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Optimizing Catchment–Storage–Command Relationships for Sustainable Crop Production in Kaimur Plateau region of Madhya Pradesh

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ABSTRACT :

This study was carried out to assess the relationship between catchment area, storage capacity, and command area, and to evaluate water use efficiency and income benefits from supplemental irrigation in rainfed farming systems of sub-humid Madhya Pradesh, India. The region faces irregular rainfall and frequent dry spells, reducing crop productivity. To overcome this, rainwater was collected in a farm pond from a 5.4 ha catchment area during the Kharif season and used for supplemental irrigation in Rabi. The results showed that soybean in Kharif gave a yield of 1648 kg/ha with a net return of ₹37,208/ha and a B:C ratio of 1.89, while rice yielded 1504 kg/ha with net return ₹6,972/ha and a B:C ratio of 1.27. In Rabi, wheat in the soybean–wheat sequence produced 1345 kg/ha with a return of ₹2,281/ha (B:C ratio 1.09), whereas chickpea in the rice–chickpea sequence gave a higher net return of ₹7,408/ha and B:C ratio of 1.37. Overall, using harvested water for partial irrigation improved water use efficiency and income, especially in rice-based cropping systems. This approach offers a practical model for improving water productivity in rainfed micro-watersheds.

KEYWORDS: Catchment, storage, command area, supplemental irrigation, water harvesting

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INTRODUCTION:

Water is a limited resource, and its careful management is essential for ensuring sustainable agriculture. In micro-watersheds, the balance between the catchment area, storage structures, and command areas determines how water is made available and distributed. The catchment–storage–command, area relationship is a similar concept of water harvesting tanks constructed under different watershed development programs that used for storing runoff water, groundwater recharge, and utilization as supplemental irrigation for increasing crop yields and multiple other uses (Narsimlu *et al*., 2024). An imbalance in this relationship leads to poor water productivity and environmental degradation. The catchment–storage–command (CSC) relationship represents the hydrological linkage between the area generating runoff (catchment), the structures that store it (storage), and the agricultural land that utilizes it (command). In India, nearly 51% of the net sown area is rainfed, contributing to 40% of the country's food grain production. (GOI, DAFW). Since it depends heavily on monsoon rainfall, this farming system is highly vulnerable to weather uncertainties. Irregular and unpredictable rainfall patterns often lead to large fluctuations in crop yields, making rainfed farming both unstable and risky (Keatinge, 1922). In the rainfed agricultural landscapes of Madhya Pradesh, particularly the Kymore Plateau and Satpura Hills zone, farmers are highly dependent on the monsoon rains. However, the distribution of rainfall in this region is highly erratic, with frequent dry spells during critical stages of crop growth. This result in either crop failure or significantly reduced yields, especially during the Rabi season, where residual soil moisture is often inadequate. To address this, rainwater harvesting through farm ponds has emerged as a promising solution. Farm ponds can store surplus rainwater during the monsoon and provide supplemental irrigation during moisture-stressed periods, thus enhancing water productivity and ensuring better economic returns. Rainwater harvesting through farm ponds is becoming increasingly important for agriculture and domestic and industrial purposes (Adhikari *et al.,* 2009; Patode *et al*,. 2024).

MATERIAL AND METHODS :

The All India Coordinated Research Project for Dryland Agriculture is located at Kuthulia farm, College of Agriculture, Rewa at the latitude 24^0 30’ North and longitude 81^0 15’ East on an elevation of 365.7 m above mean sea level and belongs to Sub Zone Kymore Plateau. Sub Zone Kymore Plateau is a part of agro climatic zone IV known as Kymore Plateau and Satpura hills.

The major soil groups are Vertisols and assorted soils and silty loam to silty clay loam in texture with sub angular blocky structure and certain interogrades of mont morillonite, illite and kaolinite type of clay minerals. These soils have medium moisture retention capacity. The moisture content of soil profile at 1/3 bar and 15 bar ranges from 21.2 to 23.2 percent and 12.4 to 13.5 percent (on gravimetric basis) respectively. Generally, these soils have medium available water capacity about 14 cm/meter of soil profile depth. The bulk density of the soil varies from 1.36 to 1.52 g/cm^3. The clay content of the profile decreases with depth whereas percent sand and silt increased with depth. The soils are normal with pH value 7.3 and electrical conductivity varied from 0.37-0.44 dsm^{-1} at 25^{o}C. The soils are low in available nitrogen, medium in available P_2O_5 and high in available potassium. The maximum temperature ranges from 21.2°c to 45.1°c while the minimum temperature ranges from 7.5°c to 27.8°c and the annual rainfall is 1012.1 mm.

Runoff data from the catchment area was used to estimate the required storage capacity of the farm pond. Based on the method described by Sthool et al. (2013), a farm pond was constructed in the AICRPDA experimental field to store water from a 5.4-hectare catchment area more details shown in Table 1. A cropping pattern was followed where rice and soybean were grown during the Kharif season, and chickpea, mustard, coriander, and wheat were cultivated in the Rabi season. Depending on the available water in the pond and crop requirements, protective irrigation was provided to soybean during Kharif and to chickpea during Rabi. Sprinkler irrigation was used to maximize the efficient use of stored water.

COMPUTATION OF RUNOFF:

The following formula was used to estimate the runoff from the catchment area, and the pond dimensions were calculated accordingly (Singh, 1986).

$$R = \frac{kPA}{10}$$

Where, R = Runoff rate in cubic meters, k = Expected per cent runoff of the total rainfall, P = Average annual rainfall in mm, A = Catchment area, ha.

TREATMENTS:

During the Kharif season, the farm was planted with soybean and rice after the harvest of Kharif crops, Rabi crops such as chickpea, mustard, coriander, and wheat were cultivated.

