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Effect of Partial Rootzone Drying Technique on Yield and Yield Components of Sorghum Cultivar

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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 yield and yield components 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 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 yield and yield components, 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 deficit irrigation and the two types of soil on some of the parameters such as harvest index and number of panicle used for the study. The benefit-cost ratio of sorghum production under I_{100} and I_{75} irrigation regimes were found to be economically better compared to I_{50} and I_{25} irrigation regimes for PRDI. The study, therefore, recommended the use of PRDI for optimizing sorghum production in the semi arid regions..

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 and Raja, 1996; 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 (Corbeels *et al*., 1998). 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. Hsiao *et al*. (1976) reported that when sorghum is subjected to mild to moderate stress, its harvest index increases above that of full irrigation.

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 (Graham *et al*. 2003). Irrigated agriculture uses more than 70% of the water inhibited from the earth's rivers in developing countries the proportion excess 80% (FAO, 2002). 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 and yield of sorghum cultivars.

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 (figure 1). 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).

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 *et al*. 2003). The total area of experimental field 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. yield parameters were recorded during the crop growth and development: Yield components like number of panicle per stand, panicle weight, and herbage index, 1000grain weight, seed and total yield per hectare were equally measured.

All data collected were analyzed using SAS statistical program (SAS Inst 1991). Analysis of variance (ANOVA) test was conducted and significant differences among the treatments were determined using the TUKEY method.

RESULT 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.

Yield and yield components.

Table 3a revealed that grain yield were higher in one hundred percent irrigation regime (I_{100}%). The result further revealed that seventy five percent irrigation regime (I_{75}%) was numerically higher than the other two irrigation regimes as shown in table 3a. However, partial rootzone drying irrigation resulting in also high yield in seventy five percent irrigation regime (I_{75}%) and fifty percent irrigation regime (I_{50}%). This result is benefit for sorghum. These results support the reputed drought tolerance of sorghum (Kriedmann *et al*, 2003; Mastrorilli *et al*, 1995). This result is in conformity with findings of the followings, the different experiment results in partial rootzone drying have shown that irrigation water may be reduced by approximately 30 to 50 percent in partial rootzone drying with no significant yield reduction (Kang and Zhang, 2004; Leib *et al*, 2006; Guang-cheng, *et al,* 2008; Ahmadi, 2009..

The data in table 3a Shows significant difference among the partial rootzone drying irrigation regimes, whereby results also revealed plants that received I_{100}percent irrigation regime recorded highest values panicle length (48.88cm) while I_{75}percent irrigation regime obtained the numerical value of 47.0cm. However, the I_{50}percent irrigation regime highly differed with the I_{25}percent irrigation regime with 40.0cm as shown in table 4.21. Statistically there was no different between the two types of soil used in terms of the irrigation applied. The differences among the irrigation regimes with respect to 1000grain weight were found significant had revealed in table 3a. The highest 1000grain weight value was from I_{100}percent irrigation regime, they were followed by I_{75}percentirrigation regime, I_{50}percent irrigation regime and the last value from I_{25}percent irrigation regime as stipulated in table 3a.The analysis of the data as shown in table 3a revealed that partial rootzone drying irrigation regimes exerted a significant influence on a panicle weight. It is clear from these data; the I_{100}percent irrigation regime had the highest numerical value of 161.27g while the I_{75} closely followed with 152.04g. The I_{50} percent irrigation regime value of 124.81g is at par in comparison with I_{25} irrigation regime as examined in table 3a the result also revealed that, the two types of soil were not significantly different in relation to irrigation applied.

The result in table 3b indicates that irrigation regimes significantly affected number of panicles. Result indicated that I_{100}percent irrigation regime gave higher values (5.00 and 4.00) compared with the other three irrigation regimes under both soil types. I_{75} percent irrigation regime with value of (4.00 and 3.00) followed closely while the result also showed I_{50} percent irrigation regime is at par in comparison with I_{25} percent irrigation regime value as indicated in table 4.24 under both soil types. Result indicated that I_{100} percent irrigation regime gave higher values compared with the other three irrigation regimes. I_{75} percent irrigation regime with value of (3.25) followed closely while the result also showed I_{50}percent irrigation regime is at par in comparison. Also there was no significant different between the oil types in relation to irrigation water applied. The effect of regulated deficit irrigation on harvest index (HI) showed significant difference among the regimes applied as shown in Table.3b.

The result also in Table 3b 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 Faci and Fereres, (2006), Liu *et al*; 2005; Zhang *et al*; 2004. Loveys *et al* 2004. Results also indicated no significant different between the soil types. The data in table 3b 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 3b). 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,* 2008a; Ahmadi, 2009. Statistically there was no significant different between the soil used in relation to irrigation water applied

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Economic Performance and Profitability Measures

Table 4 reports the average values of total revenue, total expenditures, variable and fixed costs expenditures of sorghum production under partial root zone drying irrigation (PRDI). The findings revealed that PRDI is profitable under the different regulated deficit irrigation regimes. However, one hundred percent (I_{100}) partial rootzone drying irrigation have the highest net and gross profits while fifty percent (I_{50}) partial rootzone drying irrigation treatments has the lowest. This could be due to efficient water supply to I_{100}, which resulted to higher yield and subsequently high profit. The value of BCR, which measures the profit per unit dollar invested, shows a remarkable performance for all the different regulated deficit irrigation regimes. According to the findings of the study, sorghums farmers can generate \$2.1, \$1.8, and \$1.5 for every \$1 dollar invested in the I_{100}, I_{75} and I_{50} respectively.

