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Irrigation and Nitrogen Management for Optimizing Resource Use Efficiency in Summer Fodder Sorghum under Coastal Tract of South Gujarat

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ABSTRACT

A field experiment was conducted during summer season (March to May) of 2021 at the College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India, to optimize irrigation schedule, nitrogen dose and schedule of nitrogen application for summer fodder sorghum. Irrigation schedules consisted of irrigation at 0.4, 0.6 and 0.8 IW/CPE. Nitrogen levels were 60 and 80 kg N ha^{-1} in two equal splits at basal and 30 days after sowing (DAS) and three equal splits at basal, 30 and 45 DAS. Irrigation at 0.8 IW/CPE endorsed the vegetative growth by upholding leaf water retention and thus improved fodder quality, yield, water use efficiency (WUE), partial factor productivity of fertilizer N (PFPF$_N$) and nutrients uptake. Application of 80 kg N ha^{-1} had significantly increased quality and yield of fodder, WUE and nutrient uptake by promoting vegetative growth. Despite non-monetary input, three splits of N with concurrent improvement in quality parameters recorded 30.4, 28.7, 30.3 and 36.8% higher green fodder yield, WUE, PFPF$_N$ and N uptake efficiency (N Upt E), respectively than two splits of N. Synergistic effect of treatments showed that, irrigation at 0.6 IW/CPE with 80 kg N ha^{-1} in three splits was most lucrative based on benefit-cost ratio. It was also effectual to achieve higher WUE and obtained equivalent fodder yield, PFPF$_N$, N Upt E as that of higher yielded combination i.e. irrigation at 0.8 IW/CPE and 80 kg N ha^{-1} in three splits with saving of 22.2% (1000 m^3) irrigation water.

KEYWORDS: Fodder sorghum, irrigation scheduling, nitrogen management, economics

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1. INTRODUCTION

Indian milk production has been raised from 155.5 mt during 2015 to 239.4 mt during 2023; showing an average compound annual growth rate of almost 9.0%. But animal productivity is low i.e. 1538 kg year^{-1} compared to global average of 2238 kg year^{-1} (Anonymous, 2024). Fodder and feed are the major inputs in milk production, accounts 70% of total cost of milk production (Dey and Kumar, 2017). The average daily green and dry fodder requirement of milching cattle is 15.2 and 13.8 kg, respectively, while concentrate is about 1.8 kg (Kalamkar et al., 2020). India own 20% of world's livestock population (536.8 m) and rank first, but has only 4.4% area under fodder crops (8.4 m ha) to produce 645.9 mt green fodder. The present availability of green and dry fodder from all the sources is about 734.2 and 326.4 mt projecting a deficit of 11.2 and 23.4%, respectively (Roy et al., 2019). Conversely, the area under permanent pastures and grazing has been declined by 24.9% over last six decades and it is declining yet again (Anonymous, 2022). Nevertheless, perishable nature, bulkiness, transportation cost like intricacy, provide limited scope to avert the picture of regional and seasonal discrepancy in green fodder availability. Sorghum [*Sorghum bicolor* (L.) Moench] is the broadly grown fodder crop for green forage, silage preparation and as hay because it evidenced high yield (Schittenhelm and Schroetter, 2014) and comparable quality traits as that of maize under moisture stress condition (Getachew et al., 2016). It occupies about 31% (2.6 mha) area of cultivated forage crops in India (Dagar, 2017). However, yield and quality of fodder sorghum greatly influenced by soil moisture availability and consequently irrigation interval during summer season (Moosavi et al., 2011 and Khaton et al., 2016). Moisture stress at critical stages absolutely affects growth, yield components, nutrient content, protein content and yield of sorghum crop (Kaaria et al., 2021 and Abreha et al., 2022). As like soil moisture, soil's native nitrogen availability and exogenous application of N-fertilizer plays an essential role in the yield and nourishing value of the forage (Iptas and Brohi, 2002 and Almodares et al., 2009). This is because; tropical soils in India, where fodder sorghum is grown are habitually low in organic matter and available N (Meena and Meena, 2012). Thus N-fertilizers found an essential but expensive input in fodder sorghum production in India. The ammonia volatilization and nitrate leaching are major fatalities that results low N recovery efficiency of applied N-fertilizer. The NH_3 valorization alone contributes 10.0–19.5% losses of applied fertilizer (Cao et al., 2013); however, it could rise beyond this with elevated soil and atmospheric temperature during summer season (McGarry et al., 1987 and Pedersen et al., 2021). Therefore, to accomplish economically feasible earnings, efficient use and management of nitrogenous fertilizers, is required to maximize yield. Nitrogen fertilization drops the acid and neutral detergent fiber and lignin content while increases crude protein content, thereby increases juiciness, sweetness and digestibility of forage (Hazary et al., 2015, Baghdadi et al., 2017, Delevatti et al., 2019 and Prajapati et al., 2023). Beside nitrogen rate, its time of application greatly determines the yield and quality of fodder sorghum during summer season particularly in N deficit soils (Bhilare et al., 2002 and Patel et al., 2024). Synchronizing N application time with periodical N requirement of fodder sorghum could increase the N utilization efficiency and yield. Thus, investigation was aimed to optimize irrigation schedule based on IW/CPE ratio, nitrogen level and its time of application for sustaining summer fodder sorghum productivity.

