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Growth, Yield and Water Use Effeciency of Forage *Sorghum* as Affected by Npk Fertilizer and Deficit Irrigation

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Abstract

Drought stress (DS) is an important limiting factor for crop growth and production in some regions of the world. Limitation in water availability precludes optimal irrigation in some production regions. Therefore, investigations on the interaction of other factors to mitigate the DS to varying degree are important. Two field experiments were conducted in the experimental farm of the National Research Centre, Shalakan, Kalubia Governorate, Egypt, during 2004 and 2005 summer seasons to evaluate the interactions between N, P, K rates and optimal vs. deficit irrigation regimes on biomass yield as well as water use efficiency (WUE) of forage *sorghum*. Omission of the 4th irrigation significantly decreased the biomass of *sorghum* c.v. Pioneer, as compared to that of the plants receiving optimal irrigation or subject to omission of the 2nd irrigation. The biomass yield increased with an increase in NPK fertilizer rates. Plant height and leaf area also decreased by omitting the 2nd irrigation as compared to that of the plants under optimal irrigation, and further declined with omission of the 4th irrigation. The biomass of the plants (dry weight basis) that received the high N, P, K rates was greater by 26%, 29%, and 35% as compared to that of the plants that received no N, P, K fertilizers, under optimal irrigation, omission of the 2nd, and omission of the 4th irrigation, respectively. The corresponding increases in water use efficiency (based on fresh weight yield) were 37%, 42%, and 55%.

Keywords

***Sorghum*-Forage-Omitting of Irrigation-NPK Fertilizer-Growth, Yield-Water Use Efficiency**

1. Introduction

Drought stress (DS) is the most important limiting factor for crop production in arid and semi-arid regions of the

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world. Severe DS during vegetative growth stage and moderate DS during flowering stage of grain *sorghum* crop contributed to about 30% of reduction in grain yield, despite high water use efficiency [1]. New land used for cultivation of forage crops, including forage *sorghum* (*Sorghum bicolor* L.), are rather marginal in soil characteristics and productivity. Sustainable production can be achieved on these marginal soils only through use of cultivars tolerant to drought and salinity stress.

Forage *sorghum* is an important biomass crop for hay and silage [2]. *Sorghum* as a livestock feed is of significant importance, particularly in the tropical zone because of its adaptation to low fertility soils and other limiting factors, such as DS [3].

Mineral fertilizers play a vital role in improving crop yields but the major challenge is to ensure adequate balance between the different nutrients and support optimal yield. Current recommendations for producing optimal forage yields of *sorghum*-sudan grass hybrids suggest application of 50 to 100 kg·N·ha^{-1}, applied in two equal doses at planting and after the first cut [4]. Timing and placement of N application should be managed to avoid significant losses while ensuring availability of adequate N when needed by the crop. *Sorghum* sudan grass is usually managed with low N fertilizer inputs (≤80 kg·ha^{-1}) since growth and yield responses to N rates have been reported only up to 80 kg·ha^{-1} [5].

The optimum P availability is important for improving mineral P concentrations and yields of most crops [6] [7]. Soil solution P, following the dissolution of P fertilizers applied to the soil, is either taken up by the plants, precipitated, or adsorbed on the exchange sites in the soil [8]. Pholsen and Somsungnoen [9] reported an increase in most growth parameters of forage *sorghum* plants with an increase in N and K rates from 450 to 650 and 50 to 100 kg·ha^{-1}, respectively. Ogunlela and Yusuf [10] reported significantly greater K content in 3 cultivars of forage *sorghum* with 75 kg·ha^{-1} K as compared to that of the plants receiving 25 or 50 kg·ha^{-1} K. Sharma and Kumari [11] reported that plant height, leaf area index, leaf area duration, plant growth rate, total dry matter production, K concentration and grain yield increased with K application rate from 25 to 50 kg·ha^{-1}. Adequate availability of soil water and nutrients is important to support optimal plant growth and production in the arid and semi-arid regions [12]. Best management of nutrients is a successful strategy to alleviate abiotic stresses [13].

The objective of this study was to investigate the interactions between different rates of N, P, K and DS on growth, yield, and water use efficiency of forage *sorghum*.

2. Material and Methods

Two field experiments were conducted at the National Research Centre, Shalakan, Kalubia Governorate, Egypt, in 2004 and 2005 to evaluate the effects different rates of N, P, K fertilization on mitigating the adverse effects of DS on forage *sorghum*. The experiment comprised of factorial combination of 3 irrigation (main) and 4 fertilizer rates (sub) as shown below with 6 replications.

