Indian Journal of Agricultural Sciences **94** (1): 100–103, January 2024/Short Communication
https://doi.org/10.56093/ijas.v94i1.123726

Impact of irrigation and nitrogen management on crop performance, yield and economics of sorghum (*Sorghum bicolor*) in Kandahar region of Afghanistan

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Received: 07 May 2022; Accepted: 18 October 2023

Keywords: Economics, Irrigation scheduling, Nitrogen management, Yield

Sorghum [*Sorghum bicolor* (L.) Moench] stands as a versatile cereal, serving various purposes including grain and forage. In Afghanistan, it predominantly thrives in the eastern and northern regions. Notably, nitrogen (N) emerges as the most deficient nutrient in Afghan soils. Given this context, determining the optimal N requirement becomes paramount to establish application rates for enhanced biomass production. Sorghum, characterized as a C_4 plant, exhibits noteworthy traits in biomass yield and N utilization efficiency (Gardner *et al.* 1994). Effective nitrogen management not only impacts crop yield but also augments its overall quality (Mahmud *et al.* 2003, Meena *et al.* 2023). The application of nitrogen fertilizer is known to raise sucrose content, protein percentage and growth rate in sweet sorghum. To get good yield of sorghum, proper irrigation scheduling at critical stages like tillering, flowering and grain formation are very crucial. In summer/*kharif* season, it requires 1 to 3 irrigations depending upon rainfall. Over time, a combination of biotic and abiotic factors, along with shifts in consumption trends and demand, has led to a consistent reduction in both cultivated area and grain production. Consequently, this research aimed to assess the sorghum's performance in terms of crop growth, yield and farm profitability. This evaluation was conducted under varying irrigation schedules and nitrogen management approaches in the Kandahar region of Afghanistan.

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The experiment was conducted during the rainy (*kharif*) season of 2020 at the research farm of Afghanistan National Agricultural Science and Technology University, Kandahar, Afghanistan. Kandahar experiences a subtropical steppe/low-latitude semi-arid hot climate. The soil at the experimental site is characterized as sandy loam, with a neutral *p*H, and low nitrogen, medium phosphorus and high potassium availability. The area's annual mean temperature was recorded at 18.5°C, with a total annual average precipitation of 190.6 mm. Relative humidity ranges from a low of 23% in June to a high of 59% in February (source: https://weather-and-climate.com). Notably, the highest temperature observed during the crop growth period was 48.9°C (from July 8 to 14), while the lowest temperature was 21.9°C (from April 1 to 7). Additionally, the maximum relative humidity reached 32.3% during July 1 to 7, and the minimum was 18.4% from June 24 to 30.

The experiment was conducted in a split-plot design with 3 replications consisting of 3 irrigation scheduling in main-plots, viz. Irrigation at sowing and flowering stage (I_1); Irrigation at sowing and grain filling stage (I_2); and Irrigation at sowing, flowering and grain filling stage (I_3) and 4 N application rates in sub-plots, viz. without N (absolute control-N0); 40 kg/ha (N40); 80 kg N/ha (N80); and 120 kg N/ha (N120).

Measurement of growth parameters, yield attributes, yield and economics: The determination of growth parameters, yield attributes, yields, harvest index, and economic aspects for sorghum followed the established methodology outlined by Parihar *et al.* (2017).

Statistical analysis: The growth parameters, yield attributes, yields, harvest index, and economic aspects of sorghum were subjected to analysis using the split-plot design with analysis of variance (ANOVA) technique, as outlined by Gomez and Gomez (1984). The ANOVA was executed to ascertain the statistical significance of the treatment effects. Treatment means were compared using the LSD at a 5% level of significance (P=0.05)

Data on plant height, leaf area index (LAI) and crop growth rate (CGR) were recorded at various crop growth stages of sorghum (Table 1). There was no significant effect of irrigation scheduling on these growth parameters of sorghum during the crop season. However, different nitrogen application rates significantly affected the sorghum plant height, LAI and CGR at 30, 60 and 90 days after sowing (DAS) compared to the control treatment (N0). Significantly higher plant height, LAI and CGR were observed with N application @80 (N80) and 120 kg/ha (N120) compared to absolute control (N0). The highest plant height, LAI and CGR were observed in N120 plots, which was at par with the N80. Irrigation scheduling and nitrogen rates had non-significant (P<0.05) interaction effect on plant height (Table 1). LAI increased with increasing dose of N, however, LAI tends to decrease at the time of harvesting as senescence takes place at the end of life-span of the crop. The findings closely align with those reported by Biri *et al.* (2016) and Olugbemi and Ababyomi (2016). The enhanced growth of sorghum due to nitrogen application can be attributed to its crucial involvement in various physiological and biochemical processes, including root development and photosynthesis (Havlin *et al.* 2016), corroborated with similar findings by Esmaili *et al.* (2008).