Conclusion

Partial rootzone drying irrigation treatments evaluated showed that significant difference on yield and yield components, the extreme stress shortens the grain filling period, which reduces the final seed size and eventual there was no yield at the I_{25} percent partial rootzone drying Irrigation regimes. The crop water use efficiency was significantly affected by the partial Root zone drying regimes. I_{100} percent partial rootzone drying regimes recorded highest values of crop water us efficiency (1.51358Kg/m^3) while the lowest recorded at I_{50} percent partial rootzone drying irrigation regime (1.05712Kg/m^3*)*. Yield of sorghum grains grown on Rhu Tapai and Rengam Soil Series as shown in both Table 4.3.1 and 4.6.1 have revealed that, there were no significant different between the two types of soil used in relation to the irrigation water applied. The result indicated that, numerically Rhu Tapai and Rengam Soil Series under Partial Rootzone Drying recorded the following mean values (5254.4 and 5040.3Kg/ha) respectively. These indicated that when Rhu Tapai Soil Series is correctly treated with sufficient organic matter and appropriate agronomic practices applied can produce competitive yield in comparison with Rengam Soil Series under sorghum production. The value of BCR, which measures the profit per unit dollar invested, shows a remarkable performance for all the different regulated deficit irrigation regimes. According to the findings of the study, sorghums farmers can generate \$2.1, \$1.8, and \$1.5 for every \$1 dollar invested in the I_{100}, I_{75} and I_{50} respectively

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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})	i.27	1.31
CEC (cmol (+) Kg^{-1} soil	9.53	7.i4
Total nitrogen (%)	0.09	0.15
Exchangeable bases (cmol (+) Kg^{-3} soil		
Ca	0.2	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
15 bar	3.02	17.2

Based on ECEC

Table 3a: Effects of partial rootzone drying irrigation on sorghum yield and yield components.

Treatment	Yield (Kg/ha)	Panicle length (cm)	Panicle weight (g)	Harvest index (Kg/m^3)
Irrigation				
I_{100}	8037.10^a	48.87^a	177.24	43.88^a
I_{75}	7539.40^a	47.00^a	162.04^a	43.55^a
I_{50}	5613.30^b	40.00^b	144.61^b	27.41^b
I_{25}	0000.00^c	00.00^c	000.00^c	00.00^c
Rhu Tapai Soil	5254.40^a	34.75^a	122.45^a	31.85^a
Rengam Soil	5040.30^a	33.18^a	116.61^a	25.57^b

Means followed by the same letter within column are not significantly difference at $P \leq 0.05$ using DNMRT

Table 3b: Effects of partial rootzone drying irrigation on sorghum yield and yield components.

Treatment	Number of panicles	1000Grain weight (g)	Crop Water use efficiency (Kg/m^3)
Irrigation			
I_{100}	6.00^a	39.32^a	1.51358^a
I_{75}	6.00^a	38.86^a	1.30686^b
I_{50}	3.00^b	28.51^b	1.05712^c
I_{25}	0.00^c	00.00	0.00
Rhu Tapai Soil	5.00^a	27.43^a	0.98952^a
Rengam Soil	5.00^a	26.95^a	0.94927^a

Means followed by the same letter within column are not significantly difference at $P \leq 0.05$ using DNMRT

Table 4: Costs and Benefits Analysis

Items	PRD		
	I_{100}	I_{75}	I_{50}
	Value($/ha)		
Outputs			
Yields(Kg)	8037.1	6939.4	5613.3
Unit price(100kg)	0.31	0.31	0.31
Total revenue	2491.5	2151.2	1740.1
Variable inputs Costs			
Seed	0.75	0.75	0.75
Water used	7	7	7
Fertilizer	15.72	15.72	15.72
Land hiring/renting	22.1	22.1	22.1
Labor costs:			
Land preparation	3.14	3.14	3.14
Weeding	1.26	1.26	1.26
Fertilizer application	0.63	0.63	0.63
Water application	8.81	8.81	8.81
Harvesting	3.14	3.14	3.14
Total variable costs	62.55	62.55	62.55
Fixed inputs costs			
Depreciation costs	1100	1100	1100
Total fixed costs	1100	1100	1100
Total costs	1162.5	1162.5	1162.5
Net profit	1328.9	988.66	577.57
Gross profit	2428.95	2088.66	1677.57
Benefit costs ratio	2.1431	1.8504	1.4968

Source: Field experiments
*PRDI = Partial rootzone drying irrigation