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Assessment of Relationships between Rainfall and Canal Water for Maximization of Yield of Major Crops under Telugu Ganga Project command in Andhra Pradesh

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ABSTRACT: Among different inputs of agriculture, water is the most important input for profitable agriculture. A study was conducted to assess the influence of canal water supplied to paddy, groundnut and other crops grown in four districts under the Telugu Ganga Project command area in Andhra Pradesh. In the present paper, an assessment of the variability in the data and relationships of rainfall (mm) received, canal water (Mcum) supplied and the yield (kg/ha) of major crops *viz*., paddy, groundnut, sugarcane, sorghum and cotton attained under the TGP command area during 1997 to 2018 are discussed. Linear and quadratic regression models of yield were calibrated to predict the yield through rainfall received and canal water supplied in different years. The models were assessed based on the coefficient of determination (R^2) and standard error of mean (SEM) of the predicted yield over years. The rainfall received in different years did not significantly influence the yield of crops as indicated by the non-significant R^2 values. However, canal water released in different years was found to significantly influence the yield of paddy, groundnut, cotton and sugarcane. The quadratic regression models gave higher and significant values of R^2 compared to linear regression models of all crops. A grouping of 22 years data divided into 3 groups was made based on the mean and standard deviation (SD) of rainfall, canal water and yield of crops *viz*., observations which are (i) less than (Mean – SD); (ii) lying between (Mean – SD) to (Mean + SD); and (iii) more than (Mean + SD) limits. Based on the study, the quadratic regression model gave R^2 value of 0.772 for paddy, 0.600** for groundnut, 0.525** for sugarcane, 0.146 for sorghum and 0.264* for cotton, compared to 0.681**, 0.581**, 0.514**, 0.146 and 0.263* based on linear model for the 5 crops respectively. Maximum crop yield was found to occur in 3rd group. Maximum paddy yield of 5440 kg/ha was attained at mean canal water release of 1768.3 Mcum and occurrence of mean rainfall of 1151 mm during 4 years (2010, 2008, 2005, 2006), while groundnut yield of 2195 kg/ha was attained at canal water of 1822.6 Mcum and rainfall of 1041 mm during 4 years (2009, 2006, 2008, 2010). Similar results were obtained for other crops studied under the TGP command area. The canal water and rainfall corresponding to the highest mean yield attained in a group could be considered as optimum for maximizing the returns from a crop. This will also help in the efficient utilization of water resources with regard to the quantity and frequency of canal water to be provided for irrigation of crops. Since the canal water under TGP command is assured, the farmers could efficiently utilize the canal water by growing less water requiring crops and derive maximum returns under semi-arid conditions in Andhra Pradesh.**

Keywords: Canal water, Rainfall, Crop yield, Regression and Optimization.

INTRODUCTION

India is a developing country for irrigation infrastructure. Many efforts are regularly made for bringing the rain fed area into irrigated agriculture for sustainable food production. Irrigation projects have to be assessed for irrigation potential utilisation on a continuous basis. Crop area estimation at mandal level would require a replacement with suitable technology implementation. In Andhra Pradesh, the Telugu Ganga irrigation project is an inter-state project formulated to irrigate about 5.75 lakh acres in the drought prone areas of Rayalaseema region comprising of Chittoor, Kadapa, Kurnool and uplands of Nellore by utilising 29 TMC of water from Krishna flood flows, and 30 TMC of water from Pennar river flood flows. The main objective of water resources department in Andhra Pradesh is to create irrigation potential under drought prone areas, upland areas and maintain all projects for enhancing the productivity of different species per unit of water. About 70% of population of Andhra Pradesh is depending on agriculture. It is necessary to have a continuous monitoring on the performance of different irrigation systems. In view of the importance of irrigated agriculture prevailing in Andhra Pradesh, the performance evaluation of irrigation systems for crop area, availability of water and its sufficiency would help in making suitable interventions and enabling water management plans, apart from improving the water resources. The present study is conducted with the objective of evolving a suitable crop water allocation pattern for optimal use of canal water for growing multiple crops.

Correlation analysis could be carried out between variables to assess the type of relationship *viz*., positive or negative relationship, apart from the magnitude of relationship and its significance over a period of timeas described by Gomez and Gomez (1984). The regression models for prediction of yield and optimization of variables for maximizing the yield of crops over a period of time. The author has screened different regression models for selection of optimal variable subsets for maximizing the yield based on different models. Maruthi Sankar (1986) has discussed about the usefulness of R^2-adequacy and Residual Mean Square Error criteria for identifying an efficient regression model for prediction and optimization of variables for maximizing the yield.

In order to efficiently utilize the canal water for growing different crops, we should always avoid a mismatch between supply and demand of water required for crops. Rao and Rajput (2006) studied about the mismatch that occurred in the supply and demand of water for crops grown under the Nagarjuna Sagar Left Canal in Andhra Pradesh. The authors gave strategies for overcoming the mismatch issues possibly occur when the canal water is released for crops. Ahmed (2002) discussed about the need of conjunctive use of both ground water and surface water for attaining maximum returns from crops under any soil and climatic situation. The author examined different aspects of ground water and surface water available under the Burdekin delta area. He has described about the efficient use of water from these two sources for managing the crops in an efficient manner. A similar study was conducted by Mahfuzur *et al.* (2014) on the management of water under the Ganga Basin. The authors have compared different strategies for optimal utilization of water by making an efficient comparison of ground water and surface water available under the Ganga Basin project.

In order to irrigate crops, a detailed assessment of performance of irrigation has to be made before recommending to farmers for large scale adoption. Avil Kumar *et al.* (2014) assessed the irrigation performance under the Left Bank canal of the Nagarjuna Sagar project. The authors have made an efficient assessment of the irrigation requirement by adopting the remote sensing and Geographic Information System tools in their study. Babu *et al.* (2009) have also studied on making improvements to the aspects of water use efficiency for crops under the Nagarjuna Sagar canal command area. The authors have provided optimal strategies for efficient use of water for irrigation purpose for different crops grown under the command area. In a study by Chandra (1996), the author has optimized the canal water requirement under the Gambhiri irrigation system in Rajasthan. The optimal values of canal water would be useful for irrigating crops for attaining maximum productivity and profitability of crops. Mahtsente and Birhanu (2015) made a detailed study on two important aspects of water demand analysis and irrigation water requirement for growing some leading crops under the Holetta catchment in Awash sub-basin in Ethiopia. The authors have developed efficient strategies for optimal irrigation water requirement for different crops for maximizing the productivity and profitability of crops grown in Ethiopia.

