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Simulation of optimal size and economic analysis of runoff recycling irrigation pond

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Abstract
Rainfed rice in eastern India suffers from frequent moisture stress leading to severe yield reduction due to uncertainty of rainfall coupled with inadequate field level rainwater conservation structures. Construction of RRIP (Runoff Recycling Irrigation Pond) is an alternative for the storage of excess rainwater during monsoon and reuse it as supplemental irrigation to the rice in the same season and pre-sowing irrigation to green gram crop in winter season. Simulation study revealed that RRIP of 17, 14 and 12% of total cultivated area were optimal for rice-green gram cropping system for 5, 10 and 15 cm ponding condition (PC), respectively. The above-mentioned optimal sizes of RRIP provides the benefit cost ratio (BCR), internal rate of return (IRR) and payback period (PBP) as 1.83, 20.23%, 13.19 years for 5 cm PC, 1.85, 22.96%, 11.04 years for 10 cm PC and 1.84, 21.45%, 10.99 years for 15 cm ponding condition.

Keywords: Runoff recycling irrigation pond, simulation modeling

1. Introduction
The objective of this study is to develop simulation capabilities to determine optimum pond size and irrigation strategies for supplemental irrigation systems. Water is most essential and necessary climatic factors that determine the growth and development of crops and ultimately the yield (Sidram, *et al*. 2020) [2]. In many regions, rainfall is not a reliable climatic factor to meet crop water requirement demand. Hence, need of supplemental irrigation had often led to an over-exploitation of groundwater. But runoff recycling irrigation ponds (RRIP) may provide an alternative sustainable solution to store water when it is abundant and to be used during the shortage periods (Tamburino and Vico, 2018) [5]. This technology has the potential to increase availability of water for supplemental irrigation, so to increase cropped area which leads to increase in net returns from crops. It also offers solution to overcome the increased frequencies of drought, mainly mid-season and terminal drought under climate change situation (Srinivas Rao *et al*, 2017) [4]. According to FAO (2011) [6], irrigation typically doubles farm yields and the number of crops grown in one year is increased from one to two.
There is insufficient experience regarding pond construction with experimental approach with in farmers and contractors on size, location, irrigation scheduling constraints. Hence, modelling approach used for developing optimal size of a pond in relation to the preferred farming style, location, weather and supplemental irrigation (Penning de Vries and Ruaysoongnern, 2010) [1].

2. Material and Methods
2.1 Study area
The Budelkani micro-watershed area is situated in the rainfed region of Sundargarh district, Odisha, India. It includes three villages namely Budelkani, Majhapara and Ledimong with total geographical area of 651.25 ha. The watershed is situated at distance of 32 km from the headquarters of Sundargarh district. It is situated between 22°0' 33" N to 22° 1' 22" N Latitude and 84° 10' 57" E to 84° 13'14" E Longitude. The data was collected from the Krishi Vigyan Kendra- Sundargarh over a period of 23 years from 1993-2015. The mean annual rainfall of this watershed is 1138.62 mm. The maximum temperature was observed to be 45 ^{0}C in the month of May and minimum was 4 ^{0}C in the month of December. The minimum and maximum relative humidity was found to be 23.1% and 94.3% in month of February and September,

Respectively. The wind speed in the area was very low and varied from 0.27-1.6 ms^{-1}. The climatic condition of study area is humid and subtropical in nature. The elevation of Budelkani watershed is 265.0 m from the mean sea level.

2.2 Simulation of Runoff recycling irrigation pond (RRIP)

Proper sizing of an RRIP must be determined by considering all inflows and outflows to and from the RRIP. The inflows are the direct rainfall in the RRIP and surface runoff coming from its catchment (cropping field). The outflows are evaporation, seepage and percolation, and supplemental irrigation given to the crops from the RRIP.The water balance components of RRIP were mentioned below as follows.

$$S_i - S_{i-1} = \Delta S_i = Q_{SRi} + Q_{Pi} - Q_{Ei} - Q_{SIi} - Q_{Si} \quad (1)$$

Where, S = RRIP water storage, m^3; Q_{SRi} = volume of SR coming from the field to RRIP, m^3; Q_{Pi} = volume of direct rainfall in RRIP, m^3; Q_{Ei} = volume of water lost as evaporation from RRIP, m^3; Q_{SIi} = volume of water used as SI in the cropped field, m^3; Q_{Si} = volume of water lost as seepage and percolation from the RRIP storage, m^3 and i = time index taken as 1 day in the study.