Irrigation treatments: Optimal irrigation (OI; No water stress), vs. two deficit irrigation (DI) treatments, *i.e.* omitting 2nd (DI-1) or 4th (DI-2) irrigation. The water uses for OI and DI treatments were 7960 and 6960 m^3·ha^{-1}, respectively. Sub treatments were rates of N:P:K (in kg·ha^{-1}); 0 (0:0:0), 1 (36:8.4:32), 2 (72:16.8:64), 3 (144:33.6:28). Plot size was 3 × 7 m.

The full rates of P (as calcium super phosphate, 6.8% P) and K (as potassium sulfate, 40.3% K), as per treatments, were broadcast and mixed with the soil during pre-plant tillage. Forage *Sorghum* (*Sorghum bicolor* (L.) Moench*)* cv. Pioneer was planted on July, 15th both years. The seed rate was 96 kg/ha^{-1} in both seasons. Nitrogen rates, as per treatments, were applied as ammonium sulfate (20.5% N) in two equal doses; 21 and 35 days after sowing. The standard production practices for forage *sorghum* followed in the province were adapted (Recommendations of Egyptian Ministry of Agriculture, unpublished). The amount of each irrigation was 750 m^3·ha^{-1}, except the irrigation after sowing was 1000 m^3·ha^{-1}.

The following measurements were made on two plants from every subplot before cutting (Cutting was done 70 days after planting): Plant height (cm); number of green leaves; leaf area; fresh and oven dry (70˚C for three days) weights of stem and leaves.

Water Use Efficiency (WUE; kg·m^{-3}) was calculated as marketable yield (kg) per unit water use (m^3). Fresh and dry yields of forage per plot were measured and yield per ha was calculated.

Statistical significance of the treatments effects was evaluated by analysis of variance (ANOVA) test as described by [14].

3. Results and Discussion

Water stress *i.e.* omitting either the 2nd or 4th irrigation, significantly influenced plant height, leaf area, fresh weight of plant tops, and stem dry weight (**Table 1**). The negative effects of water stress were greater by omitting the 4th irrigation as compared to those by omitting the 2nd irrigation. Our results concur with those of Carmier *et al.* [15] who reported that irrigation influenced plant height and dry matter.

Mohammadkhani and Heidri [16] subjected the six-day-old seedlings to different concentrations of poly ethylene glycol (PEG) 6000 to induce drought stress treatment. After 24 h treatment in PEG 6000 the electrolyte leakage increased. Under drought stress the activities of protective enzymes in roots and shoots increased sharply. Drought induced by 40% concentration of PEG, which induced water potential of 1.76 MPa, which affected soluble sugars and proline content. The soluble sugars play an important role in the production of other compounds, energy, and stabilization of membranes [17], act as regulators of gene expression [18] and signal molecules [19]. Proline is important in water adjustment through stomatal aperture which, in turn, affects transpiration and photosynthesis [20]. Boomsma and Vyn [21] reported that water stress influenced plant uptake of water as well as nutrients. Li *et al.* [22] demonstrated that water stress impaired the oxidative defense systems in plants.

Omitting the 4th irrigation significantly decreased the fresh and dry yield of *sorghum* as compared to those of the plants grown under optimal irrigation or omitting the 2nd irrigation (**Table 2**). Li *et al.* [22] reported that *sorghum* yield affected by spatial or temporal stress from drought. Akmal and Jansenes [23] concluded that water deficit affected growth and yield of ryegrass. Ferre and Faci [24] demonstrated that deficit irrigation or reduced frequency of irrigation during the grain filling stage did not significantly affect the corn yield. They concluded that flowering stage was the most sensitive to water deficit as evident from significant reduction in biomass yield and harvest index due to water stress during flowering stage. They reported a linear relationship between amount of irrigation and grain yield.

Our study also revealed that WUE was greater for the plants subjected to omission of the 2nd irrigation than those of plants grown under optimal irrigation or omission of 4th irrigation (**Table 2**). The latter treatment resulted in the least WUE, both based on fresh or dry biomass weight. Ferre and Faci [24] reported that the negative impact of water deficit on WUE was greater when subjected to deficit irrigation during flowering stage than that during any other growth stages.

Table 1. Effects of drought stress on growth of *sorghum* plants (per plant basis; mean across 2004 and 2005 seasons).

Irrigation	Plant height (cm)	No of Leaves	Leaf area (cm^2)	Fresh weight (g)			Dry weight (g)		
				Stem	Leaves	Total	Stem	Leaves	Total
Optimal Irrigation	113	4.7	3653	69.8	30.3	100.1	37.1	12.5	49.6
Omit 2nd irrigation	92	4.4	2287	68.3	24.2	92.5	32.2	11.5	43.7
Omit 4th irrigation	82	3.9	1808	40.3	20.3	60.6	17.5	9.9	27.4
LSD ($P \leq 0.05$)	6	NS	453	23.3	3.3	32.1	16.2	NS	22.3

LSD = Least Significant Difference; NS = Non-Significant.