Different irrigation management approaches influenced the growth trajectory throughout the crop cycle, leading to variations in terms of biomass accumulation, leaf expansion, and other growth parameters. These effects were also supported by Garofalo and Rinaldi (2013). There was no significant effect of irrigation scheduling on yields (kg/ha) of sorghum (Table 2). However, significantly higher (54.48 and 47.43% seed) (15.5 and 13.87% straw) (22.22 and 19.66% biological) yield was recorded with N application @120 and 80 kg/ha compared to absolute control. The highest (1546, 5546 and 7092 kg/ha) and lowest (1001, 4801 and 5802 kg/ha) seed, straw and biological yields were recorded under N120 and absolute control treatments, respectively (Table 2).

The interaction effect of irrigation scheduling and nitrogen rates on sorghum seed yield (Table 2) was found to be statistically non-significant (P<0.05). This outcome can be attributed to enhanced nutrient availability and soil moisture, which in turn, positively influenced various physiological processes and the accumulation of food material. This observation aligns with the findings of Ali (1993). The increase in yield may be attributed to the beneficial impact of nitrogen nutrition on growth parameters, ultimately leading to improved nutrient uptake, efficient metabolite distribution and sufficient translocation, and accumulation of photosynthates (Havlin *et al.* 2016). These results are consistent with the research conducted by Assefa *et al.* (2010) and Wang *et al.* (2015).

The findings regarding sorghum production and monetary efficiency indicate that irrigation scheduling did not have a notable impact on production (kg/day) and monetary efficiency (AFN/day) of sorghum (Table 2). However, significantly higher production and monetary efficiency (14.7 and 14.1 kg/day and 773.9 and 739.9 AFN/day) was observed with N application @120 and 80 kg/ha, followed by N @40 kg/ha (13.1 kg/day and 679.3 AFN/day) compared to absolute control (9.5 kg/day and 416.6 AFN/day) (Table 2). The interaction between irrigation scheduling and nitrogen rates yielded no significant (P<0.05) impact on sorghum production efficiency (kg/day). Similar outcomes were observed in studies conducted by Almodares *et al.* (2009), Shamme *et al.* (2016) and Barik *et al.* (2017).

Table 1 Effect of irrigation scheduling and nitrogen application rates on plant height, leaf area index and CGR of sorghum

Treatment	Plant height (cm)			Leaf area index (LAI)			CGR (g/plant/day)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	0–30 DAS	30–60 DAS	60–90 DAS
Irrigation scheduling									
I_1	35.6	66.5	145.0	0.432	1.989	2.955	0.235	0.931	0.630
I_2	35.7	66.9	147.3	0.434	2.000	3.009	0.241	0.934	0.697
I_3	35.2	66.2	148.0	0.444	2.034	3.114	0.248	0.958	0.703
SEm±	0.610	1.150	2.045	0.009	0.042	0.053	0.006	0.035	0.067
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen application rates									
N0	33.2	58.3	131.9	0.311	1.335	2.067	0.149	0.514	0.435
N40	35.9	66.1	144.0	0.447	1.967	3.190	0.251	0.947	0.729
N80	36.3	70.7	152.4	0.488	2.274	3.364	0.281	1.093	0.746
N120	36.5	71.1	158.7	0.500	2.454	3.483	0.285	1.210	0.799
SEm±	0.755	2.739	4.900	0.008	0.060	0.084	0.009	0.026	0.076
LSD (P=0.05)	2.24	8.14	14.56	0.023	0.179	0.249	0.025	0.077	0.227

Refer to the methodology for treatment details. DAS, Days after sowing; CGR, Crop growth rate.

Table 2 Effect of irrigation scheduling and nitrogen application rates on yields, harvest index and production, and monetary efficiency of sorghum

Treatment	Seed yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)	Production efficiency (kg/day)	Monetary efficiency (AFN/day)
Irrigation scheduling						
I_1	1324	5251	6575	20.0	12.6	634.9
I_2	1335	5258	6593	20.1	12.7	643.1
I_3	1386	5334	6719	20.5	13.2	679.3
SEm±	24.8	109.5	91.8	0.602	0.236	18.71
LSD (P=0.05)	NS	NS	NS	NS	NS	NS
Nitrogen application rates						
N0	1001	4801	5802	17.3	9.5	416.6
N40	1371	5309	6680	20.5	13.1	679.3
N80	1476	5467	6943	21.3	14.1	739.9
N120	1546	5546	7092	21.8	14.7	773.9
SEm±	25.5	108.6	118.3	0.384	0.242	19.45
LSD (P=0.05)	75.6	322.7	351.5	1.14	0.72	57.8

Refer to the methodology for treatment details.