Value of Q_{SRi} is given as:

$$Q_{SRi} = SR_i . A_{field} \quad (2)$$

Where, A_{field} = field area given as:

$$A_{field} = FA - A_{RRIP} \quad (3)$$

Where, FA = farm area and A_{RRIP} = area of the RRIP.

Volume of direct conservation of rainfall in RRIP is:

$$Q_{Pi} = P_i . A_{RRIP} \quad (4)$$

Panigrahi, *et al*., (2005) [9] reported that by covering the water surface of the RRIP with cut pieces of 600-gauge low density polyethylene (LDPE) sheets, evaporation loss could be reduced by 50% as compared to that from RRIP with open top surface. Since, irrigation water in the rainfed upland rice ecosystem is a scarce commodity, the surface area of RRIP is assumed to be covered by the cut pieces of 600-gauge LDPE sheets to reduce the evaporation loss. Volume of evaporation loss of RRIP storage is given by Panigrahi, *et al*., (2005) [9] as follows.

$$Q_{Ei} = 0.37 . E_{pani} . A_{wsi} \quad (5)$$

Where, E_{pani} = pan evaporation on i-th day and A_{wsi} = water spread area of RRIP on i-th day, which is a function of depth of water in RRIP.

Value of supplemental irrigation, Q_{SIi} from RRIP is given as:

$$Q_{SIi} = \frac{SI_i . A_{field}}{\eta} \quad (6)$$

Where, η = efficiency of irrigation system which is assumed as 100% because of the PVC pipes used in the conveyance of irrigation water.

The cumulative storage (S) in RRIP is:

$$S = \sum_{i=1}^{n} \Delta S_i \quad (7)$$

Where, n is the number of days since simulation starts.

2.3 Irrigation management practice of the cropping pattern

Simulation of RRIP size is done keeping in view that the RRIP would supply SI to monsoon season rice crop during the critical growth stage (CGS) when there is 20% MAD (Manageable Allowable Depletion) of SAT (saturation) in the effective root zone of rice. Rest of the growth stages of rice are kept rainfed. Depending on the actual availability of water in RRIP storage, maximum amount of 5 cm SI is provided. Moreover, the RRIP should be able to meet the PSI (pre-sowing irrigation) demand of the winter crop (green gram) if the residual soil moisture in seeding zone of this crop at sowing time is not sufficient for germination of the seeds.

In case of green gram, if the soil moisture content drops below 75% of Available Soil Moisture (ASM) in the seeding zone depth of 15 cm, then a required amount of water is applied to the crop from RRIP to maintain the soil moisture content in 15 cm depth of top soil during CGS stage of green gram.

There are three kinds of criteria used for rice crop management i.e., 5, 10 and 15 cm of ponding of water in crop field. Hence the RRIP was simulated for all these criteria.

2.4 Crop yield response to soil water

In the present study, a multilinker regression model relating rice grain yield to actual evaporate-transpiration (Panigrahi *et al*. 2005, Panigrahi, 2001b) [9, 3] was used to find out the responses of rice grain yield to various soil water status due to SI. In case of green gram an, additive model of dated crop water production function (Rao *et al*, 1990) [7] was used to simulate the crop yield.

2.5 Economic analysis

In any economic analysis, all cash flows must be evaluated at some reference time. In the economic model used for the study, following items are considered: 1) initial investment, 2) RRIP maintenance cost 3) irrigation cost 4) land lease cost 5) production cost of the crop and 6) annual returns from irrigation. It is assumed that all input except irrigation is same for both irrigated and rainfed crops. The benefit obtained from SI was evaluated against the investment and operational costs for developing the RRIP irrigation system. All the cost and return were worked out using government schedule rate and minimum support price of 2019.

Initial investment of RRIP irrigation system includes the following components: a) Cost of construction of RRIP, b) material cost for lining RRIP, c) material cost for covering RRIP water surface and d) labour cost for lining. Cost of construction of RRIP is computed by knowing the volume of RRIP that needs to be excavated below the ground level and the rate of excavation of the soil. The lining cost of RRIP by 600-gauge LDPE sheets is computed by knowing the area of LDPE sheets required for lining both the beds and side slopes and its present market price. Cost of covering of the RRIP by LDPE sheets depends on the area of LDPE sheet available to cover, which in turn depends on the size of the RRIP and the price of the sheet. The labour cost/wages for lining the RRIP with LDPE sheet and then covering them with soil is 2 men-days for 6 to 8% size of RRIP for a farm area of 1000 m^2. An increment of 0.5 man-day is required for each 1% increase of RRIP above 8% size. RRIP maintenance cost is taken as a constant yearly cost assumed to be 2% of the initial investment of RRIP (Panigrahi, 2001) [3]. The existing lease rate of land in eastern India is Rs. 4000/ha/year for upland rainfed farming system.

