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Increasing agricultural production through optimal use of harvested rainwater at Targhadia watershed (Rajkot, Gujarat, India)

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Abstract
A situation specific computer programme incorporating hydraulic design and hydrological criteria, set of different runoff coefficient, CN=88 for runoff generation and USDA,SCS,CN method is incorporated to design parameters for water harvesting structures at title watershed. The computer programme is used with average of the daily rainfall time (1971-97) to compute probable quantity of water that could be available by the end of estimated date of harvest. Recommended agronomic measures (crop coefficient, dates of sowing & harvest, duration, critical crop growth stages) for the specified regions are considered to compute water requirement and irrigation scheduling (at 66.67% field application efficiency) of prevailing crops in the regions under a variety of conditions (i) no deficiency of irrigation water (ii) yield reduction by 10%, and (iii) yield reduction by 20%. Gross returns, net returns on cost of cultivation and output input ratio at cost ‘A’ of all the prevailing crops (based on average of data 1980-81 to 1997-98), water requirements of crops and probable available water in the structure by the end of estimated date of harvest are used to formulate the linear programming problems which have been solved by stepwise optimization technique. The results suggest a set of optimal plans (alternatives) for cultivation during either Kharif or Rabi only, under different specific conditions. Application of the problems to an existing irrigation tank 'B' and comparison of the results reveal similar crops selection for cultivation during both the seasons. These solution can also be adopted for better agricultural production under similar situations elsewhere.

INTRODUCTION

The Central Water Commission estimated that the average natural runoff from rainfall (India) is about 180Mha-m while annual replenishable ground water is about 60Mha-m. In view of the topographic, hydrological and other constraints, only 70Mha-m of surface water and about 42 Mha-m of ground water can be economically harnessed with conventional development methods for beneficial use. The ultimate potential due to major and medium projects have been assessed as 58Mha (first in the world with 19.6% share), of which 60% has been estimated to be developed by 1999-2000.The current extent of utilization of surface and ground water resource is about 70% and 30% of the utilizable water resources respectively but it is only 37% of net sown area and about 29% of the total cultivated area under irrigation. India's hope of bringing 50% cultivated area under irrigation by end of the century could be fulfilled only through scientific water development and management.

Sustainable agriculture (FAO's version) is the successful management of resources for agriculture to satisfy the changing human needs, while maintaining or enhancing the quality of environment and conserving natural resources. Development and management of the land and water within a watershed for sustainable use demands precise estimates of water availability and its strategies for planning, development and management on sustainable basis. Experiences on rain water harvesting systems from certain regions and the encouraging results obtained thereafter strongly suggest that water harvesting systems are technically feasible, economically viable and eco-friendly. There is an urgent need to develop location specific integrated rain water harvesting on watershed basis has thus been suggested as a feasible solution to tide out the prevailing situations.

MATERIALS AND METHODS

Different components of water requirement and irrigation scheduling under a variety of irrigation timing and irrigation application options (Table 1) of all the existing crops (Bajra, Castor, Cotton, Cumin, Fennel, Garlic, Gram, Groundnut, Guar, Isabgul, Jowar, Maize, Moong, Mustard, Onion, Sesamum, Tur, Urad and Wheat) being cultivated in Gujarat are worked out using the FAO's recommended CROPWAT model (Smith, 1992). Detailed data on gross returns, net returns (Rs ha^{-1}) on cost 'A'(actual cost of cultivation at farmers level) and output input ratio at cost 'A' of all major crops for a period of 1980-81 to 1997-98 collected from the reports on cost of cultivation of crops from Department of Economics and Statistics, Gujarat Agricultural University, Junagadh 362001 (AGRESCO,1999) have been analyzed. Average of the parameters, actual irrigation water requirement under 'option 72' and availability of irrigation water by the end of harvest date are used in formulation and solving of optimization problems (Khandelwal, 1999).

Table 1 Irrigation timing and irrigation applications options considered in the CROPWAT model for Targhadia watershed (Rajkot).