A three-step modeling approach for comprehensive analysis of planning problem involving integrated use of surface and groundwater in irrigation for a Bagmati river basin in Nepal as discussed by Onta *et al*. (1991). The use of LP model for irrigation water management revealed that about 89.4% of available channel water was utilized during winter season. Out of this, 55.9% and 18.5% were allocated for wheat and barley respectively. Remaining 25.6% of channel water was allocated for cotton and watermelon. Since there was enough channel water supplies, only 10.6% of groundwater was utilized. In the absence of any constraint on conjunctive water use, there was no significant groundwater exploitation, and 100% channel water was efficiently utilized, which is much cheaper than groundwater. Based on LP analysis, out of total available channel water, 43.2% was allocated to cotton, which was most profitable compared to other crops and their activities, followed by 38.3%, 9.5% and 9% for different crop activities including watermelon, barley and wheat respectively as described by Malekian *et al.* (2012). Mohan *et al.* (1998) developed a stochastic linear programming model for assessing the availability and utilization of water for crops. The model considers randomness of rainfall, ground water and other water resources and could be used for irrigation planning and optimization of water resources in an efficient manner. In a study by James *et al*. (1992), the authors have used dynamic programming technique for assessing and improving the strategies of irrigation for maize crop.

The optimal schedules developed were found to be useful for attaining maximum yield and monetary returns from maize compared to other crops. The dynamic programming model would be useful for assessing the effects of different parameters of rainfall, canal water, ground water and any other type of irrigation for provided for crops.

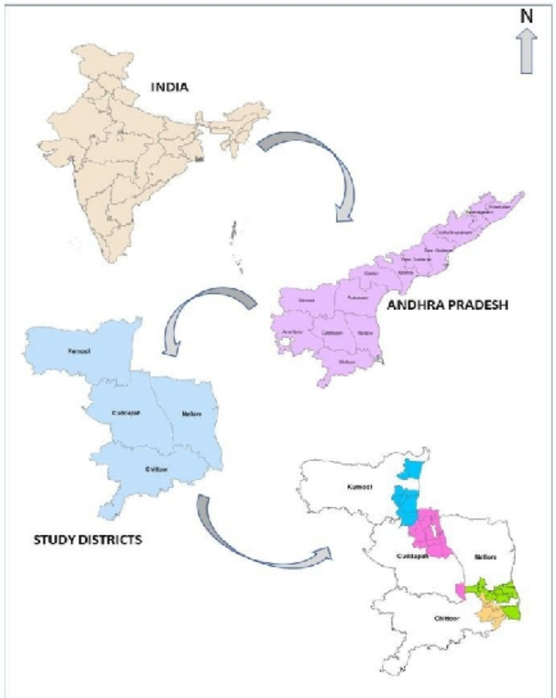

Fig. 1. Study area of Telugu Ganga Project.

MATERIALS AND METHODS

In order to make an evaluation of the crop water allocation pattern for optimal use of canal water for growing different crops under the TGP command area would be the conjunctive use of both surface and groundwater. This is based on a coordinated and harmonious development of these two sources of irrigation for maximizing the net returns without causing any adverse effect on the land and aquifer environment. The important aspect of conjunctive water use planning is to find out (i) optimal area under different crops depending on both the canal and groundwater availability, and (ii) optimal allocation of canal and groundwater resources for keeping the water table within the permissible limits.

Assessment of relationship between parameters. The descriptive statistics of yield attained by major crops, rainfall received and canal water released to the crops in *rabi* season during 22 years of the study period were determined. An assessment of the relationships between different parameters has been made and the relationship were tested based on t-test. Linear and quadratic regression models of yield through rainfall and canal water were developed for prediction of yield through two major water resources of rainfall and canal water. The valid Statistical grouping of years was made for identifying the maximum yield of paddy, groundnut, sugarcane, sorghum and cotton crops attained at optimum values of rainfall and canal water under the TGP command area during 1997 to 2019. Relationships between (i) yield of crops and rainfall; and (ii) yield of crops and canal irrigation could be determined over a period of time (Gomez and Gomez 1984). The magnitude and direction (positive or negative) of the relationship between variables could be assessed.

Regression models for prediction of yield. Regression models could be calibrated for predicting the yield through different independent variables (Draper and Smith 1998). In a simple regression model, only two variables are considered, where one variable would represent the 'cause' and other would represent the 'effect'. The variable representing 'cause' is known as 'independent variable' (denoted as 'X') and variable representing the 'effect' is known as 'dependent variable' (denoted as 'Y'). A regression model could be assessed based on coefficient of determination (R^2). The coefficient of determination indicates about variation in 'Y' explained by 'X' and could be tested based on Snedecor's F-test. The linear regression model calibrated for predicting the yield (Y) of a crop through canal water (CW) could be given as

$$Y = \alpha + \beta\,(CW) \qquad (1)$$

Here α is intercept and β is slope of canal water. The slope indicates about the rate of change in yield for an unit change in canal water. The quadratic regression model for predicting yield as a function of linear and quadratic terms of canal water (CW) could be given as

$$Y = \alpha + \beta_1\,(CW) + \beta_2\,(CW)^2 \qquad (2)$$

Here α is intercept; $\beta_1$and β_2 are slopes of linear and quadratic terms of canal water respectively. The linear and quadratic regression models are assessed based on coefficient of determination (R^2) along with SEM derived under each model (Maruthi Sankar, 1986).

Grouping of years for optimization of rainfall and canal water for maximum yield. In order to identify an optimum quantity of rainfall and canal water for attaining maximum yield of crops, grouping of canal water released (Mcum), rainfall (mm) received and crop yield attained (kg/ha) into 3 groups could be made by using mean and standard deviation (SD) of the parameters over 22 years during 1997 to 2018. The 3 valid groups were formed by grouping the years based on the statistical criteria *viz*., observations which are (i) less than (Mean – SD); (ii) lying between (Mean – SD) to (Mean + SD); and (iii) more than (Mean + SD) limits. Mean and SD of observations of yield, canal water and rainfall could be determined in each group. Based on a comparison of mean yield of each group, maximum yield could be identified. The canal water and rainfall corresponding to the highest mean yield attained in a group could be considered as optimum for attaining maximum yield of a crop in the TGP command area. The 3 groups of years have to be made separately for each crop and mean and SD of canal water, rainfall and yield have to be derived. We could easily identify the optimum canal water and rainfall for attaining the maximum yield of a crop grown in the TGP command area during the study period. The optimum canal water could be allocated so that farmers could attain maximum yield of crops under the TGP command area.