Supplemental irrigation was provided to crop by 5 hp electric pump set using plastic pipe as delivery system. The existing hired rate of the pumping unit Rs. 300/ha for providing an irrigation depth of 5 cm. For various RRIP sizes, cropped field area under each category was different and hence, irrigation cost was also found to be different.

Annual cost (A) is the sum of maintenance cost, land lease cost and irrigation cost. Considering the annual inflation rate as 6%, interest rate for agricultural loan as 12% and economic life of the lined RRIP as N years, present worth value of annual cost (PW_A) in year n is:

$$PW_A = \sum_{n=1}^{N}[A(1+f)^{n-1} \times (1+I)^{-n}] \quad (8)$$

Total cost of the irrigation system ($Total_{cost}$) is:

$$Total_{cost} = I_{Inv} + PW_A \quad (9)$$

In which I_{Inv} is initial investment of RRIP irrigation system. In the similar way, present worth of annual cost, present worth of annual return from irrigation (PW_{RI}) was also computed.

2.5.1 Economic Indicators

Different financial indicators like net present value (NPV), benefit cost ratio (BCR), internal rate of return (IRR) and pay-back period (PBP) were studied for deciding the optimum size of RRIP irrigation system and to justify the investment. NPV and BCR due to application of SI from the RRIP were computed as:

$$NP = PW_{RI} - Total_{cost} \quad (10)$$

$$BCR = \frac{PW_{RI}}{Total_{cost}} \quad (11)$$

PBP was estimated for each RRIP size by considering the initial investment, annual cost and return from the SI. All the cost and output price were assumed to increase with 6% inflation rate every year over 25-year life span of the structure. IRR was computed as the interest at which the BCR value was just 1.0 (Panigrahi, *et al*., 2005) [9]. Values of financial indicators were computed for 23 years. (1993-2015) for different size of RRIPs having different ponding criteria.

3. Results and Discussion

Simulation model of RRIP was run for all the 23 years to find what percentage of size of RRIP to be adopted. The average of all sizes of RRIP for 23 years were taken to find particular size of RRIP for a particular criterion. The initial investment, annual cost and annual returns from irrigation/s were calculated for each RRIP size for all the simulated years. The initial investment was found to be in the range of Rs. 3280.10 to Rs. 31701.12 when the RRIP size increases from 5% to 20%. For each year, particular size of RRIP, the irrigation cost and the annual costs were computed over different criteria (5, 10 and 15 cm ponding). For 5 cm ponding condition, the size of RRIP was varied from 12% to 20%, while for 10 cm and 15 cm ponding condition, the sizes were varied from 11 to 17% and 9 to 16%, respectively. The averages taken from these were found to be 17, 14 and 12% for 5, 10 and 15 cm ponding depth, respectively. Net present value (NPV) was observed to vary from ₹ -58884.65 to ₹ 155809.78, for 5 cm ponding criteria. Likewise, PBP, BCR and IRR varied from 6.15 to 20.59 years, 1.31 to 2.91 and 15.37 to 36.72%, respectively. All these simulated results were shown in Table 1. Further, Rice and green gram yield and their straw and stover, which were in ratio of 1.5 and 3.6 were found to be varied in 1936 to 2070 kg/ha, 709 to 793 kg/ha and 2904 to 3105 kg/ha, 2552 to 2856 kg/ha, respectively.