However, significantly higher gross returns (AFN/ha) (54.0 and 47.0%) and net B:C ratio (1.87 AFN/AFN invested) were recorded with N application @120 and 80 kg/ha, followed by N application @40 kg/ha (36.61%) and (1.81) compared to absolute control, which implies that N application @80 kg/ha is economically optimum dose for sorghum crop in the Kandahar region of Afghanistan.

There was no significant effect of irrigation scheduling on gross returns (AFN/ha) and net BC ratio (Net returns/AFN invested) of sorghum (Fig. 1). These were due to the higher yield obtained by higher nitrogen application and were confirmed by findings of Alam *et al.* (2010) and Ali (1993). Application of 80 kg N/ha could be a viable choice for achieving better crop growth, higher crop productivity, farm profitability and use efficiency in sorghum irrespective of application of 2 or 3 irrigations at different stages of *kharif* sorghum in Kandahar region of Afghanistan.

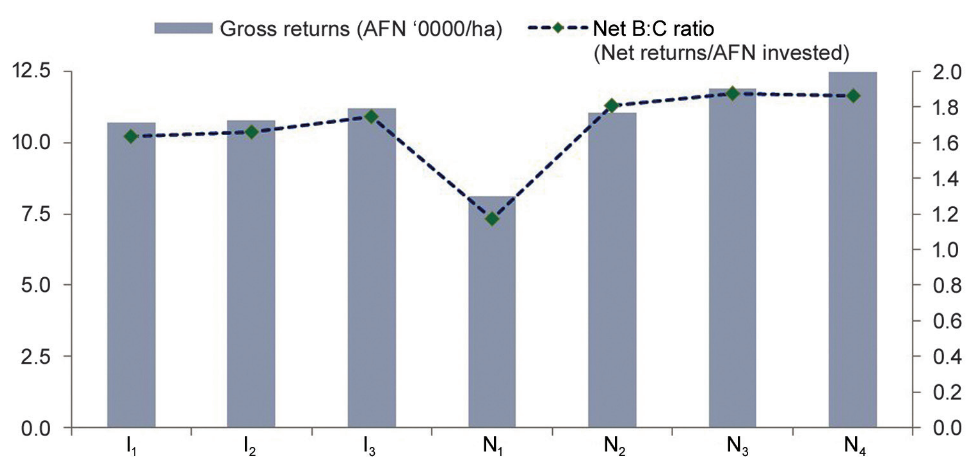

Fig. 1 Effect of irrigation scheduling and nitrogen application rates on gross returns and net BC ratio of sorghum.
Refer to the methodology for treatment details.

SUMMARY

In Afghanistan the information on the performance of sorghum crop to applied nitrogen (N) fertilizer coupled with water management are still scarce. Therefore, a field study was carried out during rainy (*kharif*) season of 2020 at the research farm of Afghanistan National Agricultural Science and Technology University, Kandahar, Afghanistan. Kandahar in collaboration with ICAR-Indian Agricultural Research Institute, New Delhi evaluated the effect of different irrigation scheduling and nitrogen management options on growth, yield and economics of sorghum. The experiment was laid out in a split-plot design with 3 replications consisting of 3 irrigation schedules in main-plots and 4-N rates in sub-plots. Growth parameters of sorghum, viz. plant height, dry matter accumulation, crop growth rate and leaf area index were significantly increased by N120 and N80 compared to N0 plots. Significantly superior yields, viz. seed yield (1546 and 1476 kg/ha), straw yield (5546 and 5467 kg/ha), biological yield (7092 and 6943 kg/ha) and harvest index (21.3 and 21.8%) were observed with N120 and N80 plots, respectively.

The N120 and N80 plots remained at par with each other with respect to net B:C ratio (1.87). However, the highest production efficiency (14.7 kg biomass/day) and monetary efficiency (773.90 AFN/day) was obtained with N120 plots. Therefore, the findings of present study suggest that N application @80 kg/ha could be a viable option to attain higher productivity, farm profitability and input-use efficiency irrespective of 2 or 3 irrigations in sorghum in Kandahar region of Afghanistan.

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