Forage Res., **47** (3) : pp. 308-312 (2021) **http://forageresearch.in**

EVALUATION OF ENERGY EFFICIENCY AND OPTIMUM RESOURCE MANAGEMENT IN FORAGE SORGHUM [*SORGHUM BICOLOR* (L.) MOENCH] UNDER SEMI-ARID TROPICS

SATPAL[1,*], SURESH KUMAR[2], ANIL KUMAR[3], B. GANGAIAH[4], K. K. BHARDWAJ[5] AND NEELAM[6]

[1]Forage Section, Department of Genetics and Plant Breeding,
[2]Directorate of Research, [3]Department of Agricultural Meteorology,
[5]Department of Soil Science, [6]Department of Agronomy,
CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India
[4]ICAR - Indian Institute of Millets Research, Hyderabad - 500 030 (Telangana), India
*(*e-mail : satpal_fpj@hau.ac.in*)

(Received : 22 October 2021; Accepted : 26 December 2021)

SUMMARY

An experiment was conducted at Forage Section Research Farm, CCS HAU, Hisar, during *kharif* seasons of 2015 to 2017 on single-cut forage sorghum to quantify the impact of input resources (variety, fertilizer, weed control, plant protection, irrigation) on fodder production while working out the energy use efficiency indices with weather variables excluding each management practice from full package of practices (FPP) and from the differences in crop performance, input impact was assessed. The study revealed that management practices contributed to 49% improvement in green fodder yield of improved cultivar of single cut forage sorghum. Absence of improved genotype, weed control, plant protection fertilizer and irrigation resulted in 39, 33, 31, 30 and 22 per cent loss, respectively, in productivity as compared to FPP. The radiation use efficiency and heat use efficiency were also highest in full package of practices and thus are more energy efficient. Seed treatment exclusion from FPP did not affected crop productivity and resource use efficiency significantly. Radiation and heat use efficiency of forage sorghum (185.35 kg ha^{-1} & 14.13 MJ^{-1}kg ha^{-1} °C day) with FPP, as compared to all other treatments except FPP-seed treatment. Helio Thermal Unit and Hydro Thermal Unit were not significantly influenced by different management treatments.

Key words : Fodder yield, input management, weather impact, agro-meteorological indices, thermal-energy efficiencies, forage sorghum

Sorghum [*Sorghum bicolor* (L.) Moench], belonging to family Poaceae, is widely grown fodder crop of India to support the green as well as dry fodder requirement of its vast livestock resources that stands at whopping 536.76 million as per latest 19th livestock census (Anonymous, 2020). Sorghum cultivated for both fodder and grain purposes in arid and semi-arid regions is well known for its adaptability to harsh and variable climatic conditions not only in India but also in Africa too. This crop is favoring the more turbulent condition (three coordinate *i.e.* x, y and z direction) movement of air near the crop field) in the atmosphere especially during the advance growth stage. India with 5.4% (8.4 M ha) of the cultivated area under forage crops has a 36% deficiency in green fodder resources for livestock feeding (IGFRI, 2017). Sorghum is a widely grown cereal forage crop with short duration alongwith ability to produce high biomass under wide edapho-climatic situations across the country including saline conditions (Satpal *et al.*, 2021). Sorghum is also among the most efficient crops in conversion of solar energy and use of water. Radiation use efficiency (RUE) is an important quantifier of crop production in relation to photosynthesis, as it combines both the amount of solar radiation captured by the crop and the efficiency of the crop to produce dry matter. The range of RUE for C_4 species was estimated to lie between 4.0 and 5.8 g MJ^{-1} (Hatfield and Dold, 2019). Since sorghum is a climate resilient crop, the present study was carried out to quantify the RUE and other agro-meteorological indices of the crop under various input management conditions to find out the energy efficient resource management to harness the maximum productivity under semi-arid region of Haryana state. Further, efficiencies were also assessed in terms of fodder, crude protein and digestible dry matter yields. In the absence of biotic and abiotic stresses, plant dry matter accumulation depends on the quantity of radiation absorbed by the canopy

(Sinclair and Muchow, 1999). Satpal *et al.* (2020) also reported that varieties vary in their response to the inputs applied. The differential behavior of the two genotypes could be explained solely by the variation in their genetic constituent (Meena *et al.*, 2012). Climate and ecological changes play vital role in germination and emergence and also in subsequent growth and development and final yield (Kumar *et al.*, 2009; Eitzinger *et al.*, 2009). Keeping the above points in view, an experiment was conducted with the primary objective to quantify the management component that had the greatest influence on single cut forage sorghum productivity, as compared to the full package of practices (FPP).

