Environment and Ecology 40 (3B) : 1541—1547, July—September 2022
ISSN 0970-0420

Crop Water Production Functions in Relation with Rainwater Supplemental Irrigation Levels under Rainfed Alfisols in Maize (*Zea mays* L.) Crop

Barikara Umesha, K. S. Reddy, B. S. Polisgowdar, U. Satishkumar M. S. Ayyanagoudar, Sathyanarayan Rao, H. Veeresh

Received 28 February 2022, Accepted 30 May 2022, Published on 11 August 2022

ABSTRACT

The rainwater harvesting in the semi arid regions enhance the livelihoods of rainfed farmers by mitigating the dry spells under changing climate. The present study was laid out in a split-split plot statistical design with three replications. There were five main irrigation treatments viz., I_0, I_1, I_2, I_3, I_4, two sub treatments viz., M_0 (no mulching), M_1 (mulching @ 5 t ha^{-1} with glyricidia) and two sub-sub treatments viz., NF (normal fertilizer) and HF (high fertilizer) to study the effect of supplemental irrigation and crop management practices on maize grain yield, biomass and water productivity in semi arid alfisols of southern part of Telangana state. The results of present study showed that, the highest average grain yield of 3.19 t ha^{-1} was recorded in I_4 followed by I_3 (2.73 t ha^{-1}), I_2 (2.38 t ha^{-1}), I1 (2.22 t ha^{-1}) and lowest was in I0 (1.78 t ha^{-1}). The two seasons highest average biomass (6.58 t ha^{-1}) was recorded in I4 followed by I3 (5.87 t ha^{-1}), I_2 (5.11 t ha^{-1}), I_1 (4.66 t ha^{-1}) and the lowest was in I_0 (3.62 t ha^{-1}). The highest average water productivity (10.65 kg ha^{-1} mm^{-1}) was recorded in I_4 followed by I_3 (9.54 kg ha^{-1} mm^{-1}), I_2 (8.66 kg ha^{-1} mm^{-1}), I1 (8.67 kg ha^{-1} mm^{-1}) and the lowest was in I_0 (7.60 kg ha^{-1} mm^{-1}). The developed crop water production functions indicated that, the grain yield was increased with increase in depth of supplemental irrigation. The coefficient of determination (R^2) between average grain yield and average crop water use under different crop management practices of M_1HF, M_1NF, M_0HF and M_0NF were 0.98, 0.91, 0.97 and 0.92 respectively. The coefficient of determination (R^2) between grain yield and crop water use (mm) for combined crop water function was 0.86 under different supplemental irrigation.

Keywords Semi-arid, Mulching, Dryspell, Critical irrigation, Water productivity.

Barikara Umesha*
*Scientist (Soil and Water Engg),
University of Agricultural Science, Raichur 584128, Karnataka, India

K. S. Reddy
Principal Scientist (SWCE), DRM,
Central Research Institute for Dryland Agriculture (CRIDA), Santoshnagar, Saidabad (Post), Hyderabad 500059

B. S. Polisgowdar[1], U. Satishkumar[2], M. S. Ayyanagoudar[3]
[1,2,3]Professor,
Department of Soil and Water Engineering, CAE, Raichur
University of Agricultural Science, Raichur

Sathyanarayan Rao
Dean (Agriculture),
University of Agricultural Science, Raichur

H. Veeresh
Assistant Professor,
Department of Soil Science and Agricultural Chemistry,
University of Agricultural Science, Raichur

Email: umeshbarikar@gmail.com
*Corresponding author

INTRODUCTION

Water scarcity and frequent droughts are threats to the livelihood of dryland farming communities and the economy in many parts of the world (Meena and Meena 2020, Alam 2015) particularly countries like India where more than 55 % of total agricultural area is rainfed (Kumar *et al*. 2015) supporting 40 % of India's food demand of 1.2 billion people. In semi-arid regions, climate change is expected to cause more variability which leads to occurrence of extreme rainfall events and increase in the frequency of droughts (Iglesias and Garrote 2015, Lasage and Verburg 2015). According to Reddy *et al*. (2014) average annual rainfall is expected to be increased by 5.16 % in 2030 and 9.5 % in 2060 in semi arid of southern part of Telangana state in India. The occurrence of frequent droughts in the semi arid regions received increasing attention in adoption of rainwater harvesting structures in recent years. To keep in pace with the demand for food for the increasing population, the Indian drylands should be made more productive through appropriate rainwater harvesting and management techniques. The adoption of rainwater harvesting techniques is good options to help rainfed farmers in developing countries to resilient the expected impacts of climate change on water resources (Lasage and Verburg 2015). Small local rainwater harvesting structures like farm ponds are crucial to maintain crop productivity through application of critical/supplemental irrigation in the small holdings of Indian dryland agriculture (Kumar *et al*. 2015).

