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Growth and yield of *rabi* sorghum as influenced by deficit irrigation practices and nitrogen levels

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Abstract
Water is considered as a key input for agriculture which is becoming scarce due to its requirement in agricultural, industrial and domestic sectors. To improve water use efficiency(WUE), precise strategies need to be formulated. Deficit irrigation (DI) is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop or application of water below crop-water requirements. A field experiment was conducted during *rabi* season 2021-22 to assess the performance of sorghum under different irrigation practices and nitrogen at Agricultural College Farm, Bapatla. The experiment was conducted in a split -plot design with three replications. The experiment consisted of twelve treatment combinations with 3 Irrigation practices *viz*., full irrigation(I_1), managed deficit irrigation (I_2) and deficit irrigation(I_3) as main plots and four nitrogen levels. *viz*., 100(N_1), 80(N_2), 60(N_3) and 40 (N_4) kg N ha^{-1}) in sub-plots. The results revealed that significantly higher plant height, drymatter accumulation and leaf area index(LAI)at harvest was recorded with full irrigation (I_1) compared to deficit irrigation. Full irrigation produced significantly higher of *rabi* sorghum compared to deficit irrigation but was on par with managed deficit irrigation. Among nitrogen levels, significantly higher grain and stover yield was recorded with 100 kg N ha^{-1} compared to other levels. Among the irrigation practices significantly higher water use efficiency was recorded with deficit irrigation compared to I_1 and I_2. Application of 100 kg N ha^{-1} recorded higher WUE compared to 40 and 60 kg N ha^{-1} but was statistically comparable with 80 kg N ha^{-1}.

Keywords: Deficit Irrigation practices, nitrogen levels and Water use efficiency

Introduction
Sorghum is the world's fifth most important cereal after wheat, rice, maize and barley (FAO, 2010). It is a very important grain and forage crop of semi-arid regions and grain sorghum is a drought tolerant crop that is suitable for rainfed and deficit irrigation due to its physiological adaptability to short-term water stress (Assefa *et al*., 2010) [5]. Irrigated agriculture is the largest contributor for food security consuming 90 percent of the water resource in the arid and semi-arid regions. Currently, irrigated agriculture is caught between two perceptions that are contradictory; some perceive that agriculture is highly inefficient by growing 'water-guzzling crops' (Postel *et al*., 1996) [17], while others emphasize that irrigation is essential for the production of sufficient food in the future, given the anticipated increases in food demand due to world population growth and changes in diets (Dyson, 1999) [6]. Irrigation management must respond to limited water supplies by producing the best long -term economic returns per unit of water. Deficit irrigation (DI) is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop or application of water below crop-water requirements. DI aims at stabilizing yields and at obtaining maximum crop water productivity rather than maximum yields. Managed Deficit Irrigation (MDI) concentrates irrigation applications at stages of crop growth critical to determine potential yield. A promising management strategy for improving water use efficiency (WUE) is managed deficit irrigation (MDI), which attempts to optimize yield and WUE by synchronizing crop water use with the crop's reproductive stages. Sorghum, an exhaustive crop, requires high nutrient supply during its life cycle. Among the major nutrients, nitrogen changes plant composition much more than any other nutrient as it is an indispensable fundamental constituent of many organic metabolites including amino acids, proteins, nucleic acids and phytochromes. If supplied appropriately, it can enhance cereal yield by 50% (Krishnaprabu, 2018) [11]. Several studies are indicating improved crop yields and related physiological properties due to the use of nitrogen fertilizer under normal irrigation.

To study the deficit irrigation practices and nitrogen influence in *rabi* sorghum, this trial was taken up in Krishna Agroclimatic zone of Andhra Pradesh.

Materials and Methods

The field experiment was conducted at Agricultural College, Bapatla during the *rabi* season of 2021-22. The experimental site was sandy loam soil with pH of 6.85, low in available nitrogen (210 kg ha^{-1}) and organic carbon content (0.48%), medium in available phosphorous (21.5 kg ha^{-1}) and potassium (240 kg ha^{-1}). Sorghum variety, NTJ- 5 was taken as the test variety adopting a spacing of 45cm × 15 cm. Irrigations were imposed at different growth stages of soghum. In I_1(full irrigation) four irrigations were given at 35 DAS (Flag leaf emergence), 55 DAS (Booting), 75 DAS (Soft dough stage) and 85 DAS (Hard dough). In case of managed deficit irrigation(I_2), three irrigations were given at 35 DAS (Flag leaf emergence), 55 DAS (Booting) and 85 DAS (Hard dough stage). Two irrigations were given in case of deficit irrigation(I_3) at 35 DAS (Flag leaf emergence) and 75 DAS (Soft dough). Depth of irrigation was 5cm. Pre-sowing irrigation was common for all the treatments to ensure uniform germination. However, the irrigation scheduled at 35 DAS was delayed by five days and given at 40 DAS due to continuous rains received (48th SMW). Recommended dose of P(60 kg ha^{-1})and K(40 kg ha^{-1}), entire dose was applied as basal before sowing and nitrogen was applied as per treatments in two splits *viz*., half as basal and remaining half at 30 DAS. All the data recorded was subjected to statistical analysis as suggested by Panse and Sukhatme (1985) [16].