Option			Description
Code	Irrigation Timing	Irrigation Application	
22	Optimal (2)	Optimal (2)	Irrigation at critical depletion (100%, readily available moisture) and Refill soil to its field capacity
71	Deficit (7)	Reduction Yield (10%)	Irrigation at given yield reduction (10%) and Refill soil to its field capacity
72	Deficit (7)	Reduction Yield (20%)	Irrigation at given yield reduction (20%) and Refill soil to its field capacity

RESULTS AND DISCUSSION

Optimization of Net Returns of Crops with Harnessed Water

Optimal net return on cost 'A' for cultivation of crops considering all three dates of sowing and (Table 2) reveal increasing trend of net return on cost 'A' with increase in runoff coefficient under the two conditions of CN = 88 being imposed and not being imposed. For the Kharif season only, total of optimal net return on cost 'A' increases from Rs 10544.64 (KCN Y →□ Kharif season, runoff coefficient 0.135 with CN=88 condition imposed) to Rs 19742.50 (KCNW →□ Kharif season, runoff coefficient 0.25 with CN = 88 condition imposed) from cultivation of crops Onion and Urad, which are irrigated by runoff water stored in the structure. It shows an increase in cultivation of onion crop (highest remunerative) from 0.1466 ha to 0.6745 ha (out of 1.00 ha) with increase in runoff coefficient from 0.135 to 0.250 (with CN = 88 condition) and as per availability of irrigation water at the estimated harvest date. Almost similar trend is noticed when CN = 88 conditions is not imposed. The net return increases from Rs 11585.18 to 21709.04 with increase in area of onion from 0.2063 ha to 0.7874 ha.

For the Rabi season only, optimal net return on cost 'A' increases from Rs 7867.64 (RCN Y → Rabi season, runoff coefficient 0.135, CN=88 condition imposed) to Rs 15205.67 (RCN W → Rabi season, runoff coefficient 0.250, CN = 88 condition imposed) from cultivation of crops Garlic and Onion, which are irrigated by runoff water stored in the structure. It shows an increase in cultivation of garlic crop (highest remunerative) from 0.0465 ha to 0.0681 ha (out of 1.00 ha) and increase in cultivation of onion from 0.2705 to 0.5410 with increase in runoff coefficient (under CN = 88 condition) and as per availability of irrigation water at the estimated harvest date. Almost similar trend is noticed when CN = 88 conditions is not imposed. Net return on cost 'A' increases from Rs 8696.81 to 16774.17 with increase in area of garlic from 0.0491 ha to 0.0729 ha and increase in area of onion from 0.3009 ha to 0.5983 ha. Total probable area under irrigation increases from 0.3170 ha to 0.5146 ha and from 0.3400 ha to 0.6716 ha (Table 2) respectively for the two conditions of CN = 88 for generation of runoff purpose.

For the Summer season only(while considering all three dates of sowing/harvest), optimal net return increases from Rs 5598.86 (SCNY → Summer season runoff coefficient 0.135, CN = 88 condition imposed) to Rs 11258.32 (SCNW → Summer season, runoff coefficient 0.250, CN = 88 condition imposed) from cultivation of crops Groundnut and Onion, irrigable by runoff stored in the structure. It shows an increase in cultivation of groundnut from 0.0804 ha to 0.1229 ha and increase in cultivation of onion from 0.1868 ha to 0.3917 ha (out of 1.00 ha) with increase in runoff coefficient from 0.135 to 0.250 (under CN=88 condition for runoff generation) and as per availability of irrigation water at the estimated harvest date. Almost similar trend is noticed when CN = 88 conditions is not imposed. Gross return increases from Rs 5937.95 to 12472.70 with increase in area of groundnut from 0.00595 ha to 0.1318 ha and increase in area of onion from 0.2088 ha to 0.4358 ha with increase in runoff coefficient from 0.135 to 0.250 (under the condition of 'CN = 88' for runoff generation) and as per availability of irrigation water at the estimated harvest date. Probable area under irrigation may vary from 0.2935 ha to 0.5549 ha and 0.2878 ha to 0.6107 ha (Table 2) under the two distinct conditions.

Table 2. Probable optimal net returns on cost 'A' from cultivation of selected crops in the study area (Z - Rs ha^{-1}).