RESULTS AND DISCUSSION

Yield of major crops attained during 1997. The crop water allocation pattern has been evolved for an optimal use of canal water for attaining maximum yield of crops in the Telugu Ganga Project. Major crops grown in the TGP command area were selected based on the extent of area. The crops selected are paddy, groundnut, sugarcane, sorghum, cotton, chilies, sunflower, black gram, pearl millet and green gram grown during 1997 and 2018. The yield of crops attained in each district and also pooled over the entire TGP command during 1997 are given in Table 1. During 1997, paddy yield ranged from 2450 to 3100 kg/ha with mean yield of 2798kg/ha, while groundnut yield ranged from 785 to 2351 kg/ha with mean yield of 1230 kg/ha. Sugarcane yield ranged from 0 to 757q/ha with mean yield of 733 q/ha, while sorghum yield ranged from 0 to 1350 kg/ha with mean yield of 1200 kg/ha. Cotton yield ranged from 0 to 1150 kg/ha with mean yield of 1150 kg/ha, while chilies yield ranged from 0 to 155 q/ha with mean yield of 155 q/ha. Sunflower yield ranged from 0 to 950 kg/ha with mean yield of 950 kg/ha, while black gram yield ranged from 575 to 950 kg/ha with mean yield of 855 kg/ha. Pearl millet yield ranged from 0 to 1732 kg/ha with mean yield of 1732 kg/ha, while green gram yield ranged from 0 to 602 kg/ha with mean yield of 602 kg/ha.

Table 1: Yield of crops (kg/ha) attained in different districts under TGP command during 1997.

Sr. No	Crop	Yield of crops (kg/ha)				
1.		Chittoor	Nellore	Kurnool	Kadapa	Pooled TGP
2.	Paddy	2750	3100	2890	2450	2798
3.	Groundnut	960	2351	785	825	1230
4.	Sugarcane (q/ha)	710	757	0	0	733
5.	Sorghum	0	0	1350	1050	1200
6.	Cotton	0	0	1150	0	1150
7.	Chilies (q/ha)	0	0	155	0	155
8.	Sunflower	0	0	0	950	950
9.	Black gram	950	575	0	0	855
10.	Pearl millet	1732	0	0	0	1732
11.	Green gram	0	602	0	0	602

Source : Chief planning officer, Vijayawada

Yield of crops attained during 2018. The yield of crops attained in each district and also pooled over the entire TGP command during 2018 are given in Table 2. During 2018, paddy yield ranged from 3282 to 4562 kg/ha with mean yield of 3953 kg/ha, while groundnut yield ranged from 989 to 2928 kg/ha with mean yield of 1530 kg/ha. Sugarcane yield ranged from 0 to 995 q/ha with mean yield of 943 q/ha, while sorghum yield ranged from 0 to 1725 kg/ha with mean yield of 1517 kg/ha. Cotton yield ranged from 0 to 1358 kg/ha with mean yield of 1358 kg/ha, while chillies yield ranged from 0 to 167 q/ha with mean yield of 167 q/ha. Sunflower yield ranged from 0 to 1136 kg/ha with mean yield of 1136 kg/ha, while black gram yield ranged from 0 to 1062 kg/ha with mean yield of 855 kg/ha. Pearl millet yield ranged from 0 to 2475 kg/ha with mean yield of 2475 kg/ha, while green gram yield ranged from 0 to 655 kg/ha with mean yield of 655 kg/ha.

Table 2: Yield of crops(kg/ha) attained in different districts under TGP command during 2018.

Sr. No.	Crops	Yield of crops (kg/ha)				
1		Chittoor	Nellore	Kurnool	Kadapa	Pooled TGP
2	Paddy	4156	4562	3812	3282	3953
3	Groundnut	1200	2928	989	1004	1530
4	Sugarcane (q/ha)	891	995	0	0	943
5	Sorghum	0	0	1725	1308	1517
6	Cotton	0	0	1358	0	1358
7	Chillies (q/ha)	0	0	167	0	167
8	Sunflower	0	0	0	1136	1136
9	Black gram	1062	647	0	0	855
10	Pearl millet	2475	0	0	0	2475
11	Green gram	0	655	0	0	655

Source : Chief planning officer, Vijayawada, Andhra Pradesh state

Based on the pooled data of crops over all districts in the TGP command, a comparison of yields attained by different crops is made in Fig. 2 for 1997 and 2018. It is observed that the yields of all crops attained during 2018 were significantly higher compared to the yields attained during 1997. The pooled analysis indicated that during 2018, mean paddy yield of 3953 kg/ha was attained, followed by pearl millet with 2475 kg/ha, groundnut with 1530 kg/ha, sorghum with 1517 kg/ha, cotton with 1358 kg/ha, sunflower with 1136 kg/ha, black gram with 855 kg/ha and green gram with 655 kg/ha. In case of sugarcane, mean yield of 943 q/ha was attained, while in case of chillies, mean yield of 167 q/ha was attained in the entire TGP command area.

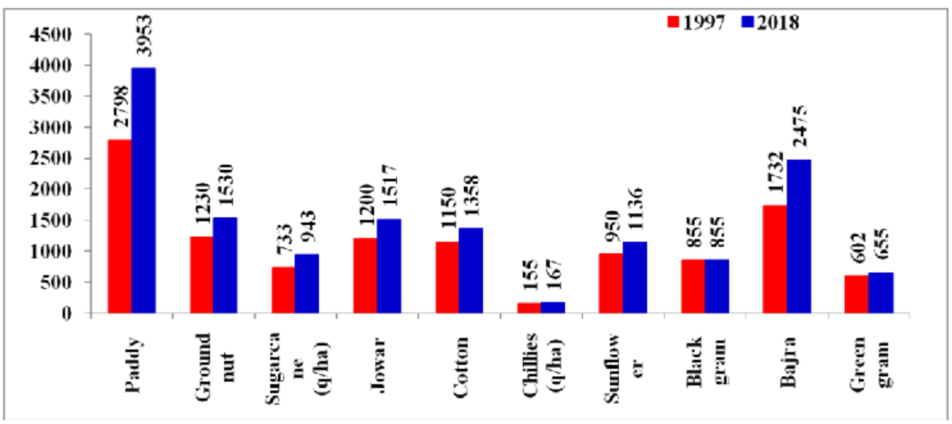

Fig. 2. Mean yield of crops attained under TGP command during 1997 and 2018.