Table 1: Simulation of RRIP size and economic indicator for 5 cm ponding

Year	Size of RRIP	PBP, Year	BCR	IRR,%	NPV,Rs.	Rice Yield, kg/ha	Green Gram Yield, kg/ha	Rice Straw, kg/ha	Green Gram Stover, kg/ha
1993	14%	15.00	1.58	17.64	-919.69	2070	727	3105	2619
1994	16%	15.53	1.50	17.43	-9682.40	2052	716	3078	2577
1995	19%	8.22	2.61	25.81	99832.2	1944	782	2915	2814
1996	15%	15.55	1.42	16.65	-14473.1	1997	784	2996	2821
1997	19%	9.88	2.21	20.70	62388.34	1981	717	2972	2583
1998	19%	12.97	1.67	18.69	13689.94	1995	733	2993	2641
1999	18%	15.85	1.39	16.46	-20553.05	1995	726	2992	2615
2000	18%	6.15	2.91	36.72	155809.78	1938	737	2907	2653
2001	13%	20.59	1.31	15.37	-58884.65	1991	709	2986	2552
2002	12%	16.50	1.38	16.44	-21180.58	1936	793	2904	2856
2003	15%	19.19	1.32	15.61	-47897.16	2049	752	3073	2706
2004	16%	9.89	1.88	20.38	59916.04	1950	713	2925	2567
2005	16%	15.11	1.56	17.63	-7591.13	2068	743	3102	2674
2006	12%	14.89	1.59	18.12	-772.93	2055	734	3083	2644
2007	17%	9.51	2.42	24.12	83923.69	2050	739	3075	2661
2008	15%	6.37	2.83	32.15	120087.10	1978	718	2967	2586
2009	16%	15.24	1.52	17.50	-8930.80	1981	737	2972	2654
2010	20%	14.52	1.63	18.25	7561.45	1976	773	2964	2784
2011	19%	9.70	2.41	22.95	73280.64	2029	791	3043	2848
2012	17%	9.87	2.24	21.67	66504.63	1983	723	2974	2602
2013	20%	17.72	1.34	16.35	-29519.32	1985	740	2977	2663
2014	17%	12.48	1.78	19.43	54367.41	1978	759	2967	2731
2015	20%	12.67	1.71	19.15	20450.59	2025	790	3038	2843
Final Simulated	17%	13.19	1.83	20.23	25974.19	2000	745	3000	2682

Table 2: Simulation of RRIP size and economic indicator for 10 cm ponding

Year	Size of RRIP	PBP, Year	BCR	IRR, %	NPV, Rs.	Rice Yield, kg/ha	Green Gram Yield, kg/ha	Rice Straw, kg/ha	Green Gram Stover, kg/ha
1993	13%	11.50	1.56	15.81	43146.05	2181	762	3271	2745
1994	14%	12.19	1.55	15.01	10463.33	2171	751	3257	2703
1995	11%	7.44	2.82	40.03	123066.37	2084	817	3125	2940
1996	12%	9.05	2.09	27.42	92581.55	2137	819	3206	2947
1997	17%	9.23	1.83	22.48	79668.46	2122	752	3183	2709
1998	16%	9.23	1.95	24.95	83002.57	2135	768	3203	2767
1999	11%	19.56	1.14	13.47	-66990.60	2135	761	3202	2741
2000	13%	9.23	1.98	26.62	90016.42	2128	772	3192	2779
2001	13%	10.54	1.63	19.72	55040.63	2117	744	3176	2678
2002	10%	13.17	1.46	13.86	-1777.03	2080	828	3119	2982
2003	13%	18.95	1.19	13.51	-60416.39	2181	787	3272	2832
2004	14%	7.44	2.84	40.87	132402.54	2109	748	3164	2693
2005	13%	10.79	1.61	18.24	50986.69	2195	778	3293	2800
2006	10%	8.85	2.14	28.26	101925.85	2191	769	3286	2770
2007	13%	13.29	1.42	13.68	-6559.19	2195	774	3293	2787
2008	13%	12.90	1.50	14.07	5318.04	2105	753	3158	2712
2009	14%	10.38	1.80	20.17	56926.60	2101	772	3152	2780
2010	16%	9.77	1.80	22.08	79341.70	2116	808	3174	2910
2011	16%	13.80	1.36	13.65	-13717.75	2178	826	3267	2974
2012	15%	7.57	2.29	38.71	113490.38	2123	758	3184	2728
2013	15%	12.78	1.53	14.28	9166.14	2152	775	3228	2789
2014	17%	8.92	2.10	27.95	99930.18	2118	794	3177	2857
2015	13%	7.37	2.94	43.15	164679.40	2165	825	3248	2969
Final Simulated	14%	11.04	1.85	22.96	53986.61	2140	780	3210	2808

Table 2 showed the simulated size of RRIP for 10 cm ponding condition and calculated values of PBP, BCR, IRR and NPV. It also represented the simulation of rice and Green Gram yield and their straw/Stover. Simulated size for 10 cm ponding was varied from 10 to 17%, while PBP, BCR, IRR and NPV were varied from 7.37 to 19.56 years, 1.14 to 2.94, 13.47 to 43.15% and ₹ -66990.60 to ₹ 164679.40, respectively. The simulated rice production and their straw were found in rang of 2080 to 2195 kg/ha and 3119 to 3293 kg/ha respectively. Similarly, for green gram production and stover were varied from 744 to 828 kg/ha and 2678 to 2982 kg/ha, respectively.