MATERIALS AND METHODS

Field experiment was conducted during *kharif* seasons of 2015, 2016 and 2017 at Forage Section Research Farm, CCS Haryana Agricultural University, Hisar (29° 10' N, 75° 46' E, at an average elevation of 215.2 m above mean sea level). The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 7.6), low in organic carbon (0.47%), low in available N (169.4 kg/ha), medium in available P (13.7 kg/ha) and high in available K (238.6 kg/ha). Rainfall during different seasons (year wise) is given in Fig. 1. The experiment consisted of eight treatments *viz.* T_1: Control (only improved cultivar 'HJ 541' without any input), T_2: Full package of practice (FPP) *i.e.* seed treatment + weed control + fertilizer + irrigation + plant protection + improved cultivar, T_3: FPP minus fertilizer, T_4: FPP minus weed control, T_5: FPP minus plant protection, T_6: FPP minus seed treatment, T_7: FPP minus irrigation, T_8: FPP minus improved genotype (local cultivar Duggi was used). These treatments were tested in randomized block design (RBD) with three replications. The sowing dates were 4th July 2015, 19th June 2016 and 18th July 2017, respectively. All the other standard agronomic practices for the cultivation of forage sorghum were followed uniformly in all the treatments (Anonymous, 2013). The recommended dose of fertilizers used in FPP was 75 kg N and 15 kg P_2O_5/ha, out of which 50 kg N and full dose of phosphorus was applied basal and 25 kg N was top dressed in the form of urea at 30 days after sowing. Crude protein yield (CPY) and digestible dry matter (DDM) yields (kg/ha) were calculated by multiplication of crude protein content and IVDMD (*In vitro* dry matter digestibility) with dry matter yield (kg/ha), respectively.

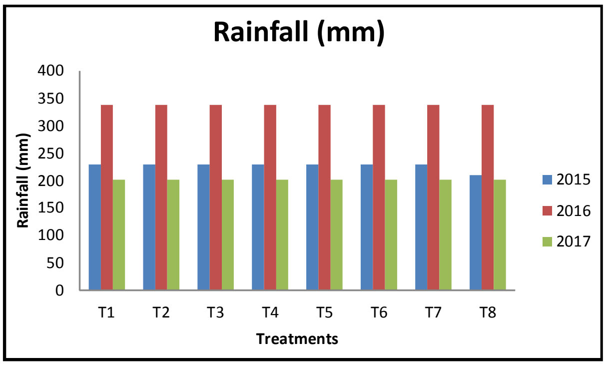

Fig. 1. Rainfall during the season (year wise).

Evaluation of Agro Meteorological Indices

(A) Accumulated Growing Degree Days (GDD): It was calculated by summation of daily mean temperature above base (T_b=10°C) temperature for a corresponding period from sowing and expressed in degree celcius (°C).

$$GDD = \Sigma [(T_i + T_n)/2 - Tb]$$

Where, T_i = Daily maximum temperature T_n = Daily minimum temperature

(B) Accumulated Photothermal Unit (PTU): It is calculated by multiplying GDD with maximum possible sunshine hours (N) PTU = GDD × N

(C) Accumulated Heliothermal Unit (HTU): It is calculated by multiplying GDD with actual sunshine hours (n). HTU = GDD × n

(D) Hydrothermal Unit (HYTU): It is determined by multiplying the GDD with the average relative humidity, expressed in °C day percent. HYTU (kg ha^{-1} °C day) = GDD × Average relative humidity (RHa), The computation of the hydrothermal unit used the GDD and average relative humidity during the different phenophase from sowing to green fodder harvesting.

(E) Radiation use efficiency (RUE): It is defined as the amount of green fodder and dry matter produced for the unit intercepted photosynthetically active radiation (PAR). RUE is expressed in kgha^{-1} MJ^{-1}. RUE of forage sorghum from date of sowing to first cut 1 was computed by expression given below.

$$RUE = \frac{\text{Yield of sorghum } (\frac{kg}{ha})}{\text{Accumulatedi PAR (MJ)}}$$

Daily solar radiation PAR data collected from Department of Agricultural Meteorology, College of Agriculture, CCS HAU, Hisar and RUE was computed.