Table 2. Effects of drought stress on yield of *sorghum* and water use efficiency (WUE) (Mean across 2004 and 2005 seasons).

Irrigation	Fresh yield ($Mg \cdot ha^{-1}$)	Dry yield ($Mg \cdot ha^{-1}$)	WUE ($kg \cdot m^{-3}$)	
			Fresh wt basis	Dry wt basis
Optimal Irrigation	94.7	46.8	12.38	6.18
Omit 2nd irrigation	97.1	45.6	13.98	6.53
Omit 4th irrigation	81.7	36.8	11.68	5.28
LSD ($P \leq 0.05$)	1.70	4.3	ND	ND

LSD = Least Significant Difference; ND = LSD was not calculated.

The increased rates of N, P, K increased the plant growth and biomass (**Table 3**). This trend is in agreement with those reported by Bokhtiar and Sakurai [25] on sugar cane; Bayu *et al.* [26] on *sorghum*; and Barros *et al.* [27] on intercropped maize/cowpea. Nitrogen is an important component of major structural, genetic, and metabolic compounds in plant cells, including chlorophyll, amino acids, ATP (adenosine triphosphate), and nucleic acids such as DNA [28]. Phosphorus is a vital component of: DNA, RNA, and ATP. Thus phosphorus is essential for the general health and vigor of all plants. Adequate P nutrition is critical for root development, increased stalk and stem strength, increased flowering and seed production, uniform and early crop maturity, improved crop quality, and increased resistance to plant diseases [28]. Potassium is important for various regulatory functions in plants. It is essential in nearly all processes needed to sustain plant growth and reproduction. Potassium plays a vital role in photosynthesis, translocation of photosynthates, protein synthesis, ionic balance, regulation of plant stomata and water use, activation of plant enzymes, and many other processes [28]. The forage yield at the highest N, P, K rates was 27% and 61% greater than that of the plants that received no N, P, K on fresh and dry weight basis, respectively (**Table 4**). The corresponding increases for the medium N, P, K rates were 8% and 46%.

Shrotriya [29] reported that balanced application of NPK caused up to 122% increase in *sorghum* yield in India. Increased plant growth with optimal N, P, K application provides vegetative cover, thus enhancing moisture retention, nutrient use efficiency and soil productivity [30]. Pholsen and Somsungnoen [9] reported that an increase in N and K rates significantly increased most growth parameters of *sorghum* plants. The highest total dry weight and seed yield were obtained from plants receiving 650 and 100 $kg \cdot ha^{-1}$ N and K, respectively. Increased rates of N, P, K increased WUE (**Table 4**). Barros *et al.* [27] showed that WUE improved with increasing rate of nutrients.

The interaction between N, P, K rates and irrigation treatments was significant with respect to plant height, leaf area, total fresh weight and stem as well as total dry biomass weights (**Table 5**). The increases in leaf area at the highest N, P, K rates as compared to that of the plants receiving no N, P, K were 248%, 126%, and 37% re-

Table 3. Effects of NPK rates on growth parameters of *sorghum* plants (per plant basis; mean across 2004 and 2005 seasons).

Fertilizer rates	Plant height (cm)	No of Leaves	Leaf area (cm^2)	Fresh weight (g)			Dry weight (g)		
				Stem	Leaves	Total	Stem	Leaves	Total
0	74	4.0	1512	42.3	18.0	60.3	21.8	8.8	30.6
1	87	3.9	2191	58.3	23.5	81.8	26.8	10.8	37.7
2	107	4.2	3015	62.2	28.3	90.5	30.8	12.4	33.2
3	115	5.0	3616	75.5	31.4	106.8	36.3	13.1	49.4
LSD ($P \le 0.05$)	5	1.0	328	5.6	3.2	6.2	4.3	2.9	4.6

LSD = Least Significant Difference; N:P:K Rates ($kg \cdot ha^{-1}$); 0 = None; 1 = 36:8.4:32; 2 = 72:16.8:64; 3 = 144:33.6:128.

Table 4. Effects of NPK rates on yield of *sorghum* and water use efficiency (WUE) (mean across 2004 and 2005 seasons).

Fertilizer rates	Fresh yield ($Mg \cdot ha^{-1}$)	Dry yield ($Mg \cdot ha^{-1}$)	WUE ($kg \cdot m^{-3}$)	
			Fresh wt basis	Dry wt basis
0	86	30.9	10.50	5.30
1	87	38.7	12.07	5.50
2	93	45.2	13.00	6.30
3	109	49.7	15.13	6.87
LSD ($P \le 0.05$)	0.50	0.53	ND	ND

LSD = Least Significant Difference; ND = LSD was not calculated; N:P:K Rates ($kg \cdot ha^{-1}$). 0 = None; 1 = 36:8.4:32; 2= 72:16.8:64; 3 = 144:33.6:128.

spectively in optimal irrigation, omission of the 2nd, and omission of the 4th irrigation treatments, respectively. The corresponding increases in total fresh weight were 98%, 67%, and 67%.

