, girth, tillers, harvest index, root dry matter used for the study. The study, therefore, recommended the use of PRD irrigation for optimizing sorghum production in this agro ecological zone.
Keywords: Partial root zone drying, growth, sorghum

1. Introduction

Deficit irrigation is an optimization strategy in which irrigation is applied during drought sensitive growth stages of a sorghum crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water for the growth and yield of sorghum crop. Water restriction is limited to drought tolerant phonological stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. Hence, this inevitably results in plant draught stress and consequently in production loss. Deficit irrigation maximizes water productivity, which is the main limiting factor (English, 1990). In other words, deficit irrigation aims at stabilizing yields and at obtaining maximum water productivity rather than maximum yields. Since drought tolerance varies considerably by genotype and by phenological stage.

Deficit irrigation requires defined knowledge of crop response to drought stress for each of the growth stages (Kirda *et al,* 2005). In addition, correct application of deficit irrigation requires a systematic assessment of the economic impact of the yield reduction caused by drought stress in relation to sorghum (English, 1990, English *et al,* 1989, Sepaskhah and Khajehabdollah, 2005). In areas where water is the most restraining factor maximising water productivity may be economically more profitable for the sorghum farmer than maximising yields. For instance, water saved by deficit irrigation on sorghum production can be used to irrigate more land given the high opportunity cost of water and this may largely pay costs for the economic loss due to yield reduction (Loveys *et al*, 1998).

Another benefit of deficit irrigation is the possibility of controlling sowing dates of sorghum crop by irrigation, which allows improved planning of agricultural practices. If a common irrigation strategy is adopted in a region, peaks in irrigation water supply will occur during drought sensitive stages. This might result in under-irrigation of land at the tail end of the irrigation network, causing more severe yield reduction than anticipated.

Deficit irrigation can be accomplished by means of partial rootzone drying and regulated deficit irrigation methods. Partial rootzone drying is an irrigation technique that improves water use efficiency of crops without significant crop reduction. The technique was developed on the basis of knowledge of the mechanisms controlling transpiration and requires that approximately half of the root system be always in a dry or drying state while the remainder is irrigated. On the other hand, regulated deficit irrigation is an irrigation technique which controls vegetative and reproductive growth. It was initially applied in peach and pear orchards to control growth by imposing water stress at key stages of fruit development. Farre and Faci (2006) reported greater water use efficiency with sorghum compared to sorghum with deficit irrigation in Spain on a loam soil. Tolk and

Howell (2003) reported the mean water use efficiency for sorghum of 1.46kg per m^3 at Bushland on the Pullman clay loam soil but they reported greater water use efficiency for the Ulysses silt loam soil. They also reported that deficit irrigation of sorghum at Bushland did not reduce yield but increased water use efficiency.
The pressure on limited fresh water resources is on the augment. Irrigated agriculture is the largest water consuming sector and it faces competing demand from other sectors such as the industrial and domestic sector (Guang-Cheng *et al,* 2008). Irrigated agriculture uses more than 70% of the water inhibited from the earth's rivers in developing countries the proportion excess 80% (FAO, 2009). The possibility for further irrigation development to meet food requirement in the coming years is severely constraint by declining water resources especially in the sorghum production regions of semi-arid. Although on a global scale, water resources are still ample, serious water shortages are developing in and around semi-arid regions as existing water resources reach full exploitation. The agricultural sector faces the challenge to produce more food with less water (Kijne *et al,* 2003). Shortage may be seasonal, year round or progressively significant as demands from other users expand. Owing to the wide scale expansion of irrigation farming water has become increasingly a scarce resource. Scarcity is further complicated when water supplies are doubtful. Declining water resources and increasing food requirement requires a greater efficiency in water use, both in rain-fed and in irrigated agriculture. To cope with scarce supplies, deficit irrigation which is the application of water below full crop water requirement is an important contrivance to achieve the goal of reducing irrigation water use and maximising water use efficiency for higher yields per unit of irrigation water applied.
Therefore irrigation water management in an era of water scarcity will have to be carried out most efficiently aiming at saving water and at maximising the productivity. Deficit irrigation has widely been reported as a valuable strategy for dry regions (English, 1990, Fereres and Soriano, 2007) where water is the limiting factor in crop cultivation. The main objective of the study was to assess the effect of partial rootzone drying irrigation on the growth performance of sorghum cultivar.