(F) Heat use efficiency (HUE): HUE was also computed for GFY, DMY, CPY and DDMY. HUE (kg ha^{-1} $°C^{-1}$ day) is the dry matter produced per unit degree day consumption in the influencing weather condition in the experimental region.

$$\mathrm{HUE} = \frac{\text{Yield of sorghum } (\frac{\text{kg}}{\text{ha}})}{\text{Accumulated GDD } (°\text{C day})}$$

Data were analyzed by using OPSTAT software available on CCS Haryana Agricultural University website (Sheoran *et al*., 1998). The results are presented at 5 per cent level of significance (P=0.05) for making comparison between treatments.

RESULTS AND DISCUSSION

Perusal of the data from Table 1 revealed that among management practices, highest green fodder, dry matter, crude protein and digestible dry matter yield (55017, 14192, 1364 and 7496 kg/ha) were recorded by the forage sorghum crop cultivated with full package of practices (FPP) which was on a par with FPP minus seed treatment and was significantly superior to rest of the treatments. Improved genotype (HJ 541) has 39 and 44 per cent higher green fodder and dry matter yield than local genotype Duggi both grown with FPP. The differential behavior of the two genotypes could be explained solely by the variation in their genetic constitution. The maximum reduction in GFY due to use of local genotype (T_8) with FPP was followed by 30-35 per cent reduction in the absence of fertilizer, weed control and plant protection each. The reduction in GFY was least (22%) in FPP minus irrigation. This might be ascribed to the adequate maintenance of soil moisture by the rainfall during the *kharif* season. The CPY and DDMY were also highest with FPP and on a par with FPP minus seed treatment. The relative reduction in GFY due to absence of FPP was 48.6% in the absence of FPP, 38.8% in the absence of improved cultivar, 30.0 to 33.0% in the absence of fertilizer, weed control and plant protection each and 22.0% in the absence of irrigation, respectively. Maximum days to 50% flowering (97.0) were taken by FPP which were on a par with FPP minus seed treatment but was significantly higher than all the other treatments. Minimum number of days to 50% flowering (79.2) was taken by FPP minus improved genotype (Duggi variety).

Influence of prevailing air temperature on phenology and yield of crops can be studied under the field condition through accumulated heat unit system (Pandey *et al*., 2010). Perusal of the data from Table 2 revealed that maximum growing degree day was reported in FPP which was on a par with all the treatments except FPP minus improved genotype because the local cultivar 'Duggi' used in this treatment took less no. of days to 50% flowering (harvesting stage). Plants have a definite heat requirement before they attain certain phenophases. A change in temperature during phenophases of a crop adversely affects the initiation and duration of different phenophases and finally the economic yield (Prakash *et al*., 2017). The photothermal unit, growing degree day, heliothermal use and hydrothermal use were not influenced significantly among treatments as the experiment was laid out in single environment in all the three years.

TABLE 1

Effect of production inputs on yield of single-cut forage sorghum (3-year mean data)

Treatment	Days to 50% flowering	Green fodder yield (kg/ha)	Dry matter yield (kg/ha)	Crude protein yield (kg/ha)	Digestible dry matter yield (kg/ha)
Control (T_1)	92.9	28239	7062	587	3521
FPP (T_2)	97.0	55017	14192	1364	7496
FPP - Fertilizer (T_3)	94.1	38489	9433	803	4703
FPP - Weed control (T_4)	94.0	36864	9319	753	4575
FPP - Plant protection (T_5)	93.4	37889	9711	770	4793
FPP - Seed treatment (T_6)	96.4	53720	13809	1272	7229
FPP - Irrigation (T_7)	93.6	42878	10745	918	5303
FPP - Improved genotype (T_8)	79.2	33686	8012	642	3972
SEm±	0.8	1591	420	36	217
CD (P=0.05)	2.4	4873	1287	109	664
CV (%)	1.47	6.70	7.10	6.94	7.22

TABLE 2
Weather indices for green fodder yield (3-year mean data)