The interaction of effects of irrigation and NPK fertilizer on yield was significant only on dry biomass yield (**Table 6**). The increases in biomass yield at the highest N, P, K rates as compared to that of plants receiving no N, P, K were 26%, 29%, and 35%, respectively, at optimal irrigation, omission of the 2nd, and omission of the 4th

Table 5. Effects of drought stress and N, P, K rates on growth of forage *sorghum* plants (per plant basis; average of two seasons).

Irrigation	Fertilizer rates	Plant height (cm)	No of Leaves	Leaf Area (cm^2)	Fresh weight (g)			Dry weight (g)		
					Stem	Leaves	Total	Stem	Leaves	Total
Optimal Irrigation	0	80	4.2	1537	46.3	19.0	65.3	25.0	9.5	34.5
	1	108	4.4	3201	69.8	29.8	99.6	37.3	11.7	49.0
	2	127	4.7	4500	72.3	34.5	106.8	38.8	13.7	52.5
	3	137	5.3	5354	90.7	38.0	128.7	47.1	15.0	62.1
Omit 2nd irrigation	0	73	4.1	1479	50.3	18.8	69.1	25.6	10.0	35.6
	1	88	3.9	1796	67.3	21.5	88.8	27.0	10.8	37.8
	2	103	4.2	2613	72.2	25.3	97.5	34.5	12.5	47.0
	3	110	5.3	3348	83.5	31.0	114.5	41.5	12.5	54.0
Omit 4th irrigation	0	68	3.8	1569	20.2	16.3	46.5	14.6	7.0	21.6
	1	72	3.4	1576	37.8	19.3	57.1	16.2	10.0	26.1
	2	91	3.8	1943	42.0	21.2	63.2	19.1	11.0	30.1
	3	98	4.5	2145	51.2	25.2	76.4	20.1	11.7	31.8
LSD ($P \leq 0.05$)		8	NS	567	NS	NS	10.8	7.7	NS	8.0

LSD = Least Significant Difference; NS = Non-Significant; N:P:K Rates ($kg \cdot ha^{-1}$). 0 = None; 1 = 36:8.4:32; 2 = 72:16.8:64; 3 = 144:33.6:128.

Table 6. Effects of drought stress and N, P, K, rates on yield of forage *sorghum* and water use efficiency (WUE).

Irrigation	Fertilizer	Fresh yield ($Mg \cdot ha^{-1}$)	Dry yield ($Mg \cdot ha^{-1}$)	WUE ($kg \cdot m^{-3}$)	
				Fresh wt basis	Dry wt basis
Optimal irrigation	0	80	42	10.5	5.5
	1	91	45	11.9	5.9
	2	97	48	12.7	6.3
	3	110	53	14.4	7.0
Omit 2nd irrigation	0	80	41	11.5	5.9
	1	93	39	13.4	5.6
	2	102	49	14.7	7.0
	3	113	53	16.3	7.6
Omit 4th irrigation	0	66	31	9.5	4.5
	1	76	35	10.9	5.0
	2	81	39	11.6	5.6
	3	102	42	14.7	6.0
LSD at 5%		NS	0.9	ND	ND

LSD = Least Significant Difference; ND = LSD was not calculated; NS = Non-Significant; N:P:K Rates ($kg \cdot ha^{-1}$); 0 = None; 1 = 36:8.4:32; 2 = 72:16.8:64; 3 = 144:33.6:128.

irrigations. The results support that the beneficial effects of optimal N, P, K fertilizer was greater under increased DS.

Soil nutrient availability induces large changes in plant functional attributes, which affect the water and carbon economy of plants [31]. In particular, nitrogen (N) can affect the cold and drought tolerance, yet there is no clear consensus on the magnitude or direction of its effect. Low tissue N concentration may hinder either cold or drought hardening [32]. Proper available nitrogen in soils enhanced the growth of plants and lowered the adverse effect on growth caused by water stress [33].

Water use efficiency also responded favorably to increased rates of N, P, K (**Table 6**). The WUE was greater for omission of the 2nd irrigation as compared to that of the plants under optimal irrigation or omission of the 4th irrigation. The WUE (fresh weight basis) for the plants which received high rates of N, P, K as compared to those of the plants received no N, P, K were greater by 55%, 42%, and 37%, respectively, for omission of the 4th irrigation, the 2nd irrigation, and optimal irrigation. The corresponding increases on dry weight basis were 33%, 29%, and 27%. Therefore, the WUE response to N, P, K fertilizer was greater with severity of water stress.

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