[All Three Sowing Dates Considered, catchment=command=1 ha]

SEA SON	CROP	NET RETURNS COST 'A'	SEA SON	CROP	NET RETURNS COST 'A'
K CN Y	ONION URAD	Z=10544.64 K10=0.1466 K12=0.8534 [1.0000]	K N CY	ONION URAD	Z=11585.18 K10= 0.2063 K12= 0.7937 [1.0000]
R CN Y	GARLIC ONION	Z= 7867.64 R3=0.0465 R9=0.2705 [0.3170]	R N CY	GARLIC ONION	Z= 8696.81 R3=0.04912 R9=0.30091 [0.34003]
S CN Y	ONION URAD	Z=5598.86 S4=0.1868 S5=0.1067 [0.2935]	S NC Y	ONION URAD	Z=5937.95 S4=0.2088 S5=0.0790 [0.2878]
K CN Z	ONION URAD	Z=14119.72 K10=0.3518 K12=0.6482 [1.0000]	K NC Z	ONION URAD	Z=15518.26 K10=0.4327 K12=0.5680 [1.0000]
R CN Z	GARLIC ONION	Z=10718.51 R3=0.0552 R9=0.3754 [0.4206]	R NC Z	GARLIC ONION	Z=11833.80 R3= 0.0585 R9=0.4164 [0.4223]
S CN Z	ONION URAD	Z=770.44 S4=0.2646 S5=0.1306 [0.3952]	S NC Z	ONION URAD	Z=8630.48 S4=0.2957 S5=0.1396 [0.4343]
K CN W	ONION URAD	Z=19742.50 K10=0.6745 K12=0.3255 [1.0000]	K NC W	ONION URAD	Z=21709.04 K10=0.7874 K12=0.2126 [1.0000]
R CN W	GARLIC ONION	Z=15205.67 R3=0.0681 R9=0.5410 [0.6093]	R NC W	GARLIC ONION	Z=16774.17 R3=0.0729 R9=0.5988 [0.67164]
S CN W	ONION URAD	Z=11258.32 S4=0.3917 S5=0.1632 [0.5549]	S NC W	ONION URAD	Z=12472.70 S4=0.4358 S5=0.1749 [0.6107]

NOTE: Seasons: K → Kharif,R → Rabi,S→Summer;
CN → CN=88 Condition Imposed,NC → CN=88 Condition Not Imposed;
Runoff Coefficient: Y → 0.135, Z → 0.180, W → 0.250
Numerals within Parenthesis Probable Area Under Irrigation out of 1.00 ha

Optimal return of cost 'A' for cultivation of crops during first, second and third dates of sowing reveals similar increasing trend as that of gross return cultivation of the same crops. Since the average of net return is subjected to variation over the data period, due to numerous reasons, the same data sets were further run in the LP model by replacing the objective function as (1) net return - standard deviation and (2) net return + standard deviation. The results of the model run for all three cases of runoff coefficient under CN = 88 imposition showed similar trends. Although optimal value of net return changed with the respective case as per coefficient of variation, but attributing crop coefficient for selection purpose alone, remains more or less same. Such analysis confirms selection of crops based on gross return (irrespective of coefficient of variation) subjected to availability of water at estimated date of harvest and end of the season.

Application of LPP to case study (Tank 'B')

Computed water requirement at 66.67% field application efficiency by CROPWAT (Smith, 1992) for all the selected crops, computed values of net harness able volume of water available by end of estimated harvest date and season under the given three conditions of runoff coefficient and two conditions of CN = 88, for the study case (tank 'B' with 4 ha catchment area) have been used in solving the optimization problem.

In general selection of crop during Kharif, Rabi and Summer seasons are identically same for both the cases. When values of the coefficient associated in the LPP solution for both the cases are compared, it is seen that values in case of tank ‘B’ are always higher and are in order of 4.6282 to 10.2692. Increase in these value (tank ‘B’) merely indicate possibility of bringing more area under cultivation during Kharif period, more than assumed command of 4 ha. This could be attributed to the fact that effective rainfall plays a major role in meeting with actual evapotranspiration demand and the remaining quantities of water may be allocated to more area of the same crop, being it most remunerative. Identical selection of crops ascertains working of model from assumed catchment and command of 1 ha to catchment and command of 4 ha in case of the tank 'B' (Table 3).

Alternate optimal net return 'A'

After achieving the most probable net return on cost 'A' and irrigation to cultivation of selected crops in Kharif and as well as Rabi season, sometime an irrigator may require to go for next optimal return. In order to set up such alternates, the LP problem was run with exclusion of highest coefficient of crop (chosen for irrigation/cultivation) in each of the season. The alternate optimal net return with respect to the crops of Kharif season are presented in Figure 1 and for Rabi season are presented in Figure 2 respectively. An irrigator may obtain net return of Rs 674 - 1458 to 10545 - 21709 per ha from cultivation of crops (subjected to incurred cost of cultivation) during the Kharif season from same available quantities of water at end of harvest of the selected crop(s) under the earlier mentioned runoff coefficient and imposition of CN = 88 conditions. Similarly an irrigator may expect to get net return of Rs 834 - 1201 to 7868 - 16774 per ha from cultivation of crops (subjected to incurred cost of cultivation) during the Rabi season from the same available quantities of water at end of harvest of the selected crop(s) under the earlier mentioned runoff coefficient and imposition of CN = 88 conditions. Table 4.17 and Table 4.18 provide ample scope of choosing irrigation to cultivation of crops under the prevailing conditions of net return, date of sowing/ harvest, quantities of available water, runoff coefficient and others, as per case may be during Kharif and Rabi seasons respectively.