Results and Discussion

Plant height (cm)

In *rabi* sorghum, plant height recorded at harvest (Table 1) was significantly higher with full irrigation (I_1-139.3.0cm) which was significantly superior to deficit irrigation (122.8cm). However, I_1 was found on a par with managed deficit irrigation (I_2-132.6cm). Increased plant height recorded with full irrigation might be due to sufficient soil moisture in root zone that might have resulted in better uptake of nutrients, resulting in increased plant height. Similar results of increased plant height with increased number of irrigations was reported by Wakchaure *et al.* (2016) [21] and Ashok *et al*. (2018) [4]. Among the nitrogen levels, application of 100 kg N ha^{-1} (N_1) recorded highest plant height (147.1cm) which was significantly superior to 80 kg N ha^{-1}(135.4cm), 60 kg N ha^{-1}(131.3cm) and 40kg N ha^{-1}(112.4cm). However, 80 kg N ha^{-1}was found to be on a par with 60 kg N ha^{-1}at harvest. The results are in accordance with the findings of Hussain *et al.* (2021) [9], Kugbe *et al.* (2019) [12].

Drymatter accumulation (kg ha^{-1})

Drymatter accumulation (kg ha^{-1}) at harvest in *rabi* sorghum was maximum in I_1 with full irrigation (11892 kg ha^{-1}) and was significantly superior over I_2 with managed deficit irrigation (11060 kg ha^{-1}) and I_3deficit irrigation (10840 kg ha^{-1}) Maximum drymatter accumulation recorded with full irrigation (I_1) in sorghum could be mainly attributed to better uptake of nutrients resulting in greater biomass accumulation. These results are in line with findings of Mahdi and Gholamali (2014) [13]. At harvest maximum drymatter accumulation was observed with 100 kg N ha^{-1} (12542 kg ha^{-1}) which was found significantly superior over all other doses of nitrogen tested. However, drymatter accumulation at 60 kg N ha^{-1} was found to be statistically comparable with 40 kg N ha^{-1}(Table 1). The increase in dry matter accumulation with increase in levels of nitrogen from 40 kg N ha^{-1} to 100 kg N ha^{-1} may be attributed to production of more number of nitrogeneous compounds like aminoacids, protoplasm, proteins and photosynthates which in turn enhance photosynthetic efficiency resulting in more drymatter. These results are in agreement with the findings of Kugbe *et al.* (2019) [12], Nirmal *et al.* (2016) [14].

Leaf Area Index(LAI)

Full irrigation(I_1) in *rabi* sorghum resulted in maximum leaf area index (3.9) and it was significantly superior to deficit irrigation (2.9) and managed deficit irrigation (I_2) (3.5). These results were in close proximity to those of Ashok *et al*. (2018.) [4]. At harvest, maximum leaf area index was recorded with 100 kg N ha^{-1} (4.0) and it was significantly superior over 60 kg N ha^{-1} (3.2) and 40 kg N ha^{-1} (3.0) but it was on par with 80 kg N ha^{-1} (3.7) (Table 1). Similar results were reported by Ramadhan and Muhsin (2021) [18].

Test weight (1000 grain weight)

Maximum test weight (Table 2) was recorded under full irrigation (32.5) but it was statistically on a par with managed deficit irrigation (31.7) and significantly superior to deficit irrigation. Lower test weight was recorded in deficit irrigation (29.9). It might be due to optimum soil moisture in the root zone throughout the crop growth period, favoured partitioning of photosynthates from the shoot to grain. The results are in agreement with the findings of Pang *et al*. (2018). Among the levels of nitrogen, higher test weight was recorded with application of 100 kg N ha^{-1}(34.8) and it was significantly superior to 60 kg N ha^{-1}(29.0), 40 kg N ha^{-1} (25.8) but was statistically at par with 80 kg N ha^{-1}(34.7). The results are in conformity with the findings of Ajeigbe *et al.* (2018) [2].

Grain yield (kg ha^{-1})

Significantly higher grain yield of *rabi* sorghum (3646 kg ha^{-1}) was obtained with full irrigation(I_1) than deficit irrigation (I_3) (3195 kg ha^{-1}) but was on a par with managed deficit irrigation (I_2) (3476 kg ha^{-1}). This might be due to better availability of soil moisture throughout the crop growth period, which might have lead to increase in uptake of nutrients resulting in increased grain yield. Similar findings were reported by Subham *et al*. (2018), Komuraiah *et al.* (2018). Among the nitrgen levels tested, grain yield of sorghum obtained at highest nitrogen level of 100 kg N ha^{-1} (3761 kg ha^{-1}) was significantly superior to 80 kg N ha^{-1}, 60 kg N ha^{-1}and 40 kg N ha^{-1}. However, grain yield at 80 kg N ha^{-1} was statistically on par with 60 kg N ha^{-1} and 60 kg N ha^{-1}was at a par with 40 kg N ha^{-1}(Table 2) The increase in the grain yield with enhanced N application could be ascribed to better plant growth and drymatter production due to higher photosynthetic area and also increase nutrient uptake of the crop. These results are in corroboration with findings of Naik *et al*. (2018), Gebremariam and Assefa, (2015) [8] and Adzemi *et al*. (2013).