Treatment	GDD (°C day)	PTU GDD (°C day hour)	HTU (°C day hour)	HYTU (°C day %)
Control	1993	35191	15581	159687
FPP	2059	32743	16231	167070
FPP - Fertilizer	1972	35961	15919	164951
FPP - Weed control	2027	32369	15955	159508
FPP - Plant protection	1995	32184	15705	168939
FPP - Seed treatment	2049	31847	16002	165794
FPP - Irrigation	2013	32172	15718	173620
FPP - Improved genotype	1786	29880	14688	155554
SEm±	38	2569	367	4860
CD (P=0.05)	116	NS	NS	NS
CV (%)	3.31	13.57	4.04	5.12

Data presented in Table 3 revealed that highest Radiation use efficiency (RUE) of GFY, DMY, CPY and DDMY (185.35, 47.75, 4.60 and 25.23 kg ha^{-1} MJ^{-1}, respectively) was recorded with FPP which was on a par with FPP minus seed treatment. The energy consumption and producing per unit gram of biomass (through the assimilation) utilized the radiation and its evaluated as the radiation use efficiency (RUE) of GFY calculated with FPP was 84.40, 44.03, 43.47, 38.68, 37.24 and 22.42 per cent higher over control, FPP-weed control, FPP-improved genotype, FPP-plant protection, FPP-fertilizer, FPP-irrigation. After the highest effect of improved cultivar, the other agronomic management factors also played a significant role in harnessing the better RUE of single-cut forage sorghum particularly for GFY, DMY, CPY and DDMY. Increasing radiation use efficiencies are critical to enhance the crop production (Narayanan *et al.*, 2013).

TABLE 3
Radiation use efficiency of yield (3-year mean data)

Treatment	RUE (kg/ha/MJ)			
	GFY	DMY	CPY	DDMY
Control	100.51	25.04	2.09	12.52
FPP	185.35	47.75	4.60	25.23
FPP - Fertilizer	135.05	32.99	2.81	16.48
FPP - Weed control	128.68	32.52	2.63	15.95
FPP - Plant protection	133.65	34.25	2.72	16.88
FPP - Seed treatment	182.94	46.95	4.33	24.59
FPP - Irrigation	151.40	37.82	3.24	18.72
FPP - Improved genotype	129.19	30.77	2.47	15.09
SEm±	6.68	1.82	0.16	0.88
CD (P=0.05)	20.47	5.59	0.49	2.71
CV (%)	8.08	8.77	8.97	8.41

TABLE 4
Heat use efficiency of yield (3-year mean data)

Treatment	HUE (kg/ha °C^{-1} day^{-1})			
	GFY	DMY	CPY	DDMY
Control	14.13	3.52	0.29	1.76
FPP	26.75	6.93	0.66	3.67
FPP - Fertilizer	19.21	4.72	0.40	2.36
FPP - Weed control	17.96	4.52	0.37	2.23
FPP - Plant protection	18.95	4.83	0.38	2.39
FPP - Seed treatment	26.21	6.76	0.62	3.55
FPP - Irrigation	21.02	5.27	0.45	2.62
FPP - Improved genotype	19.09	4.57	0.36	2.28
SEm±	0.85	0.24	0.02	0.13
CD (P=0.05)	2.61	0.72	0.07	0.39
CV (%)	7.23	7.94	8.54	8.44

Data presented in Table 4 revealed that highest heat use efficiency of GFY, DMY, CPY and DDMY (26.75, 6.93, 0.66 and 3.67 kg ha^{-1} °C^{-1} day^{-1}, respectively) were recorded with FPP which were on a par with FPP - Seed treatment. Higher HUE in FPP could be attributed to the highest green fodder and dry matter yield. Higher HUE in timely sown could be attributed to the highest grain and straw yield. The higher yield was attained due increased biological activity and prevailing optimum temperature throughout the growing period of the crop and hence utilized the heat more efficiently (Prakash *et al.*, 2017). PTU, HTU and HYTU indices were not markedly altered by management practices, though FPP recorded the highest values while FPP minus improved genotype have lowest values.