Table 3. Probable optimal net returns on cost 'A'from cultivation of selected crops in the study area (Z - Rs ha^{-1}).

[All Three Dates Considered, Catchment = Command = 4 ha)

SEA SON	CROP	NET RETURNS COST 'A'	SEA SON	CROP	NET RETURNS COST 'A'
K CN Y	URAD	Z = 36983.98 K12 = 4.6282 [4.6282]	K NC Y	URAD	Z = 40928.26 K12 = 5.1218 [5.1218]
R CN Y	ONION	Z = 27884.78 R9 = 1.0973 [3.4615]	R NC Y	ONION	Z =30858.64 R9 = 1.2143 [3.5715]
S CN Y	ONION	Z = 23797.91 S4 = 0.9364 [3.1905]	S NC Y	ONION	Z = 26335.91 S4 = 1.0363 [3.6000]
K CN Z	URAD	Z =51378.03 K12 = 6.4295 [6.4295]	K NC Z	URAD	Z = 56807.81 K12 = 7.1090 [7.1090]
R CN Z	ONION	Z =38737.45 R9 = 1.5243 [3.5322]	R NC Z	ONION	Z = 42831.00 R9 = 1.6854 [3.9910]
S CN Z	ONION	Z = 33059.97 S4 = 1.3009 [3.2918]	S NC Z	ONION	Z = 3655.85 S4 = 1.4384 [3.3120]
K CN W	URAD	Z =74377.77 K12 = 9.3077 [9.3077]	K NC W	URAD	Z = 82061.42 K12= 10.2692 [10.2692]
R CN W	ONION	Z =56078.5 R9 = 2.2067 [3.6217]	R NC W	ONION	Z =61871.7 R9 = 2.4347 [3.6252]
S CN W	ONION	Z = 47859.5 S4 = 1.8833 [3.3939]	S NC W	ONION	Z = 52803.66 S4 = 2.0778 [3.4020]

NOTE:SEASONS: K $\rightarrow$ KHARIF, R $\rightarrow$ RABI, S $\rightarrow$ SUMMER
CN $\rightarrow$ CN = 88, CURVE NO IMPOSED; NC $\rightarrow$ CN = 88 NOT IMPOSED.
; RUNOFF COEFFICIENT (RCOE): Y $\rightarrow$ 0.135,Z = $\rightarrow$ 0.180, W $\rightarrow$ 0.25;
Numerals Within Parenthesis Presents Probable Area Under Irrigation (tank 'B') out of 4.00 ha.

CONCLUSIONS

Use of computed actual irrigation requirement with option of 20% yield reduction and net harnessed water availability in the structure during the crop period (by estimated harvest date) revealed that optimally selected 'Onion' and 'Urad' crop can be cultivated in unit area (1 ha assumed) under all the cases of runoff coefficient. Net return increases 10545 Rs ha^{-1} to 19742 Rs ha^{-1} under CN=88 condition being imposed. With increase in availability of water in the structure, area under 'Onion' cultivation may be increased from 0.1466 ha to 0.6745 ha (out of total 1 ha assumed), under CN=88 condition. Area under cultivation of 'Urad' reduces from 0.8534 to 0.3255 ha accordingly.