The integration of rainwater harvesting with supplemental irrigation is one strategy to reduce the drought effects on crop production in the arid and semi arid tropics. The adoption of water saving irrigation methods like drip and sprinkler along with supplemental irrigation would enhance the improvement of crop yield in semiarid regions (Daccache *et al*. 2015). The selection of crops, enhancing soil moisture, rainwater harvesting and utilizing rainwater for supplemental irrigation (SI) are key factors to improve livelihoods of rainfed farmers (Mahmood *et al*. 2015). In the recent years, many parts of the world, rainfed farmers have adopted supplemental irrigation (SI), and reported that, it substantially improves yield and water use efficiency (WUE) when applied during critical stages of crop growth periods (Guo *et al*. 2015). Scarce water resources, presently used for full irrigation can be reallocated to supplement rainfed farming to increase the water productivity in rainfed areas (Mahmood *et al*. 2015). Crop water production functions (CWPFs) are often expressed as crop yield vs. consumptive water use or irrigation water applied and are helpful for optimizing management of limited water resources, but are site specific and vary from year to year, especially when yield is expressed as a function of irrigation water applied (Tafteh *et al*. 2013, Saseendran *et al*. 2015). Yield functions are used for irrigation system design and management, economic development and the benefits of irrigation water compared with other water uses (Blair and Kulbhushan 2014, Wang and Baerenklau 2014).

Maize (*Zea mays* L.) is grown throughout the year in India. It is predominantly a crop with 85 % of the area under cultivation in the rainy season. Maize is cultivated under 177.73 million hectares globally with a production of about 961.85 million tonnes and a productivity of 5.41 metric tonnes per hectare (Varshini and Babu 2020). In India 8.81 million hectares of land is used for maize cultivation with a production of 22.57 million tonnes and a average yield of 2.56 metric tonnes per hectare (Varshini and Babu 2020). However, the productivity of rainfed maize is as low as 0.89 t ha^{-1} to as high as 2.53 t ha^{-1}. The potential productivity of maize in high rainfall regions under rainfed condition is 8.0 Mg ha^{-1} vis-a-vis the national average yield of 2.1 Mg ha^{-1}, indicating an unbridged yield gap of ~6 Mg ha^{-1} (Rao *et al*. 2015). Large yield gaps exist in other crops as well which are primarily grown under rainfed conditions. Keeping these aspects in view, the present study was undertaken, to study the effect of supplemental irrigation on maize grain yield, biomass and water productivity and to develop the crop water production functions under different crop management practices in semi arid regions in India.

MATERIALS AND METHODS

Experimental details

The field experiment was conducted at ICAR-Central

Research Institute for Dryland Agriculture (CRIDA), Hyderabad. The soil physical characteristics such as field capacity, permanent wilting point and total available water were 11.6 %, 4.1% and 75 mm m^{-1} respectively. Soil texture was sandy clay loam with Sand (70.96 %), Clay (22.32 %) and Silt (6.72 %). The experiment was laid out in a split-split plot statistical design with three replications. There were five main treatments viz., I_0, I_1, I_2, I_3, I_4, two sub treatments viz., M_0 (no mulching), M_1 (mulching @ 5 t ha^{-1} with glyricidia) and two sub-sub treatments viz., NF (normal fertilizer) and HF (high fertilizer). Maize (Monsanto, Dekalb 900 M.Gold) crop was used as test crop and total plot size was 4050 m^2 (60 blocks) with each block size 15 m x 4.5 m. The experiment was conducted during *kharif* season for two years, 2013 and 2014. The average annual and seasonal rainfall of the study area was 701.87 and 478.05 mm, respectively. The average temperature of study area is 25.5 ºC with average minimum and maximum of 8.94 and 42.06 ºC respectively.

