Rainwater Conservation and Reuse for Increasing Agricultural Sustainability of Rain-Fed Upland Ecosystem in Eastern India

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ABSTRACT

The concept of rainwater conservation in the on-farm reservoir (OFR) is adopted to mitigate the adverse effects of drought and its reuse would augment the agricultural productivity in eastern India's rain-fed upland ecosystem. Hydrologic events, based on water management and water harvesting potential of upland ecosystem, plays an important role in planning the optimum sizing of the OFR for integrated farming system.

Keywords: water management, rainwater, water harvesting.

1. INTRODUCTION

Water is one of the most precious natural resources of the earth. This vital resource is limited and shrinking at a faster pace, but there is an increasing demand for it. The projected population of India is gradually leading to a water stress situation by widening the gap between water availability and its demand. Therefore, conservation and judicious utilization of water need no emphasis. With the growing demands for food, it has become a necessity to increase the annual growth in agriculture production from the current 3.5 to 7%. To achieve this targeted agricultural production rate, judicious utilization and management of water, which is one of the most critical inputs in agriculture production, is necessary. Other water management-related issues in Indian context are: (i) trans-boundary/inter-state/inter-basin disputes on water sharing; (ii) conflicts between sharing of water between industry and agricultural sectors in a basin; (iii) rising population and decline in cultivable land; (iv) expansion of cities and industrial growth around river system has affected the irrigation/drinking water quantity/quality and other water-dependent aquatic habitats down below; (v) acute drinking water shortage during summer months in water-deficit states; (vi) climate change has shifted the onset/withdrawal of monsoon along with magnitude and timings of flood/drought occurrences; (vii) nearly 60–70% of fresh water resources discharges to ocean every year; (viii) fresh groundwater regions experiencing extensive pumping leading to seawater intrusion, arsenic problem, and rivers/open wells in villages dry-ups; (ix) extensive use of subsidized fertilizers/pesticides and untreated waste water in agriculture has contaminated groundwater and the entire food chain; (x) about 30–40% of irrigated canal commands converted to waterlogging and/or soil salinity; (xi) irrigation water use is nearly 80% of total demand, but irrigation system efficiency is nearly 30–40%; (xii) nearly 70% of total cultivable land is under rain-fed agriculture with mono-cropping and low productivity; (xiii) substantial quantity of water losses during conveyance of drinking water supply and leakage of sewage system leads to the contamination of groundwater; (xiv) needs social awareness on future water scarcity; and (xv) law and governance on use and misuse of water pricing policy on the use of water and waste water. The present study emphasizes on one of the aforementioned issues expressed in serial number (xii).

In India, the proportion of cultivated land under rain fed agriculture is 127 M-ha, which approximately 70% of the total cultivated land. Therefore, importance of rainwater management in increasing the overall agricultural production is very well realized. However, the complexity of problems associated with rain fed agriculture is more than the irrigated agriculture. It demands for an in-depth analysis of the rainwater management problem in rain fed ecosystem and development of a cost-effective technology for sustainable agricultural production.

Rice is the primary food of India and contributes about 40% to the annual food grain production of the country. India ranks second in both area and production of rice in the world. In India, the area under rice cultivation accounts to 43 M-ha out of which only 19 M-ha is irrigated. The average rice productivity of the country is reported as 1921 kg/ha. A total area of 21 M-ha is recorded as the area under rice in eastern India with productivity of 1,586 kg/ha. Thus, 50% of country's rice area is in eastern India, and its current productivity is less than country's average productivity by 335 kg/ha. The rain fed rice area in eastern India is about 67% of the country total rain fed rice area.

Due to the vagaries of monsoon, there is poor yield in the rain fed ecosystem and it shows a high degree of instability. It poses a greatest challenge to the scientist, in finding the technique to increase the overall agricultural production and cropping intensity of rain fed areas. Although the eastern India is bestowed with plenty of rainfall, three fourth of it occurs during the monsoon season (June–September). The average annual rainfall in this region varies from 1,007 to 3,126mm. Due to the spatial heterogeneity and temporal variability, there is a hindrance in realizing the production potential of the region. It creates surface flooding on one hand and on other it result in water scarcity during the critical crop growth stage.