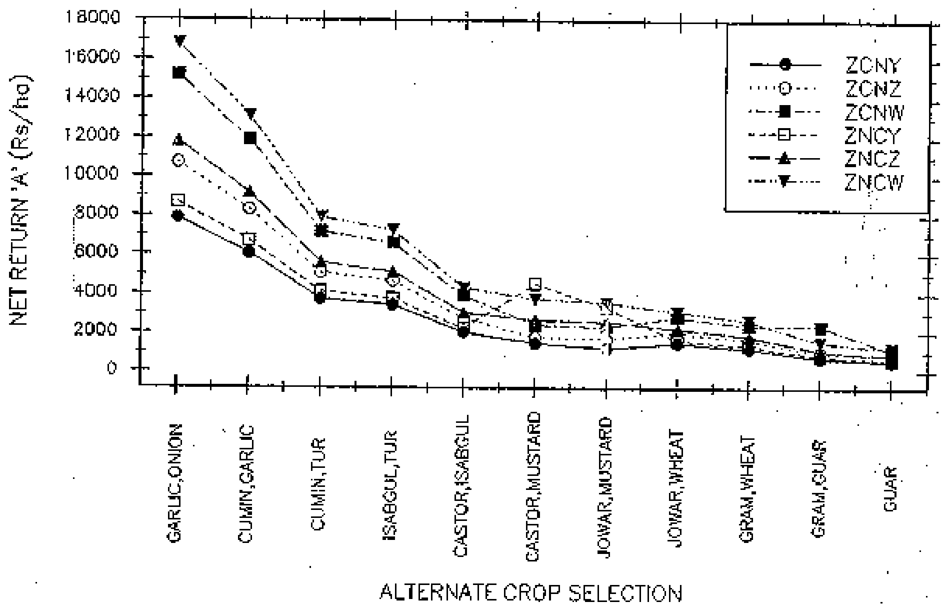

Figure 1. Optimal net return with different crop selection during Kharif season for Targhadia watershed.

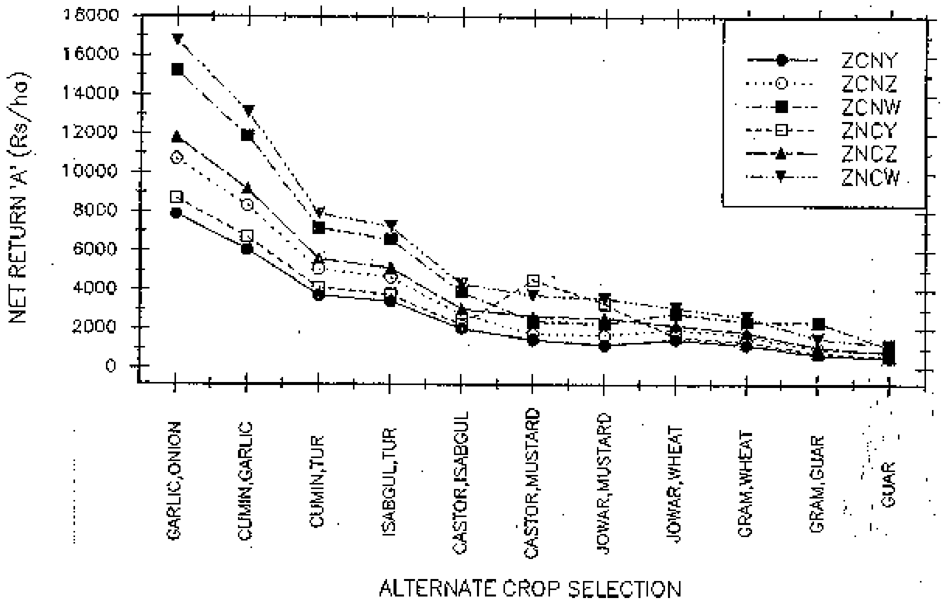

Figure 2. Optimal net return with different crop selection during Rabi season for Targhadia watershed.

Use of computed actual irrigation requirement under option '72' with option of 20% yield reduction and net harnessed water availability in the structure during the crop period (by estimated harvest date) revealed that optimally selected 'Garlic' and 'Onion' crop can be cultivated during Rabi season to get net return of 7868 Rs ha^{-1} to 15206 Rs ha^{-1} under the three conditions of runoff coefficients. With increase in availability of water in the structure area under Rabi onion cultivation may be increased from 0.2705 to 0.541 ha(out of assumed 1 ha).

Use of computed net harnessed runoff water availability in the tank 'B' (with catchment area of 4 ha)by estimated harvest date along with crop water requirement at option '72' in the LPP results in similar selection of crops during Kharif, Rabi and Summer seasons. In case of the re-designed tank 'B', area under irrigation during Rabi and summer increased with runoff coefficient 0.135 to 0.250 but remained within assumed 4 ha of command area. However, in Kharif season, area under 'URAD' increased considerably from mere 4.6282 ha to 9.3077 ha under different cases of runoff coefficient of 0.135 and to 0.250.

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