Soil moisture measurement and irrigation scheduling

The soil moisture and soil temperatures during the crop period were measured on weekly basis. Twelve soil moisture profile tubes were installed randomly and soil profile probe meter (Delta T) is used to measure the soil moisture at 15 and 30 mm below the ground surface. The soil moisture probe was calibrated by taking soil samples extensively in the test field before installation in the experimental field. Supplemental irrigation was given through special type of half circle sprinklers at different critical stages of maize crop. The rainfall greater than or less than 20 mm per week will be considered for determining a week as wet or dry week respectively (Reddy *et al*. 2014). The crop experienced two dry spells in vegetative stage and tasseling stage during rainy season of 2013. To meet out the moisture stress during dry spell, the supplemental irrigation was given on 5^{th} September and 6^{th} October of 2013. During 2014 rainy season, crop experienced dry spell during development stage and supplemental irrigation was given on 11^{th} August, 2014 to mitigate moisture stress. Fertilizer was applied at two levels viz., 100 % (90, 45, and 45 kg ha^{-1} of NPK normal) and 125 % N (25 % higher than normal) during crop period. The recommended SSP and MOP was applied at the time of maize sowing and nitrogen was applied at two levels, the first 50 % was applied during sowing and remaining 50 % is applied during flowering stages.

Crop water production function (CWPF) and statistical analysis

The crop water production functions (CWPF) are developed by using regression analysis of fitting polynomial equation of $Y= ax^2+bx +c$, where Y is the yield (t ha^{-1}) and x is the crop water use in mm. a, b and c are regression coefficients obtained through analysis. The CWPF are developed for four management options of M_1HF (mulching and 25 % extra N), M_1NF (mulching and recommended fertilizer), M_0HF (no mulch and 25 % extra N) and M_0NF (no mulch and recommended fertilizer) for the combination of all the management options. The significance of the differences between the different treatments was determined by one-way analysis of variance (ANOVA) using SPSS software according to the t-test at $p < 0.05$. Significant differences among the effects of the different supplemental irrigation and crop management practices on maize grain yield, biomass and water productivity were determined using the t-test and were indicated by different letters.

RESULTS AND DISCUSSION

Supplemental irrigation and crop management practices on grain yield and water productivity

The two years of experimental data were pooled for statistical analysis through ANOVA to study the interaction between treatments of supplemental irrigation (SI), mulching (M), fertilizer levels (F) on rainfed maize yield and water productivity. From Table 1, it is observed that, among all SI treatments, the highest average grain yield of 3.19 t ha^{-1} was recorded in I_4 followed by I_3 (2.73 t ha^{-1}), I_2 (2.38 t ha^{-1}), I_1 (2.22 t ha^{-1}) and lowest was in I_0 (1.78 t ha^{-1}). Under crop management treatments, the highest grain yield was obtained in M_1HF (3.49 t ha^{-1}) under (I_4) and least was in (I_0) M_0NF (1.41 t ha^{-1}). During both *kharif* season of 2013 and 2014, under SI treatments, the highest

Table 1. Mean grain yield, biomass and water productivity during rainy season of 2013 and 2014. NS: Non significant.