Descriptive statistics of rainfall, canal water and yield of crops over years. The details of rainfall (mm) received, canal water (Mcum) supplied and yield (kg/ha) of paddy, groundnut, sugarcane, sorghum and cotton crops attained under the TGP command area for 22 years during 1997 to 2018 are given in Table 3. The rainfall received in different years ranged from 582 mm (2016) to 1387 mm (2010) with mean of 913 mm (CV of 20.1%) during the study period. The canal water released in different years ranged from 58.5 Mcum (2003) to 2201.4 Mcum (2008) with mean of 1065.7 Mcum (CV of 69.8%) over years. The paddy yield attained ranged from 2578 kg/ha to 5512 kg/ha with mean of 4244 kg/ha (CV of 24.6%), while groundnut yield ranged from 1159 kg/ha to 2268 kg/ha with mean of 1687 kg/ha (CV of 20.7%) over years. The sugarcane yield attained ranged from 678 q/ha to 943 q/ha with mean of 834 q/ha (CV of 9.5%), while sorghum yield ranged from 852 kg/ha to 1517 kg/ha with mean of 1182 kg/ha (CV of 14.3%) over years. The skewness and kurtosis were found to be positive for rainfall received, while they were negative for canal water released over years. In case of crop yield attained over years, the skewness and kurtosis were negative in paddy and sugarcane, while they were positive in sorghum. The skewness was positive, while kurtosis was negative in case of groundnut and cotton crops. The skewness was found to be close to zero indicating that different parameters were symmetric, while the kurtosis was less than 3 indicating that the distribution was platy-kurtic.

Table 3: Details of rainfall received, canal water supplied and yield of crops attained in TGP command area during 1997 to 2018.

Year	Rainfall (mm)	Canal water (Mcum)	Yield (kg/ha)				
			Paddy	Groundnut	Sugarcane (q/ha)	Sorghum	Cotton
1997	845	100.9	2798	1230	733	1200	1150
1998	840	125.1	2951	1359	752	1245	1197
1999	822	82.0	2651	1275	745	1210	1145
2000	906	378.1	4150	1785	895	1435	1135
2001	1054	88.8	2578	1159	721	891	1098
2002	878	129.5	3497	1512	810	1045	1051
2003	740	58.5	2678	1179	678	852	1010
2004	843	1020.9	4964	1875	878	1254	1187
2005	1293	1134.6	5435	1957	912	1358	1254
2006	900	1931.6	5512	2154	925	1458	1352
2007	1063	1398.5	4589	1854	846	1235	1025
2008	1024	2201.4	5435	2254	879	1248	1069
2009	852	1351.7	5253	2103	845	1150	1048
2010	1387	1805.7	5378	2268	899	1178	1256
2011	1004	1931.9	5239	1736	898	1052	1216
2012	843	1147.5	4325	1659	783	1078	1278
2013	900	1780.0	4239	1896	899	1125	1358
2014	692	1591.0	4362	1563	874	1098	1206
2015	1054	573.0	3256	1256	843	975	989
2016	582	1375.0	5159	1632	712	1210	1256
2017	791	1272.0	4963	1876	879	1195	1189
2018	770	1969.0	3953	1530	943	1517	1358
Minimum	582	58.5	2578	1159	678	852	989
Maximum	1387	2201.4	5512	2268	943	1517	1358
Mean	913	1065.7	4244	1687	834	1182	1174
SD	184	744.1	1044	349	79	168	113
CV (%)	20.1	69.8	24.6	20.7	9.5	14.3	9.6
Skewness	0.96	-0.18	-0.40	0.04	-0.60	0.05	0.05
Kurtosis	1.47	-1.48	-1.34	-1.05	-0.98	0.08	-0.92

Source Chief Planning officer, Vijayawada, Andhra Pradesh

SD: Standard deviation CV: Coefficient of variation (%)

Relationship of yield of crops with rainfall and canal water in TGP command. The details of rainfall, canal water and yield of major crops in the entire TGP command area are shown in Fig. 3 and Fig. 4. The estimates of correlation of yield of crops attained with rainfall received and canal water released during 1997 to 2018 are given in Table 4. There was a significant correlation of 0.825** between yield of paddy with canal water released in different years. Similarly, pod yield of groundnut was found to have a significant correlation of 0.762** and sugarcane yield had a significant correlation of 0.717** with canal water released during different years. Cotton yield was found to have a significant correlation of 0.513**, while sorghum yield had no significant correlation with canal water released over years. The correlation between rainfall received and yield of crops attained was found to be non-significant during the 22 years. Among different crops, the yield of paddy was found to significantly increase over years as indicated by a positive correlation of 0.490**. Although there was a positive correlation of 0.431 for yield of sugarcane, 0.303 for yield of groundnut, 0.339 for yield of cotton and 0.026 for yield of sorghum with years, the relationships were found to be non-significant. Rao and Rajput (2009) observed significant relationships among different parameters considered in their decision support system study for managing the water efficiently under different canal command areas. Similarly, while developing optimal reservoir system for efficient levels of irrigation for different crops, Vedula and Mujumdar (1992) found significant relationships among different parameters of available canal water, water requirement of different crops, rainfall and other parameters in their study.

Table 4: Correlation between yield of crops attained, rainfall received and canal water released in the TGP command area during 1997 to 2018.