A few intense storms during monsoon season amount more than 50% of the annual rainfall. Water received during short duration of the intense storm is large in quantity and it results in soil and nutrient losses due to high runoff. In order to provide stability to agricultural production in rain fed areas, it is imperative to conserve the excess rainwater to meet the demand during deficit periods. Mishra et al. (1998) advocated for an in-situ conservation of rainwater in the diked rice field by strengthening the dike height. It revealed that about 99.5% of the rainwater can be stored in a rice plot with 30 cm dike height. Rainwater conservation also reduces the SI (surface irrigation) requirement and losses of sediments/nutrients in runoff water from the rice fields. Their experimental study was supported by water balance simulation for 30 years period (Mishra, 1999). There is an increase in water stress at various crop growth stages of rain fed rice, due to the erratic nature of onset, distribution and withdrawal of rains. During the monsoon season, due to spatial heterogeneity and temporal variability of rainfall, leads to extreme situations such as drought or flood, and results in the failure of crop.

Historical climate data analysis for Kharagpur (India) region reveals that during the rice growth period, there exist two critical dry spells of 12 days duration each (Panigrahi et al., 2002). Due to the coincidence of critical growth stage of rice (reproductive stage) with the second critical dry spell, there is a detrimental effect in obtaining higher yield without SI. Thus, to save the rice crop from substantial damage, there is an urgent need of SI during the dry spells, which may be made possible through rainwater harvesting structures. The field experimental results on the OFR have shown on an average 35–50% increase in monsoon rice productivity with the application of one SI of 5 cm, thereby, demonstrating the importance of rainwater harvesting. Rainwater harvesting can form the backbone of agricultural development and economic prosperity of rain-fed ecosystem of eastern India. Thus, a strong research and development program needs to be undertaken on rainwater harvesting and efficient use of water.

In view of the current limitations in expanding conventional irrigation, water harvesting in the OFR is thus proven to be an encouraging technology. Research conducted by Panigrahi and Panda (2003a, 2003b) during 1998–2000 demonstrates that rainwater harvested in an OFR from the rice field provides SI to rain-fed rice during its critical growth stage and partially meet the pre-sowing irrigation requirement of a short duration mustard crop in winter season (Panigrahi, et al., 2007). Optimum area under the OFR is determined as 12% of the farm area by conducting daily water balance simulation in the OFR as well as in crop fields with 22 years of hydro-metrological data. The percentage of runoff and percolation (including seepage) from monsoon rain is observed as 8 and 60%, respectively, for the upland situations in sandy loam soil. Heavy percolation losses of rainwater accelerate leaching of nitrate from the rice field that may contaminate the groundwater. As rainfall is stochastic in nature, the inflow to the OFR is also associated with random phenomena that determine the size and area occupied by the OFR, which are ultimately uncertain parameters. At different risk levels, size of the OFR (both for lined and unlined systems) that can only meet the crop demand at critical growth stages of monsoon rice and provide a pre-sowing irrigation to grow a suitable low water requiring crop such as pulses/oil seeds during the winter season needs to be determined. Moreover, size of the OFR may increase several times if more than two crops in a year are grown, and SI is provided at other less sensitive crop growth stages, which may not be acceptable to farmers due to techno-economic reasons. Many water-harvesting and SI systems have failed, despite good technique and design, because of the socioeconomic, and management factors are inadequately integrated into the development of the system (Yang, et al., 2012). In other cases, where efforts have been made to introduce the OFR and SI technologies (Oweis & Hachum, 2006), the sustainability (e.g., impact on water table) and environmental impacts have been overlooked (Helmreich & Horn, 2009; Shao et al., 2013).

Seepage and percolation (SP) losses from the diked rice field that contribute to groundwater need to be assessed, considering the precise water balance of the study area in order to maintain the water table at predetermined level. Furthermore, construction of the OFR in a small landholding deprives the farmer to get any crop yield from the area occupied by the OFR. Besides this, some money is also invested for the construction of the OFR. In return, the farmer receives assured irrigation water to save rainfed rice from failure and may be able to grow a low water requiring crop with the residual moisture/ pre-sowing irrigation from the OFR in winter season. Farmers may also get good return and meet their food requirement by growing selected fish varieties in the OFR (Sethi et al., 2005). It has been estimated that the selected fish varieties may grow up to 300 g during the four rainy months (June–September) (Pandey, et al., 2006). Fish culture in the OFRs with rice plots having weir height of 10, 12.5, and 15 cm indicates that there is ample scope to explore this new technique of rice–fish culture in the water-harvesting structures. Standardization of this technique and benefit-cost analysis are essential for acceptance of this technology for large-scale adaptation by the farmers. In situ conservation of rainwater, its harvesting and recycling, and rice–fish integration can result in a great pay if it becomes farmer's participatory program, and a bottom-up rather top-down approach.