Treatment	Yield (t ha^{-1})			WP (kg ha^{-1} mm^{-1})		
	2013	2014	Pooled	2013	2014	Pooled
M_1HF	3.90	0.67	2.26	16.20	4.30	10.25
M_1NF	3.60	0.00	1.78	14.96	0.00	7.48
M_0HF	3.30	0.00	1.67	13.71	0.00	6.86
M_0NF	2.80	0.00	1.41	11.63	0.00	5.82
Mean	3.40	0.17	1.78	14.13	1.08	7.60
M_1HF	4.10	0.97	2.55	14.61	5.50	10.06
M_1NF	3.90	0.77	2.31	13.90	4.40	9.15
M_0HF	3.50	0.69	2.11	12.47	3.80	8.14
M_0NF	3.20	0.62	1.90	11.40	3.30	7.35
Mean	3.68	0.76	2.22	13.10	4.25	8.67
M_1HF	4.80	1.05	2.92	15.96	5.20	10.58
M_1NF	4.00	0.86	2.41	13.30	4.70	9.00
M_0HF	3.60	0.74	2.18	11.97	3.60	7.79
M_0NF	3.30	0.67	2.00	10.97	3.60	7.29
Mean	3.93	0.83	2.38	13.05	4.28	8.66
M_1HF	5.10	1.39	3.26	15.90	6.90	11.40
M_1NF	4.80	1.18	2.99	14.97	6.20	10.59
M_0HF	4.10	0.75	2.42	12.78	4.10	8.44
M_0NF	3.80	0.68	2.25	11.85	3.60	7.73
Mean	4.45	1.00	2.73	13.88	5.20	9.54
M_1HF	5.30	1.69	3.49	15.56	8.00	11.78
M_1NF	5.10	1.48	3.27	14.97	7.10	11.04
M_0HF	4.70	1.39	3.07	13.80	6.60	10.20
M_0NF	4.60	1.24	2.92	13.50	5.70	9.60
Mean	4.93	1.45	3.19	14.46	6.85	10.65
		SEm	CD (p=0.05)		SEm	CD (p=0.05)
A (Irrigation)		0.02	0.08		0.10	0.32
B (Mulching)		0.02	0.05		0.07	0.21
C (Fertilizer)		0.02	0.05		0.07	0.19
A*B		0.04	0.12		0.15	0.47
A*C		0.04	NS		0.15	0.43
B*C		0.02	0.07		0.09	0.27
A*B*C		0.05	NS		0.21	NS

average water productivity (10.65 kg ha^{-1} mm^{-1}) was recorded in I_4 followed by I_3 (9.54 kg ha^{-1} mm^{-1}), I_2 (8.66 kg ha^{-1} mm^{-1}), I_1 (8.67 kg ha^{-1} mm^{-1}) and the lowest was in I_0 (7.60 kg ha^{-1} mm^{-1}). Under crop management treatments, the highest WP was obtained in I_4 (50 mm) with M_1HF (11.78 kg ha^{-1} mm^{-1}) and least was in (I_0) M_0NF (5.82 kg ha^{-1} mm^{-1}). The results of maize yield during rainy season of 2013 and 2014 indicated that, the application of supplemental irrigation during crop critical stages significantly increased the maize yield. Supplemental irrigation applied at the most sensitive stages of crop growth (i.e. flowering and grain-filling) had enhanced the crop yield over rainfed. It was due to higher moisture availability to the root zone resulting in better grain yield (Sharma and Banik 2012, Hijam *et al*. (2014). The application of organic mulch (5 t ha^{-1}) and 25 % extra nitrogen over recommended (RDF) had positive influence on maize grain yield. It was observed that, application of supplemental irrigation and incorporation of mulching in rainfed maize production improves the effectiveness of water utilization (Khongwar and Manoj 2020). The WP has increased linearly with increasing additional supplemental irrigation during critical stages in both years and among two seasons, the maximum water productivity was observed in 2013 than 2014. It is because; the yield reduction in the rainy season of 2014 due to two long dry spells in the crop development stage.

Supplemental irrigation water use efficiency (SI-WUE) under different irrigation treatments

The results of supplemental irrigation use efficiency and water productivity during rainy seasons of 2013 and 2014 are presented in Table 2. The irrigation water applied during 2013 was 0, 40, 60, 80 and 100 mm under rainfed I_0, I_1, I_2, I_3 and I_4 and respective yields were 3.4, 3.68, 3.93, 4.45 and 4.93 t ha^{-1}. The highest SIWUE (15.25 kg ha^{-1} mm^{-1}) was observed in I_4 followed by I_3 (13.13 kg ha^{-1} mm^{-1}), I_2 (8.73 kg ha^{-1} mm^{-1}) and the minimum were in I_1 (6.88 kg ha^{-1} mm^{-1}). The irrigation water applied during 2014 was 0, 20, 30, 40 and 50 mm under rainfed, I_1, I_2, I_3 and I_4 and their respective mean yields were 0.18, 0.78, 0.83, 1.03 and 1.45 t ha^{-1}. The highest SIWUE (30.0 kg ha^{-1} mm^{-1}) was observed in I_1 followed by I_4 (25.5 kg ha^{-1} mm^{-1}), I_2 (21.7 kg ha^{-1} mm^{-1}) and minimum was in I_3 (21.3 kg ha^{-1} mm^{-1}). The findings of the present study suggested the integrated use of mulching and supplementary irrigation to improve rainwater availability for sustainable crop yield. The results of present study are in line with Abbas *et al*. (2014) and the maximum output for grain yield and highest water productivity can be achieved with supplemental irrigation during dry spells at critical stages. The similar results for maize crop were also reported by (Mustapha 2012).