2. Materials and Methods

The experiment was conducted in a greenhouse at Faculty of Agrotechnology and Food Science Universiti Malaysia Terengganu, with Latitude and Longitude; 5^0.20'N 103^0 5'E. The Altitude is about 32 m. The climate of the area is tropical rain-forest with a mean annual rainfall of 2911 mm (114.6 in).The average temperature in Terengganu is 26.7^0C (min 22^0C, max 32^0C),while the mean relative humidity for an average year is recorded as 71.7% and on a monthly basis it ranges from 68% in May and June to 79% in December. Sorghum (*Sorghum bicolor L. Moench*) cultivar Samsorg-KSV8 from Nigeria was used in this research. The plants were planted on Rengam Series soil (Ultisol) and Rhu Tapai (Sandy soil) or Bris (Beach ridges interpersed with swales soil) Table 1.
Experiment consist of various treatments comprises of four different regimes of irrigation namely: (i) 100% PRDI (I_{100}), (ii) 75% PRDI (I_{75}), (iii) 50% PRDI (I_{50}), and(iv) 25% PRDI (I_{25}) which were alternated at root-zone (Partial root-zone drying irrigation), and one type of sorghum cultivar (SAMSORG 14-KSV8). Soil types were at two levels namely: Rengam (Ultisol) and Rhu Tapai, (BRIS). All treatments were arranged in a RCBD with four replications. Irrigation water was alternated (dry and wet) at every two weeks. A total of thirty two polythene bags were used for experiment. Hence, the crop water use for the sorghum cultivars was determined by estimating the reference crop evapotranspiration from climatic data using the Hargreaves method (Hargreaves and Alten, 2003). The total area of experimental in glass house was 185.81m^2 and four lateral line pipes, each were connected to the pipe with stoppers attached at each joints of laterals connecting to main pipes. Emitters or drippers were attached according to plant spacing of 75 by 50cm. On each drippers were attached with clippers for regulating the irrigation. The actual evaporation which is synonymous to crop water use was estimated by multiplying reference evapotranspiration with appropriate value of crop coefficient (Doorenbos and Pruitt, 1975).

$$ET_c = K_c \text{ x } ET_c$$

Where;

K_c = crop coefficient

ET_o = reference crop evapotranspiration in mm/day

Data collection started after transplanting. Growth parameters were recorded during the crop growth development: number of leaves per plant, plant height, stem girth and leaf area index, herbage index and root dry matter.
All data collected were analyzed using SAS statistical program (SAS Inst., 1999). Analysis of variance (ANOVA) test was conducted and significant differences among the treatments were determined using the TUKEY method.

3. Results and Discussion

Partial rootzone drying irrigation is a customized form of deficit irrigation (English *et al*, 1990), which involves irrigating only one fraction of the rootzone in each irrigation event, leaving another part to dry to certain soil water content before rewetting by changing irrigation to the dry side. In fact, half of the roots is placed in drying soil and the other half is growing in irrigated soil.

3.1 Growth Parameters

The growth parameters studied were plant height, number of leaves per plant, leaf area index, root dry matter, stem girth, tillers and harvest index. Result in Table 2 revealed that, growth traits were significantly affected by treatments in sorghum plants. Plants irrigated with one hundred percent (I_{100}) and seventy five percent (I_{75}) of crop water requirement recorded highest values of plant heights, of 233.01cm and 214.49cm respectively. The highest status obtained may be due to higher availability of moisture which might have provided a better nutrient retrieval by the crops which in turn increased assimilation of more phosphates (Ahmadi *et al*, 2010a). This is followed by the fifty percent (I_{50}) irrigation regime and the least plant height was obtained by the twenty five percent (I_{25}) irrigation regimes. The result also showed there was no significant difference from I_{100} percent and I_{75} percent of the two irrigation regimes (Tolk and Howell, 2003).

The result in Table 2 revealed that partial rootzone drying irrigation regimes had showed significant difference in number of leaves. The highest mean value of 18 was recorded for seventy five percent irrigation regimes which were closely followed by one hundred percent irrigation regime and fifty percent irrigation regime with values of 17, and 17 respectively. The least value of 12 was recorded for the twenty five irrigation regime as shown by Rhu Tapai Soil Series, Irrigation regimes of I_{100}, I_{75} and I_{50} were found to be statistically similar while I_{25} was significantly different from the others. There was significant different between two types of soil which showed from the table 2a, the Rengam Soil Series revealed lower numerical values in comparison with Rhu Tapai Soil.