2. MATERIALS AND METHODS

2.1. Experimental site and soil properties

A field experiment was conducted during summer season (March to May) of 2021 at the College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India. The experimental site was located on 20°55'22'' N and 72°53'48'' E GPS coordinates and 10 m above mean sea level. The location being situated 15 km eastward from Arabian Sea coast, predominantly enjoy maritime climate with fairly warm summer, moderately cold winter and warm humid monsoon. Agro-climatically, the site belonged to heavy rainfall zone of South Gujarat of India and received average annual rainfall of **1555** mm. The soil of the experimental field belonged to the group Ustochrepts, sub-groups VerticUstochrepts, order Inceptisols, sub-order Ochrepts popularly known as "Deep Black soil". The color of soil was dark brown having medium to poor drainage with good water holding capacity, and because of predominance of montmorillonite clay mineral, these soils cracked vertically upon drying. The experimental field was fairly leveled and uniform. Before commencement of experiment prior to sowing, soil samples were collected from entire experimental field from 0-30 cm depth, and the composite sample was prepared and analyzed for different soil properties (Table 1). Soil texture of experimental plot was clayey in nature (sand 11.28%, silt 25.45% and clay 62.27%), slightly alkaline in reaction with pH 7.50, normal in electrical conductivity (0.12 dS m^{-1}) and low in organic carbon (0.39%). The initial available nutrient status indicated that soil was low in available nitrogen (242.32 kg N ha^{-1}), medium in available phosphorus (29.92 kg P_2O_5 ha^{-1}) and fairly rich in available potassium (426.8 kg K_2O ha^{-1}).

2.2. Treatment and experimental details

The experiment consisted of total twelve treatment

Table 1: Methods used for analysis of soil and plant samples

Soil parameters	Method of analysis	Readings
pH (1:2.5 w/v)	Potentiometric pH meter (Jackson, 1973)	7.5
EC (1:2.5 w/v dS m^{-1} at 25 °C)	Schofield method (Jackson, 1973)	0.16
Organic carbon (%)	Walkley and Black's rapid titration method (Jackson, 1973)	0.39
Available nitrogen (kg ha^{-1})	Alkaline $KMnO_4$ method (Jackson, 1973)	242.32
Available P_2O_5 (kg ha^{-1})	Olsen's method (Jackson, 1973)	29.92
Available K_2O (kg ha^{-1})	Flame photometric method (Jackson, 1973)	426.8
Bulk density (Mg m^{-3})	Actual field method (Dastane, 1972)	0-15 cm soil depth-1.31 16-30 cm soil depth-1.35
Field capacity (%)	Pressure plat apparatus method (Richard, 1948)	0-15 cm soil depth-31.12 16-30 cm soil depth-29.85
PWP (%)		0-15 cm soil depth-12.44 16-30 cm soil depth-11.34
Plant parameters	Method of analysis	
Nitrogen (%)	Kjeldahl's digestion method (Jackson, 1973)	
Phosphorus (%)	Vanomolybdo phosphoric acid (Jackson, 1973)	
Potassium (%)	Flame photometric method (Jackson, 1973)	