Crop water production functions (CWPF) under different crop management practices

The combined crop water production functions for different crop management practices by taking av-

Table 2. Grain yield, irrigation water applied (IW) and supplemental irrigation water use efficiency (SIWUE) under different irrigation strategies during rainy season of 2013 and 2014.

Treatment		Irrigation water applied, mm		Crop water use, mm		Grain yield, t ha^{-1}		SIWUE, kg ha^{-1} mm^{-1}	
		2013	2014	2013	2014	2013	2014	2013	2014
Rainfed, (I_0)	M_1HF	0	0	240.6	161.0	3.90	0.67	0.00	0.00
	M_1NF	0	0	240.6	161.0	3.60	0.00	0.00	0.00
	M_0HF	0	0	240.6	161.0	3.30	0.00	0.00	0.00
	M_0NF	0	0	240.6	161.0	2.80	0.00	0.00	0.00
Mean		0	0	240.6	161.0	3.40	0.17	0.00	0.00
SI, 20 mm (I_1)	M_1HF	40	20	280.6	181.0	4.10	0.97	102.50	50.0
	M_1NF	40	20	280.6	181.0	3.90	0.77	97.50	40.0
	M_0HF	40	20	280.6	181.0	3.50	0.69	87.50	35.0
	M_0NF	40	20	280.6	181.0	3.20	0.62	80.00	30.0
Mean		40	20	280.6	181.0	3.68	0.76	91.88	38.75
SI, 30 mm (I_2)	M_1HF	60	30	300.6	191.0	4.80	1.05	8.00	33.3
	M_1NF	60	30	300.6	191.0	4.00	0.86	6.66	30.0
	M_0HF	60	30	300.6	191.0	3.60	0.74	6.00	23.3
	M_0NF	60	30	300.6	191.0	3.30	0.67	5.50	23.3
Mean		60	30	300.6	191.0	3.93	0.83	6.54	27.5
SI, 40 mm (I_3)	M_1HF	80	40	320.6	201.0	5.10	1.39	6.38	35.0
	M_1NF	80	40	320.6	201.0	4.80	1.18	6.00	30.0
	M_0HF	80	40	320.6	201.0	4.10	0.75	5.13	20.0
	M_0NF	80	40	320.6	201.0	3.80	0.68	4.75	17.5
Mean		80	40	320.6	201.0	4.45	1.00	5.57	25.62
SI, 50 mm (I_4)	M_1HF	100	50	340.6	211.0	5.30	1.69	5.30	34.0
	M_1NF	100	50	340.6	211.0	5.10	1.48	5.10	30.0
	M_0HF	100	50	340.6	211.0	4.70	1.39	4.70	28.0
	M_0NF	100	50	340.6	211.0	4.60	1.24	4.60	24.0
Mean		100	50	340.6	211.0	4.93	1.45	4.93	29.0

erage of grain yield and crop water use of two years 2013 and 2014 are presented in Fig. 1. The mean maximum grain yield was observed in M_1HF (2.26, 2.55, 2.92, 3.26 and 3.49 t ha^{-1}) followed by M_1NF (1.78, 2.31, 2.41, 2.99 and 3.27 t ha^{-1}), M_0HF (1.67, 2.11, 2.18, 2.41 and 3.07 t ha^{-1}) and minimum was recorded in M_0NF (1.41, 1.90, 2, 2.25 and 2.92 t ha^{-1}) under rainfed (I_0), I_1, I_2, I_3 and I_4 with crop water use of 200, 230, 250, 270 and 290 mm respectively. The coefficient of determination (R^2) between mean grain yield and average crop water use under M_1HF, M_1NF, M_0HF and M_0NF was 0.98, 0.91, 0.97 and 0.92 respectively. The linear equations obtained for M_1HF, M_1NF, M_0HF and M_0NF are presented in Fig. 1.