The result in Table 2 indicated interaction effects of partial rootzone drying irrigation and soils on leaf area index. They showed Significant difference among irrigation regimes applied during the growth of the sorghum cultivar under Rhu Tapai and Rengam Soil Series respectively. At the five leaves, the leaf area index was extremely low in all the irrigation regimes as well the soil types as shown in Table 2.

During the jointed stage there was a significant difference among the irrigation regimes as showed in Table 2. The result also revealed that there was significant different between the two types of soil used. However, at these stages the leaf area index was low and could be due to the number and sizes of the leaves. Table 2 shows the effect of partial rootzone drying irrigation on leaf area index (LAI) with significant difference among deficit irrigation regimes applied. The leaf area index of all irrigation regimes at flowering and dough stages were found to be statistically significant. The leaf area index for the irrigation regimes at flowering (FS) and dough stages (DS) were at par from those in the jointed stage, the results of leaf area index at the dough stage shown in Table 2 were found to be higher. The highest leaf area index (LAI) was recorded at dough stage for all the irrigation regimes but the leaf area index values in five leaf stage and jointed were numerically lower than that of flowering and dough stages. In partial rootzone drying on the irrigated side absorb enough water to maintain high shoot water potential, alternatively the roots on the non-irrigated side produce abscisic acid (ABA) or possible reduction in stomatal conductance. Partial rootzone drying therefore optimize water use and increase water productivity (Liu et *al,* 2006b, Ahmadi *et al*, 2010a and Sepaskhah *et al,* 2008).

The result in Table 3 revealed that there was significant difference among the irrigation regime applied in terms of root development under both Rhu Tapai and Rengam Soil Series. The I_{75} percent irrigation regime recorded the highest numerical value of 678.00g this was closely followed by the I_{100} percent irrigation regime with a root dry matter value of 646.30g under Rhu Tapai Soil Series. However, the result also showed that under Rengam Soil Series the I_{100} percent irrigation recorded the highest numerical values and immediately followed by the I_{75} percent irrigation regime with a root dry matter valued at 486.30g and 447.66g under Rengam Soil Series respectively. No significant different between the two ($I_{100}$and I_{75}) regimes as shown in table 4.17 under both soil types. The result in Table 2b also revealed that I_{50} percent irrigation regime was higher than the I_{25} percent irrigation regimes under both (Rhu Tapai and Rengam Soil Series). Roots in dry soil produce more ABA under normal condition (Davies and Zhang, 1991) and it is enthused as anti stress root chemical signal to shoot through transpiration stream and limits the stomatal conductance (Kang and Zhang, 2004, Liu *et al*, 2006b). Earlier studies indicated that partial rootzone drying enhanced the extension and inhibition of primary and secondary roots (Kang *et al*, 2004). The result also revealed that, the two types of soil used were statistically different.

Table 3 shows the girth of sorghum cultivar as affected by the partial rootzone drying irrigation regimes. The result revealed that there was significant difference among the irrigation regimes. Perusal of the results however shows that one hundred percent irrigation regime (I_{100}) had the highest numerical value of the stem girth as showed in table 4.18 and this was followed by seventy five percent irrigation regime (I_{75}) and the fifty percent irrigation regime (I_{50}).the least value was recorded under the twenty five percent irrigation regime I_{25}. The girth of the sorghum shows that plants irrigated using the one hundred percent and seventy five percent irrigation regimes are thicker than those irrigated by fifty percent and twenty five percent irrigation regimes. This could be attributed to the partial rootzone drying efficiency of the system in terms of water application. Table 3 had