combinations of three irrigation schedules viz. irrigation at 0.4 (I_1), 0.6 (I_2), 0.8 (I_3) IW/CPE ratio in main plot and two nitrogen levels viz. 60 (N_1), 80 (N_2) kg N ha^{-1} and two schedules of N application viz. two equal splits-50% N as basal+50% at 30 DAS (S_1) and three equal splits-33.3% N as basal+33.3% at 30 DAS+33.3% at 45 DAS (S_2) in sub plot. Treatments were assigned in four replications by randomization and data were analyzed in split plot design as per Gomez and Gomez (1984). The field was prepared by moving tractor drawn cultivator in cross direction followed by rotavator and planking to obtain fine and compact tilth. Fodder sorghum variety CSV-21 F was sown at 30 cm apart using tractor drawn seed cum fertilizer drill and thinning was carried out 10 DAS sowing to maintain plant to plant spacing of 10 cm. The ridge of 20 cm height was prepared around each sub plot with ridger to restrict the irrigation water flow outside the plot. To get rid of seepage effect of irrigation, buffer zone of 1.5 m and 2 m width was maintained between adjacent sub plot and main plot, respectively. The recommended dose of phosphorus i.e. 60 kg P_2O_5 ha^{-1} was applied through single super phosphate through seed cum fertilizer drill at the time of sowing in all the treatments at 5 cm depth. Whereas, nitrogen was fertilized through urea as per the treatment by broadcasting. To obtain optimum plant stand and establishment of sorghum, two common irrigations i.e. 1st just after sowing and 2nd five DAS each of 50 mm depth were given in each treatment. While, subsequent irrigations of 50 mm depth were scheduled based on irrigation water depth (IW) to cumulative pan evaporation (CPE) ratio approach as per the treatment. To work out the cumulative pan evaporation, the daily pan evaporation data measured with USWB class A open pan evaporimeter (Case B) installed at meteorological observatory in the proximity of the experimental field was used. Total six (300 mm), seven (350 mm) and nine (450 mm) irrigations were required in treatment I_1, I_2 and I_3, respectively. Experimental plots were kept weed free by applying pre-emergence herbicide Atrazine at 1 kg ha^{-1} after 1st irrigation and subsequently emerged weeds were hand weeded at 20 DAS. Neither serious disease nor pests were observed in the crop during the course of investigation.

2.3. Observations and treatment evaluation

The treatments in this study were evaluated for growth, yield, nutrient uptake, irrigation and nitrogen use efficiency, soil residual nutrient status and economic return to farmers. The treatment effect on growth and development of fodder sorghum was studied in terms of plant height, number of functional leaves, leaf area, dry matter accumulation $plant^{-1}$ and leaf to stem ratio. To quantify the stress effect of different irrigation regimes on fodder sorghum, leaf relative water content (RWC) was estimated at 45 DAS by following the procedure of Barrs and Weatherly (1962). Crop was harvested at 50% flowering stage to record green fodder yield. To obtain dry fodder yield, five plants in each plot were initially sun dried and there after oven dried at 65+5°C till constant weight. Green fodder yield in each plot was multiplied with respective calculated dry matter fraction to get the dry fodder yield. Soil samples were taken from two different (0–15 cm and 16–30 cm) depths in each treatment plot before and after each irrigation to calculate the consumptive use of water as per Mishra and Ahmed (1987). Water use efficiency (WUE) expressed as amount of dry fodder yield produced unit^{-1} of water consumed. Plant and soil analysis for N, P and K content were carried out after the crop harvest by following the prescribed standard methods as mentioned in Table 1. Nitrogen use efficiency (NUE) estimated as partial factor productivity of fertilizer N ($PFPF_N$=DFY/Nf) and N uptake efficiency (N Upt E=Nt/Nf). Where, DFY, Nf and Nt indicated kg ha^{-1} values of dry fodder yield, N applied through fertilizer and N uptake by fodder. Treatment economics was calculated considering prevailing market prices of green fodder and different variable and non-variable inputs used.

3. RESULTS AND DISCUSSION

3.1. *Weather during experimentation*

Fodder sorghum sown on 5th of March (10th meteorological week (MW)) showed complete emergence 7 DAS. The crop experienced weekly mean maximum temperature of 31.6°C and minimum of 14.6°C during germination and emergence stages; which was lowest temperature during entire crop period. Thereafter gradual increase in weekly mean maximum temperature by 1.8 to 2.3°C and minimum temperature by 0.2 to 0.9°C were observed in 11th and 12th MW. However, sudden rise in weekly mean maximum temperature to 38.4–38.8°C and minimum temperature 18.1-21.2 °C in 13th and 14th MW coinciding with 4th and 5th leaf stage, respectively increased the evaporative demand and thus shortened the irrigation interval. Overall the sorghum experienced the heat stress due to rise in temperature, specifically rise in weekly minimum temperature as crop advance towards harvesting stage and it was well evidenced by widening difference in growth attributes, in particular dry matter gain in different irrigation regimes. The evaporation showed the same trend as temperature, it increased as the crop advanced towards maturity. The highest weekly mean maximum temperature i.e. 39.4 °C recorded in 17th MW coinciding with flag leaf stage, while highest minimum temperature i.e. 24.1 °C was recorded at (20th MW) half bloom stage. No rainfall occurred during entire period of experimentation. Weekly weather parameters recorded during experimentation are presented in Figure 1.