2. RATIONALE

Abundant natural resources which are basic to agriculture are available in eastern India, but the people of this region are poor due to the poor management of these resources. In order to bring a substantial change in living standards of the vast population of the eastern region, it is necessary to exploit fully its land and water potentials. One of the major constraints in developing this potential is inadequate application of appropriate water management technology. The poverty alleviation is possible only by substantial increase in crop production through increased cropping intensity and productivity through proper sustainable water management. Thus, the scientific management of water resources specifically the rainwater is the key to agricultural development in eastern region. A substantial quantity of runoff, which is lost as surface drainage in this region, can be harvested in reservoirs for SI and used to recharge the groundwater reservoir. In recent decades, water harvesting and runoff recycling have gained more importance. The poor pay off from large dams and other associated problems has enhanced importance of in situ water harvesting and recycling. It has also become a useful contingency measure against weather aberration in areas where rainfall is erratic and unpredictable. Keeping in view, the topography of rice fields, introduction of rice–fish farming instead of mono-cropping of rice may be considered economically viable. Several methods of rice integration are practiced all over the world. In the Indian context, rice–fish integration in medium lands by the introduction of fishes in water- harvesting structures/OFRs located within the rice fields is to be experimented. Similarly, rice–fish integration by providing refuse in the rice plot can be evaluated and compared with the above technique.

In order to achieve sustainability there need to be an integration of agriculture with other farm enterprises such as fisheries. Concept of diversification is the need of the hour for making research outcome economically viable. The outcome of the present study will have three broad components: (i) determination of optimal size of the OFR corresponding to optimum dike height of the rice field for maximum utilization of rainwater through experimental findings and model study; (ii) standardization of techniques for rice–fish culture in the OFRs in a specific location and (iii) mass-scale adoption of the developed technology by farmers through experimental demonstration at research farm and farmers field.

In rain fed upland ecosystem, the problem of drought and submergence can be mitigated by recycling the conserved and harvested rainwater in a small tank in the farm area, popularly known as the OFR. The implementation of this technology at field level depends upon the size of the OFR with respect to the farm area and its type (lined or unlined). Since it occupies the land area in the crop field, size of the structure makes the system economically unacceptable. Based on the cropping systems at its upstream and downstream, attempts have been made to arrive at an optimum size of the OFR (lined or unlined).

3. BRIEF PERSPECTIVE

Based on the irrigation management strategies of the crops to be grown in the command area and the natural inflow and outflow components of the structure, the OFR size is decided. (Figure.1). The direct rainfall, runoff from the micro-catchments contributes to the inflow and SI, seepage and evaporation losses accounts for the outflow components of the OFR. The major outflow component of the OFR (SI) plays a decisive role in order to enhance the productivity of the upland cropping system, to increase the cropping intensity of the existing mono-cropping, and to standardize the degree of diversification during non-monsoon season with respect to high valued non-rice crops along with pisciculture. The optimum size of the OFR is decided based on the mass balance of the inflow and outflow components of the crop fields and the OFR that seems to be a correct approach. Economic evaluation of the OFR system will be required to arrive at an optimum size, followed by field experimental verification (Figure.2).

Around 45–67% of the total outflow in the unlined OFR is due to seepage and percolation (SP). Moreover, the area occupied by the unlined OFR is larger in comparison to the lined OFRs. By using low-density polyethylene (LDPE) sheets of proper thickness (600 μm), SP can be controlled to a larger extent. The lining of the OFR results in the reduction of the OFR size and in turn increases the storage of rainwater during non-monsoon season for a prolonged duration. The excess volume of rainwater stored in the OFR can be used to irrigate to the larger command or growing a second and/ or third crop in succession during non-monsoon seasons. Approximately 30% of total outflow from the OFR is estimated as evaporation loss. The evaporation loss may be minimized to a larger extent by adopting shade net or LDPE cover over the water surface area. The opportunity cost of harvested water is escalating due to the cost involved in adopting shade net or LDPE cover. The economical and a cost effective option is to adopt biological shading with the