Stover yield (kg ha^{-1})

Full irrigation(I_1) recorded maximum stover yield in sorghum, which was significantly superior over deficit irrigation (I_3) but was found to be statistically on a par with managed deficit irrigation (I_2). However, stover yield of sorghum with deficit irrigation was statistically comparable with managed deficit irrigation (I_2).Similar results were observed with the findings of Subham *et al*.(2018). Among the levels of nitrogen, 100 kg N ha^{-1} (7612 kg ha^{-1}) recorded higher stover yield and it was significantly superior to 60 kg N ha^{-1} (7079 kg ha^{-1}) and 40 kg N ha^{-1} (6726 kg ha^{-1}) and 80 kg N ha^{-1} (7212 kg ha^{-1}) (Table 2). Stover yield obtained with the application of 80 kg N ha^{-1}was statistically comparable with 60 kg N ha^{-1}. These results are in line with the findings of Nirmal *et al*. (2016) [14].

Water use efficiency (kg ha-mm^{-1})

Higher water use efficiency was recorded with deficit irrigation (12.7) and it was significantly superior over full irrigation (10.6) and managed deficit irrigation (11.0).(Table 2) This might be due to increasing the yield per unit of water. Solaimalai *et al*. (2001) [19] reported that WUE decreased with increase in the frequency of irrigation in sorghum. Similar results were also reported by Alderfasi *et al*. (2016) [3]. Higher water use efficiency was recorded with application of 100 kg N ha^{-1} (12.1) but it remained on a par with 80 kg N ha^{-1} (11.5) and was significantly superior to 40 kg N ha^{-1} (10.8) and 60 kg N ha^{-1} (11.1). Increase in WUE with increased N- fertilizer levels is likely to be related to the significant increase in total drymatter compared to grain yield alone. Similar results reported by Ajeigbe *et al*. 2018 [2].

Table 1: Growth parameters of *rabi* sorghum at harvest as influenced by irrigation practices and nitrogen levels

Treatments	Plant height (cm)	Drymatter accumulation (kgha^{-1})	Leaf area index
Irrigation practices (I)			
I_1: Full irrigation	139.3	11892	3.9
I_2:Managed deficit irrigation	132.6	11060	3.5
I_3: Deficit irrigation	122.8	10840	2.9
S.Em ±	3.2	202.37	0.08
CD (p=0.05)	9.6	633	0.32
CV (%)	10.4	6.2	8.1
Nitrogen levels (kg N ha^{-1})			
N_1: 100	147.1	12542	4.0
N_2: 80	135.4	11142	3.7
N_3: 60	131.3	10823	3.2
N_4: 40	112.4	10448	3.0
S.Em±	3.15	221.05	0.12
CD(p=0.05)	9.3	656	0.36
CV(%)	9.7	6.0	10.0
Interaction (I × N)	NS	NS	NS

Table 2: Test weight and yield and WUE of *rabi* sorghum as influenced by irrigation practices and nitrogen levels

Treatments	Test weight(g)	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Water use efficiency (kg ha-mm^{-1})
Irrigation Practices (I)				
I_1: Full irrigation	32.5	3646	7378	10.6
I_2:Managed deficit irrigation	31.7	3476	7211	11.0
I_3: Deficit irrigation	29.9	3195	6958	12.7
S.Em±	0.40	88.68	104.02	0.38
CD (p=0.05)	1.5	268	312	1.49
CV (%)	4.1	8.9	6.1	11.5
Nitrogen Levels (kg N ha^{-1})				
N_1: 100	34.8	3761	7612	12.1
N_2: 80	34.7	3460	7212	11.5
N_3: 60	29.0	3359	7080	11.1
N_4: 40	25.8	3176	6826	10.8
S.Em±	0.43	92.38	140.6	0.25
CD (p=0.05)	1.6	274	422	0.73
CV (%)	5.28	8.0	5.9	6.4
Interaction (I×N)	NS	NS	NS	NS

Conclusion

It can be concluded that for *rabi* sorghum in Krishna Agroclimatic zone of Andhra Pradesh, full irrigation at four stages35 DAS (Flag leaf emergence), 55 DAS (Booting), 75 DAS (Soft dough stage) and 85 DAS (Hard dough) resulted in significantly higher growth parameters and yield. Grain yield was comparable with managed deficit irrigation which was given only at three stages. Significantly higher water use efficiency was recorded with deficit irrigation (two irrigations) compared to full irrigation (four irrigations) and managed deficit irrigation (three irrigations). Nitrogen application at 100kgN ha^{-1}resulted in significantly maximum grain and stover yield of sorghum and water use efficiency.

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