3.2. *Growth parameters*

The data on different growth attributes studied in this experiment at 45 DAS and at harvest are presented in Table 2. Irrigation scheduling at 0.8 IW/CPE ratio recorded taller plant with more number of functional leaves and leaf area and thus accumulated higher dry matter plant^{-1}, both at initial stage (45 DAS) and at harvest. However, it remained at par with irrigation at 0.6 IW/CPE ratio for plant height at both the stages, for number of functional leaves and dry matter plant^{-1} at 45 DAS and for leaf area plant^{-1} at harvest.

Table 2: Growth and leaf RWC of fodder sorghum in relation to irrigation schedules, nitrogen levels and N schedules

Treatments	Plant height (cm)		No. of functional leaves plant^{-1}		Leaf area plant^{-1} (dm^2)		Dry matter accumulation (g plant^{-1})		Leaf RWC (%)
	45 DAS	At harvest	45 DAS	At harvest	45 DAS	At harvest	45 DAS	At harvest	
Irrigation schedules (IW:CPE ratio) (I)									
I_1: 0.4	96.62	166.71	6.31	10.05	4.76	7.98	6.66	17.23	64.14
I_2: 0.6	105.34	177.88	6.98	12.33	5.35	9.18	7.38	24.66	70.42
I_3: 0.8	111.32	190.93	7.46	14.05	5.91	10.25	8.02	28.47	74.73
SEm±	2.77	5.23	0.19	0.40	0.11	0.31	0.26	0.78	1.34
CD (p=0.05)	9.57	18.11	0.67	1.39	0.39	1.09	0.91	2.72	4.63
N levels (kg ha^{-1}) (N)									
N_1: 60	100.21	172.13	6.62	10.80	5.01	8.10	6.93	20.95	68.79
N_2: 80	108.65	184.88	7.22	13.48	5.67	10.17	7.78	25.96	70.74
SEm±	1.48	1.89	0.10	0.17	0.05	0.11	0.11	0.41	1.05
CD (p=0.05)	4.31	5.48	0.29	0.50	0.14	0.32	0.32	1.20	NS
N schedules (S)									
S_1: Two splits	106.06	174.84	6.96	11.25	5.41	8.72	7.54	20.41	70.47
S_2: Three splits	102.79	182.17	6.88	13.03	5.26	9.55	7.17	26.50	69.05
SEm±	1.48	1.89	0.10	0.17	0.05	0.11	0.11	0.41	1.05
CD (p=0.05)	NS	5.48	NS	0.50	0.14	0.32	0.32	1.20	NS

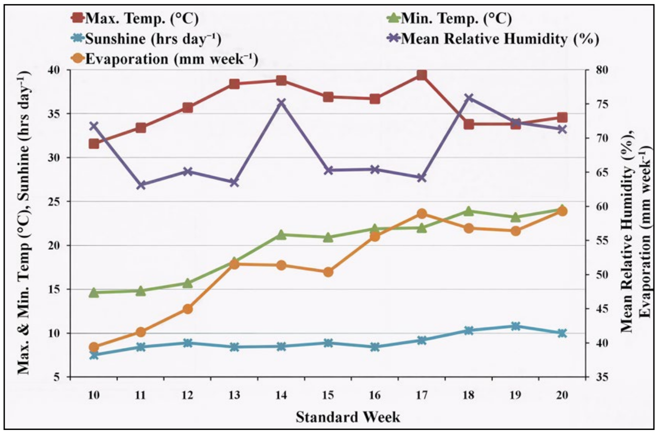

Figure 1: Weekly weather conditions during summer 2021

Frequent irrigation with irrigation at 0.8 IW/CPE ratio might have evaded the moisture stress by maintaining soil moisture in readily available range and thus proliferated the crop growth by consistently accomplishing the crop water requirement. Sufficient soil moisture also augmented the nutrient availability and its absorption by crop roots and by virtue of that increased cell division and elongation. Whereas, significant reduction in growth parameters with irrigation at 0.4 IW/CPE ratio could be attributed to negative impact on different physiological components like chlorophyll content, RWC, membrane stability (Navyashree et al., 2024) and in particular photosynthesis due to closure of stomata because of moisture stress. These results corroborated the findings of Baloch et al. (2014) and Gupta et al. (2015).