indicated that there was significant difference among partial rootzone drying irrigation regime examined on tiller. Perusal of the result showed that numerically one hundred percent irrigation regime (I_{100}) is higher with 6. While the seventy percent irrigation regime (I_{75}) followed closely also with 6 From the result also the fifty percent irrigation regime (I_{50}) and twenty five percent irrigation regime (I_{25}) values of 5 and 3 respectively (Table 3).
The result also in Table 3 shows higher irrigation levels, the hundred percent regulated deficit irrigation regime (I_{100}) and seventy five percent regulated deficit irrigation regime (I_{75}) had shown no significant different between the two irrigation regimes. however, the harvest indexes of the two irrigation regimes (I_{100} and I_{75}) was higher than that of fifty percent regulated deficit irrigation (I_{50}) and twenty five percent regulated deficit irrigation regimes (I_{25}) respectively that decreased markedly with increasing water deficit. Sorghum was therefore, had efficiency in converting biomass into grain yield under deficit irrigation situations. The result is supported by those of Liu *et al* (2006), Zhang (2003) and Loveys *et al,* (2004). Results also indicated no significant different between the soil types. The data in Table 3 show that water use efficiency was significantly affected by partial rootzone drying irrigation regimes. Water use efficiency had higher values with the I_{100}percent irrigation regime than the other three irrigation regimes. However, closer look at the result shows that I_{100}percent partial rootzone drying irrigation regime had the highest crop water use efficiency value 1.513 compared to 1.306, 1.057 for seventy five percent irrigation regime and fifty percent irrigation regime respectively (Table 3). No yield obtained for twenty five percent irrigation regimes. This translates to more economic water utilization which results in higher yield. The result is at tandem with the findings of Fereres and Soriano (2007), Du *et al,* (2010) and Ahmadi (2009). Statistically there was no significant different between the soil used in relation to irrigation water applied.

4. Conclusion

Based on the results from this study partial root zone irrigation is recommended for sorghum production and irrigation regimes at I_{100} and I_{75} performed better in terms of growth parameters, crop water use efficiency compare to I_{50} and I_{25} irrigation regimes.

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Table 1: Physio-chemical properties of Rhu Tapai and Rengam Soil Series.

Soil properties	Rhu Tapai	Rengam
Particle size distribution		
Silt (%)	2.52	3.07
Sand (%)	67.35	30.28
Clay (%)	30.13	66.65
Texture	Sandy	Clay
Organic matter (%)	0.99	1.62
pH (1:1 suspension)	4.6	4.8
Bulk Density (g/cm^{-3})	1.27	1.31
CEC (cmol (+) kg^{-1} soil	9.53	7.14
Total nitrogen (%)	0.09	0.15
Exchangeable bases (cmol (+) kg^{-1} soil		
Ca	0.20	0.17
Mg	0.02	0.10
K	0.01	0.10
% of water base on weight		
0.33 bar	6.5	23.5
1.0 bar	4.0	30.5

Table 2: Effects of partial rootzone drying irrigation on growth parameters of sorghum

Treatment	Plant height (cm)	Number of leaves/plant	Leaf area index			
Irrigation			Fls	Js	Fs	Ds
I_{100}	233.01[a]	15.00[a]	0.22[a]	4.94[a]	10.94[a]	10.73[a]
I_{75}	214.49[a]	15.00[a]	0.15[a]	3.63[a]	8.84[b]	9.72[a]
I_{50}	189.32[b]	15.00[a]	0.13[a]	2.92[b]	5.63[b]	7.36[b]
I_{25}	132.32[b]	13.00[b]	0.09[a]	1.32[c]	2.56[d]	2.76[c]
Rhu Tapai Soil	193.07[a]	17.00[a]	0.18[a]	3.21[a]	7.34[a]	7.75[a]
Rengam Soil	191.50[a]	13.00[b]	0.12[b]	3.20[a]	6.65[a]	7.54[a]

Means followed by the same letter within column are not significantly difference
at P $\leq$ 0.05 using DNMRT
*Fls = Five leaf stage, Js = Jointed stage, Fs = Flowering stage, Ds-Dough stage.

Table 3: Effects of partial rootzone drying irrigation on growth parameters of sorghum

Treatment	Root dry matter (g)	Girth (cm)	Tillers	Harvest index (kg/m^3)	*CWUE kg/m^3
Irrigation					
I_{100}	566.30[a]	5.10[a]	6.00[a]	43.88[a]	1.52461[a]
I_{75}	562.84[a]	4.51[ab]	6.00[a]	43.55[a]	1.40564[b]
I_{50}	485.45[b]	3.81[bc]	5.00[ab]	27.41[b]	1.05712[c]
I_{25}	151.80[c]	3.22[c]	3.00[b]	00.00[c]	0.00000[d]
Rhu Tapai Soil	509.91[a]	4.33[a]	5.00[a]	31.85[a]	0.99852[a]
Rengam Soil	373.29[b]	3.98[a]	4.00[a]	25.57[b]	0.95927[b]

Means followed by the same letter within column are not significantly difference
at P $\leq$ 0.05 using DNMRT
*CWUE-Crop water use efficiency