Parameter	Years	Rainfall	Canal water
Paddy yield	0.490*	0.252	0.825**
Groundnut yield	0.303	0.386	0.762**
Sugarcane yield	0.431	0.378	0.717**
Sorghum yield	0.026	0.017	0.382
Cotton yield	0.339	-0.068	0.513*
Rainfall	-0.129		
Canal water	0.701		
Rainfallvs Canal water	0.156		

* and ** indicate significance at $p < 0.05$ and $p < 0.01$ levels of significance respectively

Critical correlation value at $p < 0.05$ level of significance with 20 degrees of freedom = 0.444

Critical correlation value at $p < 0.01$ level of significance with 20 degrees of freedom = 0.561

Regression models for prediction of yield of crops through rainfall and canal water

Regression models of yield through rainfall. In order to assess the effects of rainfall received and canal water released on yield of crops attained in different years, two regression models *viz*., linear and quadratic models were calibrated using the data of 22 years during 1997 to 2018. The regression coefficients of rainfall on yield under the two models of paddy, groundnut, sugarcane, sorghum and cotton crops, along with coefficient of determination (R^2) and standard error of mean (SEM) of predicted yield are given in Table 5. The rainfall received in different years did not significantly influence the yield of crops as indicated by the non-significant values of coefficient of determination determined for different crops. The R^2 based on the quadratic model was found to be 0.138 for rice, 0.166 for groundnut, 0.153 for sugarcane, 0.004 for sorghum and 0.098 for cotton compared to 0.064, 0.149, 0.143, 0.001 and 0.005 for the respective crops under the linear model. Based on linear model of rainfall, the SEM of predicted yield was found to be 1035.6 kg/ha for paddy, 330.0 kg/ha for groundnut, 74.8 q/ha for sugarcane, 172.6 kg/ha for sorghum and 115.4 kg/ha for cotton and under the linear model, while it was 1019.3, 335.2, 76.2 q/ha, 176.8 and 112.7 kg/ha for the respective crops under the quadratic model. Rao and Rajput (2008) observed a similar effect of rainfall received on the performance of crops grown under canal command areas.

Regression models of yield through canal water. The canal water released in different years was found to significantly influence the yield of paddy, groundnut, cotton and sugarcane and has no significant influence on sorghum during the study period. The regression coefficients of canal water on yield under the linear and quadratic regression models of paddy, groundnut, sugarcane, sorghum and cotton crops, along with coefficient of determination (R^2) and standard error of mean (SEM) of predicted yield are given in Table 5. The quadratic regression models of yield through canal water supplied gave higher and significant values of R^2 compared to the linear regression models for all crops. The quadratic model gave R^2 value of 0.772** for paddy, 0.600** for groundnut, 0.525** for sugarcane, 0.146 for sorghum and 0.264* for cotton, while the linear model gave 0.681**, 0.581**, 0.514**, 0.146 and 0.263* for the 5 crops respectively. The quadratic models through canal water have provided a lower SEM value compared to the linear model for all crops. The SEM was 524.6 kg/ha for paddy, 232.1 kg/ha for groundnut, 57.1 q/ha for sugarcane, 163.7 kg/ha for sorghum and 101.9 kg/ha for cotton under the quadratic regression model, while it was 604.1 kg/ha for paddy, 231.7 kg/ha for groundnut, 56.3 q/ha for sugarcane, 159.6 kg/ha for sorghum and 99.3 kg/ha for cotton under the linear regression model. Thus the regression models of yield through canal water indicated a significant increase in the yield of paddy and groundnut under both linear and quadratic models, and yield of sugarcane and cotton under the linear model in the TGP command over years during the study period. There was no significant influence of canal water released on the yield of sorghum under both linear and quadratic regression models as indicated by the non-significant values of R^2 and regression coefficients of canal water. Rao and Rajput (2008) found significant relationship of the rainfall received, effective rainfall with the performance of crops grown under the canal command areas in their study. The authors found that the relationships were useful for developing models for predicting yield of crops through canal water, rainfall and other parameters in the canal command areas.

Regression models of yield through rainfall and canal water. The regression coefficients of rainfall and canal water on yield under the linear and quadratic regression models of paddy, groundnut, sugarcane, sorghum and cotton crops, along with coefficient of determination (R^2) and standard error of mean (SEM) of predicted yield are given in Table 5. Based on the regression models of yield through both rainfall received and canal water supplied, higher and significant coefficient of determination was found under the quadratic regression model with R^2 of 0.793** for rice, followed by 0.678** for groundnut, 0.670** for sugarcane, 0.331* for cotton and 0.148 for sorghum. Compared to this, the linear regression model gave R^2 of 0.697** for rice, followed by 0.654** for groundnut, 0.587** for sugarcane, 0.286* for cotton and 0.148 for sorghum. The SEM was found to be 527.9 kg/ha for rice, 220.3 kg/ha for groundnut, 172.8 kg/ha for sorghum and 102.7 kg/ha for cotton, while it was 50.4 q/ha for sugarcane under the quadratic model. Compared to this, the linear model gave SEM of 604.3 kg/ha for paddy, 215.9 kg/ha for groundnut, 163.5 kg/ha for sorghum, 100.3 kg/ha for cotton and 53.3 q/ha for sugarcane. The effect of canal water was found to be significant in influencing the yield of all crops except sorghum based on both linear and quadratic models calibrated for predicting yield of crops through rainfall received and canal water supplied during the study period. The results are in agreement with the findings of Bhavani *et al*. (2017) who assessed the performance of crops based on climate variability in Telangana and Andhra Pradesh states. Rao and Rajput (2006) have also observed lower SEM values, while assessing the deviations of supply and demand of canal water under Nagarjuna Sagar Left Canal. Our results are in agreement with the findings made by Zhiming *et al*. (2007) who developed optimal water requirements and irrigation scheduling based on a GIS and crop water model under the Beijing-Tianjin-Hebei region in China. The authors have observed significant relationships of the crop water requirement with rainfall, available ground water and surface water and other factors.

Table 5: Regression models of yield of crops through rainfall and canal water during 1997 to 2018 under TGP command.