Fodder sorghum appreciably responded to higher level nitrogen. Application of 80 kg N ha^{-1} recorded significantly higher plant height, more number of functional leaves, maximum leaf area and dry matter plant^{-1} than 60 kg N ha^{-1} at both 45 DAS and at harvest. The variation in growth attributes among nitrogen levels could be attributed to the differences in availability and uptake of nitrogen by sorghum crop. Trivedi et al. (2010) concluded that N availability improved photosynthetic parameters (chlorophyll content) and morphological parameters like plant height, number of leaves and leaf area. This ultimately facilitated better interception and utilization of radiant energy leading towards higher photosynthesis and finally more accumulation of dry matter in individual plant. These results were in accordance with those of Meena and Meena (2012) and Afzal et al. (2013).

Nitrogen schedules did the significant influence on plant height and number of leaves plant^{-1} at harvest only; whereas, effect on leaf area and dry matter plant^{-1} was significant at both the stages. Application of N in two splits (at basal and 30 DAS) produced taller plant with more number of functional leaves and accordingly recorded significantly maximum leaf area and dry matter plant^{-1} at 45 DAS. On the contrary N application in three splits (at basal, 30 and 45 DAS) recorded maximum plant height with more number of functional leaves, leaf area and dry matter at harvest. These results elucidated that although two splits of N dose adequately accomplished the initial N requirement of fodder sorghum. But it failed to mitigate the subsequent requirement N predominantly during peak growth period due to losses such as NH_3 volatilization and leaching. Conversely, N application in three splits (at basal, 30 and 45 DAS) enhanced N availability for an extended period of time as per the need of fodder sorghum.

3.3. *Relative water content of leaf (%)*

The relative water content (RWC) in leaf was an important parameter indicated the turgidity of leaf cells in response to moisture stress. In the present study scheduling of irrigation at 0.8 IW/CPE ratio recorded significantly higher RWC in leaf during afternoon hours than irrigation at 0.4 IW/CPE ratio and it was at par with irrigation at 0.6 IW/CPE ratio (Table 2). The higher RWC in leaf attributed to availability of adequate soil moisture to fulfill the transpiration demand of sorghum crop. The effect of N levels and split doses on leaf RWC was non-significant.

3.4. *Quality traits*

The different treatments showed the significant influence on different quality traits of fodder sorghum viz. leaf to stem ratio, nutrient content in fodder (N, P, and K) and crude protein content (Table 3). High leaf to stem ratio in fodder is more desirable as leaves has more protein, nutrients, easily digestible and palatable than stem part which are rich in fiber and lignin. The more number of leaves plant^{-1} with higher individual leaf area due to consistent availability of moisture with irrigation at 0.8 IW/CPE ratio resulted significantly higher leaf to stem ratio and increased the P accumulation in fodder than irrigation at 0.6 and 0.4 IW/CPE ratio. Likewise, it also improved the N, K and crude protein content in fodder than irrigation at 0.4 IW/CPE ratio and it was comparable with irrigation at 0.6 IW/CPE ratio. The role of N in improvement of growth and quality was well proven and that might be the reason for significant improvement in different quality traits of fodder sorghum with higher level of N (80 kg ha^{-1}) in this experiment. Similarly, application of N in three splits (at basal, 30 and 45 DAS) recorded significantly higher leaf to stem ratio and improved the N, P and protein content in fodder than two splits of N.