CONCLUSION

Based on the above findings from three years' study, it is concluded that management practices contributed to 49% improvements in green fodder yield of improved cultivar (HJ 541) of single cut forage sorghum. Among the management practices, absence of improved genotype (39%), weed control (33%), plant protection (31%) and fertilizer (30%), irrigation (22%) resulted in highest loss in productivity. The radiation use efficiency and heat use efficiency were also highest in full package of practices and thus are more energy efficient. Seed treatment exclusion from FPP did not impact crop productivity and resource use efficiency.

ACKNOWLEDGEMENTS

The authors are thankful to The Head, Forage Section, Department of Genetics & Plant Breeding, CCS Haryana Agricultural University Hisar for providing the seed of sorghum varieties used in the experiment. The experiment was conducted as coordinated trial under the guidance of All India Coordinated Research Project on Sorghum, ICAR-IIMR, Hyderabad.

REFERENCES

Anonymous 2013 : Package of Practices for *kharif* crops of Haryana, Directorate of Extension Education, CCS HAU, Hisar, pp. 127-130.

Anonymous 2020 : 20th Livestock Census - 2019, All India Report. Department of Fisheries, Animal Husbandry & Dairying, Department of Animal Husbandry & Dairying, Statistics Division, Krishi Bhawan, New Delhi. http://dadf.gov.in.

Eitzinger, J., S. Singh and D. Singh, 2009 : Impacts of Climate Change and Variability on Agriculture Experience from Europe and India. *J. Agrometeorol.*, **11**(Special issue): 24-32.

Hatfield, J. L. and C. Dold, 2019 : *Photosynthesis in the Solar Corridor Crop System. In: The Solar Corridor Crop System*. C. Leroy Deichman and Robert J. Kremer (eds.). (Elsevier Science, Academic Press), 1-33.

IGFRI 2017 : Annual Report, ICAR - Indian Grassland and Fodder Research Institute, Jhansi, India. 1-137.

Kumar, K., S. Singh and D. Singh, 2009 : Winter season's Climatic variability and impact analysis on wheat productivity in western Agroclimatic zone of Haryana. *J. Agrometeorol.*, **11**(Special Issue): 50-53.

Meena, A. K., P. Singh and P. Kanwar, 2012 : Effect of nitrogen levels on yield and quality of sorghum [*Sorghum bicolor* (L.) Moench] genotypes. *Forage Res.*, **37**: 238-240.

Narayanan, S., R. M. Aiken, P. V. V. Prasad, Z. Xin and J. Yu, 2013 : Water and radiation use efficiencies in sorghum. *Agronomy Journal*, **105**: 649-656.

Pandey, I. B., R. K. Pandey, D. K. Dwivedi and R. S. Singh, 2010 : Phenology, heat unit requirement and yield of wheat (*Triticum aestivum*) variety under different crop growing environment. *Indian Journal of Agricultural Sciences,* **80**(2): 136-140.

Prakash, V., J. S. Mishra, R. Kumar, R. Kumar, S. Kumar, S. K. Dwivedi, K. K. Rao and B. P. Bhatt, 2017 : Thermal utilization and heat use efficiency of sorghum cultivars in middle Indo-Gangetic Plains. *J. Agrometeorol.*, **19**(1): 29-33.

Satpal, B. Gangaiah, N. Kumar, S. Devi, N. Kharor, K. K. Bhardwaj, P. Kumari, D. S. Phogat and Neelam, 2020 : Performance of single-cut forage sorghum cultivars at different fertilizer levels. *Forage Res.*, **46**(2): 202-207.

Satpal, B. Gangaiah, N. Kumar, S. Devi, N. Kharor, K. K. Bhardwaj, P. Kumari, B.L. Sharma, Neelam and S. Kumar, 2021 : Performance of single cut forage sorghum [*Sorghum bicolor* (L.) Moench] genotypes under graded levels of NPK fertilizers. *Forage Res.*, **47**(2): 180-186.

Sheoran, O. P., D. S. Tonk, L. S. Kaushik, R. C. Hasija and R. S. Pannu, 1998 : *Statistical Software Package for Agricultural Research Workers*. (In) Hooda D. S. and Hasija R. C. (eds), *Recent Advances in Information Theory, Statistics & Computer Applications* (Department of Mathematics & Statistics, CCS HAU, Hisar), 139-143.

Sinclair, T. R., and R. C. Muchow, 1999 : Radiation use efficiency. *Advances in Agronomy,* **65** : 215-265.