Crops	Linear regression model	R^2	SEM	Quadratic regression model	R^2	SEM
			Yield vs Rainfall			
Paddy	$Y = 2934.8* + 1.434 (RF)$	0.064	1035.6	$Y = 8584.2 - 10.411 (RF) + 0.006 (RF)^2$	0.138	1019.3
Groundnut	$Y = 1016.5** + 0.734 (RF)$	0.149	330.0	$Y = 1920.0 - 1.160 (RF) + 0.001 (RF)^2$	0.166	335.2
Sugarcane	$Y = 685.9** + 0.162 (RF)$	0.143	74.8	$Y = 527.1 + 0.495 (RF) + 0.001 (RF)^2$	0.153	76.2
Sorghum	$Y = 1167.9** + 0.016 (RF)$	0.001	172.6	$Y = 1365.0 - 0.398 (RF) + 0.001 (RF)^2$	0.004	176.8
Cotton	$Y = 1212.2** - 0.042 (RF)$	0.005	115.4	$Y = 1895.8** - 1.475 (RF) + 0.001 (RF)^2$	0.098	112.7
			Yield vs Canal water			
Paddy	$Y = 3009.1** + 1.159** (CW)$	0.681**	604.1	$Y = 2633.8** + 2.732** (CW) + 0.001** (CW)^2$	0.772**	524.6
Groundnut	$Y = 1305.8** + 0.358** (CW)$	0.581**	231.7	$Y = 1247.5** + 0.602* (CW) + 0.001 (CW)^2$	0.600**	232.1
Sugarcane	$Y = 753.1** + 0.076** (CW)$	0.514**	56.3	$Y = 743.4** + 0.117 (CW) + 0.001 (CW)^2$	0.525**	57.1
Sorghum	$Y = 1090.1** + 0.086 (CW)$	0.146	159.6	$Y = 1086.4** + 0.102 (CW) + 0.001 (CW)^2$	0.146	163.7
Cotton	$Y = 1090.9** + 0.078* (CW)$	0.263*	99.3	$Y = 1087.9** + 0.091 (CW) + 0.001 (CW)^2$	0.264*	101.9
			Regression model of Yield vs Rainfall and Canal water			
Paddy	$Y = 2380.1** + 0.721 (RF) + 1.131** (CW)$	0.697**	604.3	$Y = 3169.5 - 1.718 (RF) + 0.001 (RF)^2 + 2.639** (CW) - 0.001* (CW)^2$	0.793**	527.9
Groundnut	$Y = 850.9** + 0.522* (RF) + 0.338** (CW)$	0.654**	215.9	$Y = 491.7 + 1.122 (RF) + 0.001 (RF)^2 + 0.618* (CW) + 0.001 (CW)^2$	0.678**	220.3
Sugarcane	$Y = 650.9** + 0.117 (RF) + 0.071** (CW)$	0.587**	53.3	$Y = 195.6 + 1.025* (RF) + 0.001 (RF)^2 + 0.147* (CW) + 0.001 (CW)^2$	0.670**	50.4
Sorghum	$Y = 1124.8** - 0.040 (RF) + 0.088 (CW)$	0.148	163.5	$Y = 1058.5 + 0.088 (RF) + 0.001 (RF)^2 + 0.107 (CW) + 0.001 (CW)^2$	0.148	172.8
Cotton	$Y = 1172.3** - 0.093 (RF) + 0.081** (CW)$	0.286*	100.3	$Y = 1678.8** - 1.134 (RF) + 0.001 (RF)^2 + 0.055 (CW) + 0.001 (CW)^2$	0.331	102.7

* and ** indicate significance at $p < 0.05$ and $p < 0.01$ levels respectively
RF : Rainfall (mm) CW : Canal water (Mcum) R^2 : Coefficient of determination
SEM : Standard error of mean of predicted yield (kg/ha for all crops and q/ha for sugarcane)

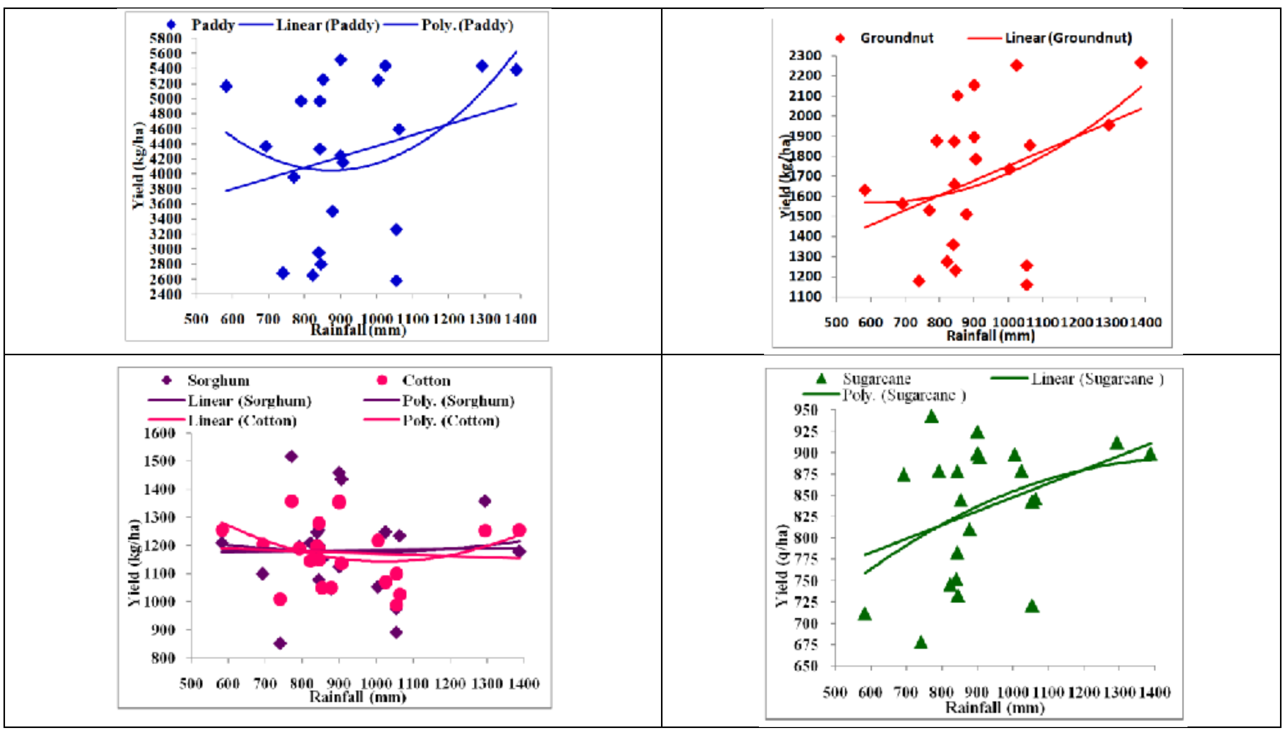

Fig. 3. Relationship of yield of crops with rainfall received during 1997 to 2018.