3.5. *Yield and input use efficiency*

The data pertaining to green and dry fodder yield, protein yield, consumptive use of water, WUE, $PFPF_N$ and N Upt E as influenced by different irrigation schedules, N levels and split application of N and their interaction effect are presented in Table 4. Each increment in irrigation level over

Table 3: Quality parameters of fodder sorghum in relation to irrigation schedules, nitrogen levels and N schedules

Treatments	Leaf: stem ratio at harvest	Nutrient content (%)			Crude protein content (%)
		N	P	K	
Irrigation schedules (IW:CPE ratio) (I)					
I_1: 0.4	0.218	0.653	0.178	1.254	4.08
I_2: 0.6	0.260	0.675	0.189	1.319	4.22
I_3: 0.8	0.291	0.704	0.204	1.365	4.40
SEm±	0.007	0.011	0.004	0.021	0.07
CD (p=0.05)	0.025	0.038	0.014	0.072	0.24
N levels (kg ha^{-1}) (N)					
N_1: 60	0.223	0.662	0.185	1.291	4.14
N_2: 80	0.289	0.693	0.195	1.334	4.33
SEm±	0.005	0.008	0.002	0.011	0.05
CD (p=0.05)	0.013	0.023	0.007	0.032	0.14
N schedules (S)					
S_1: Two splits	0.235	0.665	0.184	1.303	4.15
S_2: Three splits	0.278	0.690	0.196	1.323	4.31
SEm±	0.005	0.008	0.002	0.011	0.05
CD (p=0.05)	0.013	0.023	0.007	NS	0.14

its preceding lower level significantly improved the green and dry fodder yield, crude protein yield, N Upt E and recorded higher consumptive use of water. Nevertheless, irrigation at 0.8 IW/CPE ratio being at par with irrigation at 0.6 IW/CPE ratio registered higher WUE and $PFPF_N$. The higher yield and resource use efficiency achieved with irrigation at 0.8 IW/CPE ratio associated with improvement in growth attributes due to ideal soil moisture condition throughout the growing period of sorghum with frequent irrigation. In summer pearl millet Pareek et al. (2015) noted that increase in irrigation frequency increased the fodder yield but at the cost of declining WUE.

Application of 80 kg N ha^{-1} produced higher green fodder, dry fodder and crude protein yield and achieved 23.7% higher WUE than 60 kg N ha^{-1}. Conversely, higher $PFPF_N$ was obtained with 60 kg N ha^{-1}. Whereas, consumptive use of water and N Upt E remained unaffected due to N levels. Nitrogen is an essential component of amino acids and related proteins, which are critical not only as building blocks for plant tissue but also in cell nuclei and protoplasm. The improvement of green and dry fodder yields and WUE were mainly on account of increased in the growth attributes of fodder sorghum with increase N availability due to increasing rate of N level. Pareek et al. (2015) in pearl millet and Somashekar et al. (2015) in sorghum, also noted similar response of fodder yield and WUE to incremental

Table 4: Yield and input use efficiency of fodder sorghum in relation to irrigation schedules, N levels and N schedules

Treatments	Yield (q ha^{-1})			Consumptive use of water (mm)	WUE (kg ha^{-1} mm)	$PFPF_N$	N Upt E
	Green fodder	Dry fodder	Crude protein				
Irrigation schedules (IW:CPE ratio) (I)							
I_1: 0.4	183.7	51.7	2.12	268.4	19.25	74.54	0.49
I_2: 0.6	266.0	72.9	3.11	315.5	23.08	103.94	0.71
I_3: 0.8	309.3	82.3	3.63	338.5	24.32	118.65	0.83
SEm±	9.8	2.7	0.09	6.0	0.84	4.95	0.015
CD (p=0.05)	34.0	9.2	0.30	20.8	2.91	17.14	0.051
N levels (kg ha^{-1}) (N)							
N_1: 60	225.2	61.6	2.57	307.2	19.86	102.62	0.69
N_2: 80	280.9	76.4	3.33	307.7	24.57	95.47	0.67
SEm±	4.2	1.1	0.06	2.9	0.36	2.02	0.011
CD (p=0.05)	12.2	3.3	0.17	NS	1.04	5.85	NS
N schedules (S)							
S_1: Two splits	219.6	59.9	2.51	306.1	19.43	86.00	0.57
S_2: Three splits	286.4	78.1	3.40	308.8	25.01	112.09	0.78
SEm±	4.2	1.1	0.06	2.9	0.36	2.02	0.011
CD (p=0.05)	12.2	3.3	0.17	NS	1.04	5.85	0.032

Table 4: Continue...