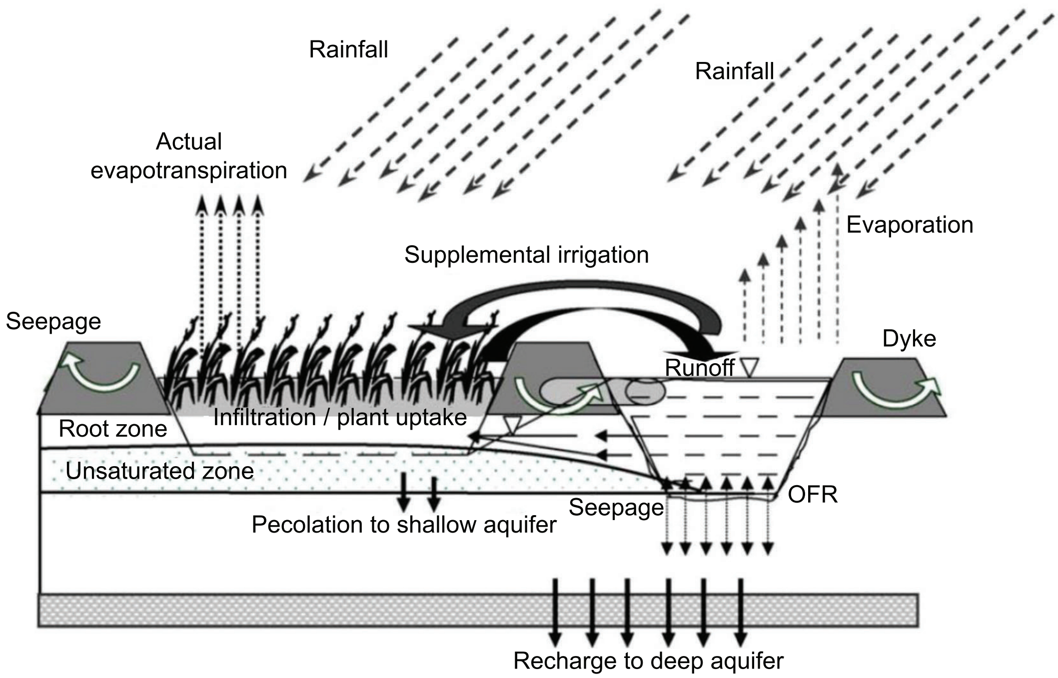

Figure 1. Schematic presentation of water balance parameters of rice field and the on-farm reservoir (OFR).

Figure 2. Field experimental setup for providing supplemental irrigation to mustard from the on-farm reservoir (OFR).

help of creeper vegetable crop and it is used in the study to control evaporation loss from the OFR. When compared to the open OFR, there is 35% reduction in the evaporation loss (Sahoo et al., 2010; 2012). The biological shading in addition to mitigating evaporation loss, possess greater advantage for generating income for the crop area diverted to the OFR construction through creeper vegetable crops.

Additional details on sizing of OFR and the related issues has been elaborated in Panda (2009).

4. SUMMARY

Rainwater conservation via on-farm reservoir shows high potential to enhance agricultural sustainability in rain-fed upland areas in eastern India. During the conventional monsoon period of 110 days, short duration rice can be cultivated under rain-fed condition (Panda 2009; Panigrahi and Panda, 2001b).

The collected rainwater in the on-farm reservoir could be recycled to meet the supplement irrigation requirement of crops. Using OFR technology, there is a great scope of double cropping, in the rain-fed uplands (Panda, 2009).

In the case of crop-fish integration, it is found that the optimum size of the unlined OFR is15% of the farm area for a return period of 5 years, having 1:1 side slope and the size of the OFR becomes larger with the increase in side slope (Panda, 2009).

The optimum size of OFR in terms of percentage of the farm area in rain fed-farming system can be determined using the developed Visual Basic-based program. (Roy et al., 2009). It can simulate the OFR sizes for various combinations of the OFR geometry, field sizes, and cropping patterns and it is completely menu-driven system. The following items such as the crops to be grown, irrigation management practices, types of the OFR (lined or unlined), side slope, depth of OFR and the farm area need to be specified by the user (Panda, 2009).

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