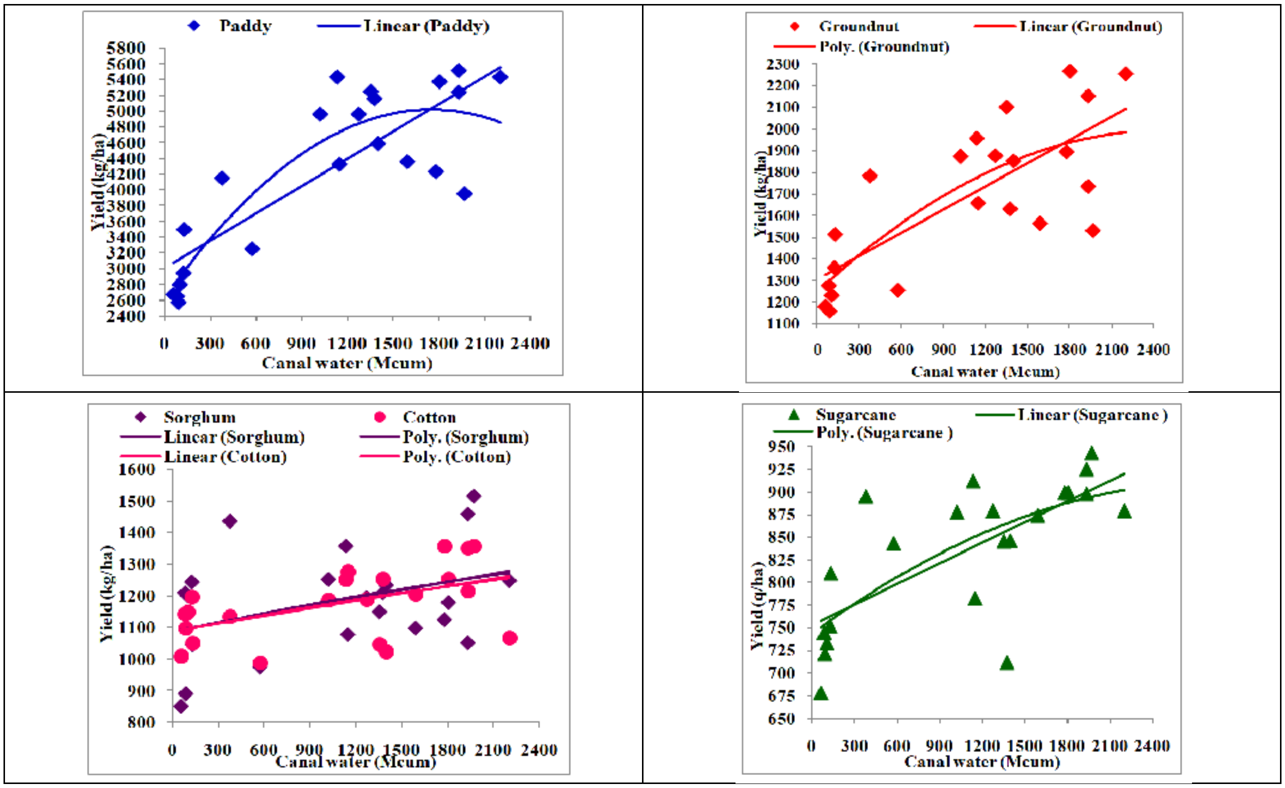

Fig. 4. Relationship of yield of crops with canal water supplied during 1997 to 2018.

Optimal allocation of water for attaining maximum yield of crops. In order to determine the optimum water requirement for attaining maximum yield of crops using the rainfall received and canal water supplied in different years, a grouping of rainfall (mm) received and canal water (Mcum) released during 1997 to 2018 and the corresponding yield of crops attained into 3 statistical groups was made using the mean and standard deviation (SD) of the three parameters over years. The group means were derived using the observations which were occurring under (i) less than (Mean – SD); (ii) (Mean – SD) to (Mean + SD); and (iii) more than (Mean + SD) groups. The groups indicated that maximum mean canal water supplied occurred in 3rd group, followed by 2nd group and 1st group for all the 5 crops. Maximum mean rainfall occurred in 3rd group for paddy and groundnut, while it occurred in the 2nd group for sugarcane and cotton, and 1st group for sorghum. The details of number of years occurred, mean rainfall received, canal water supplied and yield of crops attained in each group are given in Table 6.

Maximum paddy yield of 5440 kg/ha was attained at mean canal water release of 1768.3 Mcum and occurrence of mean rainfall of 1151 mm during 4 years (2010, 2008, 2005, 2006) under 3rd group *viz.*, observations which are more than (Mean + SD) limit. In case of groundnut, maximum pod yield of 2195 kg/ha was attained at mean canal water release of 1822.6 Mcum and occurrence of mean rainfall of 1041 mm during 4 years (2009, 2006, 2008, 2010) under the 3rd group *viz.*, observations which are more than (Mean + SD) limit. Maximum sugarcane yield of 934 q/ha was attained at a mean canal water release of 1950.3 Mcum and occurrence of mean rainfall of 835 mm during 2 years (2006, 2018) under the 3rd group *viz.*, observations which are more than (Mean + SD) limit. In case of sorghum, maximum yield of 1488 kg/ha was attained at a mean canal water release of 1950.3Mcum and occurrence of mean rainfall of 835 mm during4 years (2005, 2000, 2006, 2018) under 3rd group *viz.*, observations which are more than (Mean + SD) limit. In case of cotton, maximum yield of 1356 kg/ha was attained at a mean canal water release of 1893.5 Mcum and occurrence of mean rainfall of 857 mm during 3 years (2006, 2013, 2018) under the 3rd group *viz.*, observations which are more than (Mean + SD) limit. Our results are in agreement with the findings made by Raju and Kumar (2000) who developed strategies for optimum irrigation requirement for different crops for attaining maximum returns under Sriram Sagar project.

Table 6: Optimum values of rainfall and canal water for attaining maximum yield of crops based on statistical grouping of data over years.