Table 3: Simulation of RRIP size and economic indicator for 15 cm ponding

Year	Size of RRIP	PBP, Year	BCR	IRR, %	NPV, Rs.	Rice Yield, kg/ha	Green Gram Yield, kg/ha	Rice Straw, kg/ha	Green Gram Stover, g/ha
1993	9%	13.86	1.42	13.86	-13142.52	2213	792	3320	2853
1994	10%	8.08	1.99	26.15	109967.59	2281	789	3422	2840
1995	11%	7.69	2.13	28.75	125225.86	2109	847	3164	3048
1996	12%	17.53	1.27	13.68	-36077.60	2247	857	3371	3084
1997	10%	8.81	1.91	23.95	88515.28	2246	792	3369	2853
1998	12%	10.05	1.72	20.73	73351.78	2157	797	3235	2871
1999	10%	13.35	1.49	14.92	9342.42	2162	791	3244	2849
2000	10%	10.22	1.68	17.67	48626.45	2221	808	3331	2909
2001	13%	18.74	1.20	13.66	-39102.57	2190	779	3285	2804
2002	10%	15.96	1.33	13.75	-35581.55	2094	856	3140	3082
2003	10%	12.28	1.66	16.06	23393.54	2194	815	3290	2932
2004	11%	7.63	2.18	29.75	127516.74	2129	777	3194	2797
2005	11%	12.78	1.53	14.97	15512.50	2206	806	3309	2901
2006	10%	7.28	2.70	30.41	139038.24	2219	799	3329	2878
2007	13%	10.22	1.68	17.67	69338.51	2225	804	3338	2895
2008	10%	7.12	2.91	30.75	171417.65	2122	782	3183	2817
2009	12%	19.85	1.18	13.66	-42016.42	2109	800	3164	2881
2010	14%	7.86	2.04	27.64	120701.01	2155	839	3232	3021
2011	13%	7.28	2.19	29.86	130174.68	2236	858	3355	3089
2012	13%	7.23	2.81	30.48	158725.28	2180	791	3270	2846
2013	14%	9.56	1.74	21.79	76480.39	2202	807	3303	2905
2014	16%	9.23	1.88	23.85	80714.89	2141	823	3211	2961
2015	11%	10.18	1.70	19.45	69338.51	2187	856	3281	3081
Final Simulated	12%	10.99	1.84	21.45	63976.55	2184	812	3276	2922

Likewise, for 15 cm ponding condition Table 3 showed, simulated values of size of different RRIP, with their PBP, BCR, IRR and NPV were calculated. Simulated values of size of RRIP for 15 cm ponding criteria were varied from 9 to 16%, and their economic indicators were fluctuated between 7.12 to 19.85 years for PBP, 1.18 to 2.91 for BCR, 13.66 to 30.75% for IRR and ₹ -42016.42 to ₹ 171417.65 for NPV. While, simulated yield of rice and green gram were varied from 2094 to 2281 kg/ha and 777 to 858 kg/ha, respectively. Also, there straw and stover were found to be 3140 to 3422 kg/ha and 2797 to 3089 kg/ha, respectively.

4. Conclusion

Simulation model developed to predict the optimum size of the RRIP so as to provide supplemental irrigation to rice-green Green Gram cropping system in the rainfed farming system of Eastern India. The study revealed that 2 m depth of pond requiring 17, 14 and 12% of 1000 m^2 farm areas yielded values of NPV, BCR, IRR and PBP of ₹ 25974.19, 1.83, 20.23%, 13.19 years for 5 cm (PC), ₹ 53986.61, 1.85, 22.96%, 11.04 year for 10 cm (PC) and ₹ 63976.55, 1.84, 21.45%, 10.99 year for 15 cm (PC), respectively. The corresponding rice and green gram yield were found to be 2000, 2140, 2184 kg/ha and 745, 780, 812 kg/ha, for 5, 10 and 15 cm (PC) respectively. Similarly, their straw and stover were 3000, 3210, 3276 kg/ha and 2682, 2808, 2922 kg/ha, for 5, 10 and 15 cm (PC), respectively.

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