Treatments			Yield (q ha^{-1})			Consumptive use of water (mm)	WUE (kg ha^{-1} mm)	$PFPF_N$	N Upt E
			Green fodder	Dry fodder	Crude protein				
Treatment combinations (INS)									
I_1	N_1	T_1	147.0	41.4	1.63	265.4	15.60	68.94	0.43
		T_2	191.1	54.0	2.18	269.1	20.06	89.93	0.58
	N_2	T_1	192.3	54.1	2.22	268.5	20.16	67.65	0.44
		T_2	204.5	57.3	2.45	270.6	21.17	71.63	0.49
I_2	N_1	T_1	186.6	50.9	2.03	312.8	16.27	84.86	0.54
		T_2	260.3	72.0	3.05	316.5	22.76	120.04	0.81
	N_2	T_1	249.7	68.5	2.87	315.4	21.73	85.61	0.57
		T_2	367.4	100.2	4.49	317.3	31.57	125.26	0.90
I_3	N_1	T_1	255.5	68.4	2.95	338.1	20.24	114.01	0.79
		T_2	310.5	82.8	3.59	341.7	24.25	137.95	0.96
	N_2	T_1	286.8	76.0	3.34	336.5	22.55	94.94	0.67
		T_2	384.4	102.2	4.63	337.9	30.22	127.71	0.93
SEm±			10.3	2.8	0.14	7.10	0.88	4.94	0.027
CD (p=0.05)			29.9	8.1	0.41	NS	2.55	14.34	0.079

levels of N. Consistent availability of N with three splits of N (at basal, 30 and 45 DAS), particularly during grand growth period of fodder sorghum significantly improved the different growth attributes. That ultimately resulted in significant enhancement in dry and green fodder yield, crude protein yield, WUE, $PFPF_N$ and N Upt E than application of N in two splits at basal and 30 DAS. The effect of N schedules on consumptive use of water was non-significant.

Thorough analysis of three factor (I×N×S) interaction effect illustrated that, even though the split application of N was non-monetary input; but it was responsible to impart 6 to 47% deviation in green fodder yield under different irrigation regimes and nitrogen levels. The highest gain in green fodder yield (47.1%), WUE (45.3%), $PFPF_N$ (46.3%) and N Upt E (57.9%) registered with application of N in three splits over two splits at 80 kg N level and irrigation at 0.6 IW/CPE ratio. This result indicated that mere application of N in three equal splits i.e. at basal, 30 and 45 DAS to fodder sorghum at optimum N and irrigation regime could enhance the input use efficiency by maximizing yield. Scheduling of irrigation at 0.8 or 0.6 IW/CPE ratio along with application of 80 kg N ha^{-1} in three equal splits ($I_3N_2S_2$ and $I_2N_2S_2$) were found statistically equally effective for enhancing green and dry fodder yield, crude protein yield and WUE than rest of the treatment combinations. However, significantly maximum values of $PFPF_N$ and N Upt E were obtained with irrigation scheduling at 0.8 IW/CPE ratio along with application of 60 kg N ha^{-1} in three equal splits ($I_3N_1S_1$) and it was on par with treatment combinations $I_3N_2S_2$ and $I_2N_2S_2$. Whereas, interaction effect did not differed the consumptive use of water by fodder sorghum. Application of 80 kg N ha^{-1} in three equal splits along with ideal soil moisture condition increases N availability for longer period and thereby supported the plant to produce and maintain more number of leaves plant^{-1}. It also maximized the individual leaf area owing to rapid expansion of foliage for efficient interception and utilization of solar radiation and thus able to accumulate maximum dry matter plant^{-1} and consequently enhanced fodder yield and input use efficiencies.

3.6. Nutrient uptake and soil status

Different irrigation schedules, N levels and splits of N did the significant influence on uptake of N, P and K by fodder sorghum (Table 5). The concurrent gain in biomass and nutrient accumulation with increasing irrigation frequency enhanced uptake of N, P and K by fodder sorghum and irrigation at 0.8 IW/CPE ratio was found significantly superior in this respect. The higher level of N i.e. 80 kg N ha^{-1} not only significantly increased the uptake of N but as well as P and K. Similarly application of N in three splits conspicuously increased the nutrient uptake than two splits.