T_1: Protective irrigation
T_2: Control (no irrigation)
Design: Non replicated

Table 1. Dimensions of Farm pond worked out at AICRPDA, Rewa

Pond Size				Ht. (m)	Volume (cum)	Slope (%)	Year of constructio n	Soil type	Lining	Lifting pump
Top (m)		Bottom (m)								
L	W	L	W							
30.2	14.2	27.9	10.4	2.6	905	1:1	2020-21	Silty Clay Loam	None	Yes

RESULTS AND DISCUSSIONS :

Average chickpea yield, NMR and B:C ratio of Rabi and Kharif Crop during 202-24 are presented in Table 2. The results revealed substantial differences among the treatments in terms of seed yield, net monetary returns (NMR), benefit-cost ratio (B:C), and rainfall water use efficiency (RWUE).

Among the rice-based cropping sequences, wheat grown after rice recorded the highest mean grain yield (1541.67 kg/ha), followed by chickpea (634.17 kg/ha), mustard (425.33 kg/ha), and coriander (155.00 kg/ha). In terms of net monetary returns**,** chickpea after rice recorded the maximum returns of Rs. 7408.50/ha, followed by wheat (Rs. 1431.25/ha), coriander (Rs. 3505.00/ha), and mustard (Rs. 1906.50/ha). The highest B:C ratio was observed in soybean (1.89), followed by chickpea after rice (1.37), coriander (1.29), and rice (1.27). The control plots exhibited relatively lower productivity and profitability across all crops. For example, wheat in control plots yielded 1302.50 kg/ha with a net return of Rs. 731.25/ha and B:C ratio of 1.03, whereas chickpea yielded 523.00 kg/ha with a net return of Rs. 6642.80/ha and B:C ratio of 1.36. Interestingly, rainfall water use efficiency (RWUE) was also highest in wheat after rice (1.41 kg/ha-mm), indicating better utilization of water in this sequence, followed by rice (1.63 kg/ha-mm) and wheat after soybean (1.46 kg/ha-mm). In contrast, coriander across all sequences recorded the lowest RWUE, indicating poor water productivity. Similar results were reported by Patode *et al.*, 2020 Patode *et al.,* 2024; Vora *et al.*, 2008; Wani *et al.*, 2003. where a single supplemental irrigation of 5 cm depth led to a significant yield increase of 35 to 50% in wheat and chickpea.

The findings suggest that chickpea and wheat after rice not only offer higher net returns but also improve resource use efficiency. The superior performance of soybean in terms of B:C ratio and rice in RWUE highlights the potential of diversifying cropping systems for enhancing water productivity in micro-watershed-based land use planning.

Table 2. Average grain yield, Net monetary returns (NMR) and B:C of taken Rabi and Kharif crops during 2023-24

		Yield (kg/ha)						RWUE (kg/ha-mm)
	Treatment	Seed/grain yield in 2023	Mean seed/grain yield	Stover/ stalk yield	Cost of cultivation (Rs/ha)	Net return (Rs/ha)	B:C ratio	
K -2023-24	Soybean	1648.00	873.00	1328.40	22600.00	37208.00	1.89	0.70
	Rice	1504.00	1624.83	3083.20	25860.00	6972.32	1.27	1.63
Control	Soybean	470.00	510.00	987.00	20400.00	1220.00	1.06	0.51

	Rice	1335.00	1489.17	2803.50	23750.00	5393.05	1.23	1.44
R – 2023 after Rice	Wheat	1305.00	1541.67	2740.50	26300.00	1431.25	1.05	1.41
	Chickpea	510.00	634.17	1122.00	19800.00	7408.50	1.37	0.55
	Mustard	327.00	425.33	670.35	15915.00	1906.50	1.12	0.35
	Coriander	125.00	155.00	218.75	12120.00	3505.00	1.29	0.14
Control	Wheat	1065.00	1302.50	2236.50	21900.00	731.25	1.03	1.15
	Chickpea	468.00	523.00	959.40	18325.00	6642.80	1.36	0.51
	Mustard	262.00	341.17	529.24	13165.00	1114.00	1.08	0.28
	Coriander	98.00	129.67	166.60	10234.00	2016.00	1.20	0.11
R – 2023 after Soybean	Wheat	1345.00	1615.83	2824.50	26300.00	2281.25	1.09	1.46
	Chickpea	484.00	633.17	992.20	19800.00	6021.40	1.30	0.52
	Mustard	307.00	424.50	620.14	15915.00	816.50	1.05	0.33
	Coriander	115.00	166.67	195.50	12120.00	2255.00	1.19	0.12
	Wheat	1060.00	1317.50	2226.00	21900.00	625.00	1.03	1.15
	Chickpea	428.00	515.50	877.40	18325.00	4508.80	1.25	0.46
	Mustard	246.00	344.33	496.92	13165.00	242.00	1.02	0.27
	Coriander	93.00	151.33	158.10	10234.00	1391.00	1.14	0.10

CONCLUSIONS:

The rainwater collected in storage structures or farm ponds was used to provide one or two protective irrigations to crops during water stress periods—soybean in the Kharif season, chickpea in the Rabi season, and vegetables through micro-irrigation systems. Among the treatments, crops that received protective irrigations performed significantly better, as timely water availability during stress periods enhanced growth, yield, and profitability. The results indicate that growing chickpea and wheat after rice provides better income and makes more efficient use of resources. Soybean showed higher profitability through a better B:C ratio, while rice performed well in terms of water use efficiency. These findings highlight the importance of choosing the right crop combinations to improve water productivity and support effective land use planning in micro-watershed areas. Moreover, these results also emphasize the importance of technically sound farm pond construction, as properly designed ponds can effectively boost productivity and promote sustainability in dryland agriculture.

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