Groups	No. of years	Years included in the group	Rainfall received (mm)	Canal water released (Mcum)	Yield (kg/ha) attained
Paddy					
< (Mean – SD)	5	2001, 1999, 2003, 1997, 1998	860	91.0	2731
(Mean – SD) to (Mean + SD)	13	2015, 2002, 2018, 2000, 2013, 2012, 2014, 2007, 2017, 2004, 2016, 2011, 2009	860	1224.5	4458
> (Mean + SD)	4	2010, 2008, 2005, 2006	1151*	1768.3*	5440*
Groundnut					
< (Mean – SD)	5	2001, 2003, 1997, 2015, 1999	903	180.6	1220
(Mean – SD) to (Mean + SD)	13	1998, 2002, 2018, 2014, 2016, 2012, 2011, 2000, 2007, 2004, 2017, 2013, 2005	877	1173.3	1710
> (Mean + SD)	4	2009, 2006, 2008, 2010	1041*	1822.6*	2195*
Sugarcane					
< (Mean – SD)	6	2003, 2016, 2001, 1997, 1999, 1998	814	305.0	724
(Mean – SD) to (Mean + SD)	14	2012, 2002, 2015, 2009, 2007, 2014, 2004, 2017, 2008, 2000, 2011, 2013, 2010, 2005	966*	1265.4	867
> (Mean + SD)	2	2006, 2018	835	1950.3*	934*
Sorghum					
< (Mean – SD)	3	2003, 2001, 2015	949*	240.1	906
(Mean – SD) to (Mean + SD)	15	2002, 2011, 2012, 2014, 2013, 2009, 2010, 2017, 1997, 2016, 1999, 2007, 1998, 2008, 2004	891	1154.2	1168
> (Mean + SD)	2	2005, 2000, 2006, 2018	835	1950.3*	1488*
Cotton					
< (Mean – SD)	5	2015, 2003, 2007, 2009, 2002	917	702.2	1025
(Mean – SD) to (Mean + SD)	14	2008, 2001, 2000, 1999, 1997, 2004, 2017, 1998, 2014, 2011, 2005, 2010, 2016, 2012	923*	1018.2	1188
> (Mean + SD)	3	2006, 2013, 2018	857	1893.5*	1356*

* indicates optimum values of rainfall received and canal water supplied for attaining maximum yield
SD: Standard deviation

The optimum values of rainfall received and canal water released indicated that the five crops of paddy, groundnut, sugarcane, sorghum and cotton crops could be grown for attaining maximum yield of the crops in different districts under the entire TGP command area. The grouping of years based on mean and standard deviation over years would take care of the homogeneity of years with respect to rainfall received and the canal water released in the respective years occurring under a group. This will help the policy makers and planners for efficient management of water resources for satisfying the water requirement and enhancement of the productivity of crops, which will ultimately improve the monetary returns and livelihood of farmers. Similarly, the results are in agreement with the findings made by Ganesh *et al.* (2014); Mehanuddin *et al*. (2018) who measured the water requirement and made efficient irrigation scheduling for different crops.

Based on the study, it is observed that paddy is consuming maximum water in the TGP command area. There is a need for efficient crop planning and crop diversification by growing less water requiring crops like pulses, sorghum, millets, cotton and other crops which are equally remunerative to farmers. This would require en efficient coordination of the staff of line departments, Agriculture, Telugu Ganga Project for suitable crop planning, type of crop and quantity of canal water to be released during rabi season. This will greatly help in the efficient utilization of water resources with regard to the quantity and frequency of canal water to be provided for irrigation of crops under the TGP command area. Since the canal water under TGP command is assured, the farmers in the region could efficiently utilize the canal water for growing less water requiring and profitable short duration crops and derive maximum benefit of the available improved agricultural technologies.

CONCLUSIONS

A study was conducted to assess the variability and relationships of rainfall (mm) received, canal water (Mcum) supplied and the yield (kg/ha) of major crops *viz*., paddy, groundnut, sugarcane, sorghum and cotton attained under the Telugu Ganga Project (TGP) command area in Andhra Pradesh during 22 years from 1997 to 2018. Linear and quadratic regression models of yield were calibrated to predict the yield through rainfall received and canal water supplied in different years. The models were assessed based on the coefficient of determination (R^2) and standard error of mean (SEM) of the predicted yield over years. The rainfall received in different years was found to have no significant effect on the yield of all the 5 crops, while the canal water was found to significantly influence the yield of paddy, groundnut, cotton and sugarcane. The quadratic regression models gave higher and significant values of R^2 compared to linear regression models of all crops. The quadratic model gave R^2 value of 0.772** for paddy, 0.600** for groundnut, 0.525** for sugarcane, 0.146 for sorghum and 0.264* for cotton, while the linear model gave 0.681**, 0.581**, 0.514**, 0.146 and 0.263* for the 5 crops respectively. The quadratic models through canal water have provided a lower SEM value compared to the linear model for all crops. The SEM was 524.6 kg/ha for paddy, 232.1 kg/ha for groundnut, 57.1 q/ha for sugarcane, 163.7 kg/ha for sorghum and 101.9 kg/ha for cotton under the quadratic regression model, while it was 604.1 kg/ha for paddy, 231.7 kg/ha for groundnut, 56.3 q/ha for sugarcane, 159.6 kg/ha for sorghum and 99.3 kg/ha for cotton under the linear regression model.

A grouping of 22 years into 3 groups was made based on the mean and standard deviation (SD) of rainfall, canal water and yield of crops *viz*., observations which are (i) less than (Mean – SD); (ii) lying between (Mean – SD) to (Mean + SD); and (iii) more than (Mean + SD) limits. Maximum yield of crops was found to occur in the 3rd group. Maximum paddy yield of 5440 kg/ha was attained at mean canal water release of 1768.3 Mcum and occurrence of mean rainfall of 1151 mm during 4 years (2010, 2008, 2005, 2006), while groundnut yield of 2195 kg/ha was attained at canal water of 1822.6 Mcum and rainfall of 1041 mm during 4 years (2009, 2006, 2008, 2010). Maximum sugarcane yield of 934 q/ha was attained at mean canal water release of 1950.3 Mcum and occurrence of mean rainfall of 835 mm during 2 years (2006, 2018), while sorghum yield of 1488 kg/ha was attained at canal water of 1950.3 Mcum and rainfall of 835 mm during 4 years (2005, 2000, 2006, 2018), and cotton yield of 1356 kg/ha was attained at canal water of 1893.5 Mcum and rainfall of 857 mm during 3 years (2006, 2013, 2018). The canal water and rainfall corresponding to the highest mean yield attained in a group could be considered as optimum for attaining maximum yield of a crop. This will help in the efficient utilization of water resources with regard to the quantity and frequency of canal water to be provided for irrigation of crops. Since the canal water under TGP command is assured, the farmers could efficiently utilize the canal water by growing less water requiring and profitable short duration crops and derive maximum benefit of the available improved agricultural technologies.

FUTURE SCOPE

Based on the present study, we suggest about the need to develop stochastic model-based optimum canal water requirement for attaining maximum yield of crops, apart from maximum monetary returns under different soil and agro-climatic conditions. There is a need for correlating the optimum canal water with the desired crop water requirement, productivity of crops, effective rainfall, available soil moisture and other related parameters. There is also a need to identify suitable crops with less water requirement in order to effectively utilize the available canal water for more crops under watershed basis.

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Conflict of Interest. None.

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