As regards available nutrient status of soil (Table 5), the available N remained free from different treatment effect. Among irrigation schedules, irrigation at 0.4 IW/CPE ratio recorded significantly higher available P_2O_5 content and it was at par with irrigation at 0.6 IW/CPE ratio. Whereas, the available K_2O unchanged due to irrigation effect. In case of N levels, application of 80 kg N ha^{-1} exhausted the

Table 5: Nutrient uptake by fodder sorghum and soil available nutrient status in relation to irrigation schedules, nitrogen levels and N schedules

Treatments	Nutrient uptake ($kg\ ha^{-1}$)			Available nutrient ($kg\ ha^{-1}$)		
	N	P	K	N	P_2O_5	K_2O
Irrigation schedules (IW:CPE ratio) (I)						
I_1: 0.4	33.9	9.2	64.9	248.5	33.8	421.3
I_2: 0.6	49.8	13.9	96.7	242.9	32.7	406.2
I_3: 0.8	58.0	16.9	112.8	238.9	30.3	401.1
SEm±	1.6	0.6	3.3	5.6	0.8	11.4
CD (p=0.05)	5.5	2.0	11.4	NS	2.7	NS
N levels ($kg\ ha^{-1}$) (N)						
N_1: 60	41.1	11.6	80.0	241.5	33.6	414.6
N_2: 80	53.3	15.2	102.9	245.4	31.0	404.4
SEm±	1.0	0.3	1.4	3.0	0.4	3.4
CD (p=0.05)	2.9	0.8	4.2	NS	1.2	9.9
N schedules (S)						
S_1: Two splits	40.1	11.2	78.64	241.8	33.5	411.86
S_2: Three splits	54.4	15.5	104.31	245.1	31.1	407.22
SEm±	1.0	0.3	1.4	3.0	0.4	3.4
CD (p=0.05)	2.9	0.8	4.2	NS	1.2	NS

available P_2O_5 and K_2O status of soil than 60 kg N ha^{-1}. Likewise, significant depletion in soil available P_2O_5 content was observed with application of N in three splits than two splits, while available K_2O remained unchanged. Significant depletion in soil available P_2O_5 and K_2O status with high yielded treatment in this experiment attributed to higher uptake of nutrients.

3.7. Economics

The acceptability of agriculture technology by the farmers governed by affordability of the technology. In this experiment as the interactive effect of irrigation schedules, N levels and its split application on green fodder yield was significant, the economics was calculated accordingly (Table 6). The scheduling of irrigation at 0.8 IW/CPE ratio and application of 80 kg N ha^{-1} in three equal splits ($I_3N_2T_2$) generated maximum gross monetary return (GMR) of ₹ 1,15,333, net monetary return (NMR) of ₹ 88,168 but with highest cost of cultivation of ₹ 27,165. However, irrigation at 0.6 IW/CPE ratio with application of 80 kg N ha^{-1} in three equal splits ($I_2N_2T_2$) bestow highest benefit-cost ratio (3.28) than rest of treatment combination by recording GMR of ₹ 1,10,219 and NMR of ₹ 84,484. Further it is interested to note that at same level of irrigation (0.6 IW/CPE) and nitrogen rate (80 kg ha^{-1}) mere application of N in three equal splits with additional cost of ₹ 188 only generated the additional income of ₹ 35,125 than two splits.

Table 6: Economics of fodder sorghum as influenced irrigation schedules, nitrogen levels and N schedules

Treatment combinations (INS)			Gross monetary return (₹ ha^{-1})	Total cost of cultivation (₹ ha^{-1})	Net monetary return (₹ ha^{-1})	B:C ratio
I_1	N_1	T_1	44088	24598	19490	0.79
		T_2	57341	24786	32555	1.31
	N_2	T_1	57692	24831	32861	1.32
		T_2	61337	25019	36318	1.45
I_2	N_1	T_1	55969	25314	30655	1.21
		T_2	78098	25502	52597	2.06
	N_2	T_1	74905	25546	49359	1.93
		T_2	110219	25734	84484	3.28
I_3	N_1	T_1	76653	26745	49908	1.87
		T_2	93163	26933	66231	2.46
	N_2	T_1	86052	26977	59075	2.19
		T_2	115333	27165	88168	3.25

1 US$=INR 73.25 (average value of May, 2025)

4. CONCLUSION

Individually, scheduling irrigation at 0.8 IW/CPE, 80 kg N ha^{-1} and three splits of N (basal, 30 and 45 DAS) improved growth, quality, fodder yield, WUE and nutrient uptake. Whereas, combination 0.6 IW/CPE+80 kg N ha^{-1} in three equal splits was economically most remunerative and efficient in irrigation water utilization; and was equally effectual as 0.8 IW/CPE+80 kg N ha^{-1} in three equal splits for obtaining higher fodder yield and NUE.

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