The combined crop water production function was established using relationship between the average grain yield and crop water use of both years 2013 and 2014 rainy season and results are presented in Fig. 1. The maximum mean grain yield of 3.49 t ha^{-1} was obtained in M_1HF under I_4 (SI, 50 mm) with corresponding mean crop water use of 275.8 mm and the lowest mean yield 1.41 t ha^{-1} was in M_0NF under rainfed condition with mean crop water use of 200.8 mm. The crop water use in I_0, I_1, I_2, I_3 and I_4 was 200.8, 230.8, 245.8, 260.8 and 275.8 mm with mean yield of 1.78, 2.22, 2.38, 2.73 and 3.19 t ha^{-1} respectively. The coefficient of determination (R^2) between grain yield and crop water use (mm) for combined crop water function was 0.86. This indicates that, there is a good agreement between grain yield and crop water use during crop growth stages. The linear equation derived for combined crop water production function is presented Fig. 1.

The results of CWPFs indicated that, there is a good agreement between grain yield and crop water use with R^2 (0.86) under different irrigation and crop management practices. It was due to fact that, crop responded well to supplemental irrigation applied during critical stages. The crop water production function curves based on applied irrigation water tends to

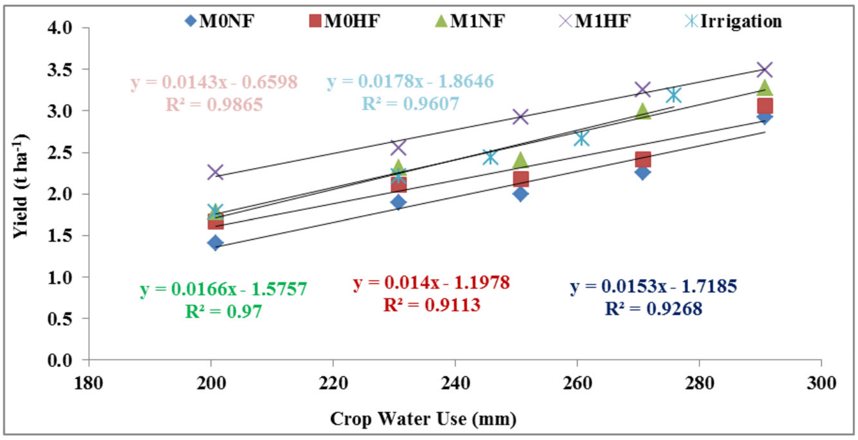

Fig. 1. Mean crop water production functions for maize under different crop management practices and supplemental irrigation (2013 and 2014).

linear as the increase in maize yield for each unit of increase in supplemental irrigation water applied. This means that the marginal productivity of supplemental irrigation water (additional yield per unit additional water) is relatively high over rainfed, showing the potential benefit of supplemental irrigation to the rainfed farmers. Likewise, the water use efficiency (absolute yield per unit supplemental irrigation water applied), tends to increase with supplemental irrigation. This shows a possible economic benefit with supplemental irrigation. However, the water production function for grain yield based on ETc is relatively linear (straight line) under mulching and fertilizer levels. This implies that, once sufficient soil moisture is available from supplemental irrigation to produce grain, the maize is equally efficient in its use of every additional unit of water and fertilizer applied.

CONCLUSION

In the present scenarios of climate change/variability condition, the adoption of rainwater harvesting structures like farm pond in semi arid regions plays important role to increase the crop productivity and improves the livelihoods of rainfed farmers. The results of present study concluded that, supplemental irrigation of 50 mm at two critical stages of maize could enhance the maize grain yield by 149 % over rainfed (1.41 t ha^{-1}). The linear crop water production function developed under different irrigation and crop management practices showed that, maize crop responded well with respect to supplemental irrigation water applied with coefficient of determination of 0.98, 0.91, 0.97 and 0.92 under M_1HF, M_1NF, M_0HF and M_0NF respectively. This implies that, there is a scope to increase the maize grain yield under rainfed condition through rainwater harvesting structures (farm pond) with supplemental irrigation.

ACKNOWLEDGEMENT

The authors are grateful to Director, ICAR-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad and University of Agricultural Sciences, Raichur for facilities provided and permission given to take present research work in CRIDA institute at Hyderabad. Authors would like to express thanks to Council for Scientific and Industrial Research (CSIR) New Delhi for financial help provided during the study period.

REFERENCES

Abbas SH, Asaf AB, Muhammad A, Zafar IM, Riaz D, Maqsood Q, Murad, Abid M, Munir M (2014) Effect of supplemental irrigation on wheat water productivity under rainfed ecology of pothohar. *Pak Innov J Agric Sci* 3(l):10-13.

Alam K (2015) Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Ban-

gladesh. *Agric Water Manag* 148: 196–206.
Blair LS, Kulbhushan KGR (2014) Crop yield function and evapotranspiration comparison for crops near hatch, New Mexico, USA. *J Arid Land Stud* 24(1): 125-128.
Daccache A, Knox JW, Weatherhead EK, Daneshkhah A, Hess TM (2015) Implementing precision irrigation in a humid climate–recent experiences and on-going challenges. *Agric Water Manag* 147: 135–143.
Guo Z, Yu Shia, Zhenwen Y, Yongli Z (2015) Supplemental irrigation affected flag leaves senescence post-anthesis and grain yield of winter wheat in the Huang-Huai-Hai Plain of China. *Field Crops Res* 180: 100–109.
Hijam R, Dhanapal GN, Dineshkumar SP (2014) Utilization of harvested water for protective irrigation and mulching with integrated nutrient management to mitigated dryspell for maize (*Zea mays* L.) production under dryland conditions. *Ind J Dry Agric Res Develop* 29(1):85-88.
Iglesias A, Garrote L (2015) Adaptation strategies for agricultural water management under climate change in Europe-Review. Agric Water Manage 155:113-124.
Khongwar A, Manoj D (2020) Effect of surface soil removal and organic amendment on aggregate stability and erosion indices of soil cultivating sesame (*Sesamum indicum* L.) *Environ Ecol* 39 (1): 129-133.
Kumar M, Reddy KS, Adake RV, Rao CVKN (2015) Solar powered micro-irrigation system for small holders of dryland agriculture in India. *Agric Water Manag* 158:112-119.
Lasage R, Verburg PH (2015) Evaluation of small scale water harvesting techniques for semi-arid environments. *J Arid Environ* 118:48-57.
Mahmood A, Oweis T, Ashraf M, Majid A, Aftab M, Aadal NK, Ahmad I (2015) Performance of improved practices in farmers' fields under rainfed and supplemental irrigation systems in a semi-arid area of Pakistan. Agric Water Manage 155:1-10.
Meena AK, Meena RN (2020) Climate change and its impact on agricultural productivity in India: A Review. *Environ Ecol* 38(1): 24-30.
Mustapha AB (2012) Effect of dryspell mitigation with supplemental irrigation on yield and water use efficiency of pearl millet in dry sub-humid agroecological condition of maiduguri, Nigeria. 2nd *Int Conf Environ Sci Biotech* 48(9): 46-49.
Rao Ch, Rattan Lal, Prasad JVNS, Gopinath KA, Rajbir Singh, Vijay SJ, Sahrawat KL, Venkateswarlu B, Sikka AK, Virmani SM (2015) Potential and Challenges of Rainfed Farming in India, In: Adv in Agro (edn.) Sparks, D.L.Academic Press, pp 113–181. doi.org/10.1016/bs.agron.2015.05.004.
Reddy KS, Kumar M, Maruthi V, Umesha B, Vijayalaxmi, Rao CVKN (2014) Climate change analysis in southern Telangana region, Andhra Pradesh using LARS-WG model. *Curr Sci* 107(1):54-62.
Saseendran SA, Lajpat R, Ahujaa, Liwang M, Thomas JT, Gregory SM, David CN, Jay MH, Allan AA, Ardel DH, José LC, Quanxiao XF (2015) Developing and normalizing average corn crop water production functions across years and locations using a system model. *Agric Water Manag* 157: 65-77.
Sharma RC, Banik P (2012) Effects of integrated nutrient management on baby corn-rice cropping system: Economic yield, system production, nutrient-use efficiency and soil nutrient balance. *Ind J Agric Sci* 82: 220-224.
Tafteh A, Hossein B, Niaz AE, Feridon (2013) Evaluation and improvement of crop production functions for simulation winter wheat yields with two types of yield response factors. *J Agric Sci* 5(3): 111-122.
Varshini SV, Babu R (2020) Effect of graded levels and split application of nitrogen on plant nutrient uptake, post-harvest soil available nutrients and economics of Hybrid maize (Co MH-6). *Environ Ecol* 38(4): 835-841.