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Artificial groundwater recharge through rice (*Oryza sativa* L.) cultivation: A systematic review

Adarsh S and Giffy ThomasDOI: <https://doi.org/10.22271/chemi.2019.v7.i3.16.07>**Abstract**

Rice cultivation aids ground water recharge. Rice requires continuous supply of water through irrigation. Around 60 percent of the irrigation water is used by the plants; remaining 40 percent filters through soil recharging the aquifer below. Yet, this concept was vague in its meaning, which renders its implementation difficult. In this paper, an attempt is made to understand the concept; perspective to its essentiality through structured literature review thus trying to identify the overall ideas associated with the topic. The results from studies using soil water balance approach revealed rice as the best recharge potential crop for fallows, rice and non-rice cropped areas for three cropping seasons. Clays with a little salinity is better to recharge groundwater from irrigated paddy field. Increase in relative humidity with decrease in sunshine hours cause rise in groundwater recharge. Water table rises positively in monsoon counter balanced by lower during winter. Agricultural practices with modified cropping pattern mitigate salinization and water logging issues. Rice water management integrates three-dimensional surface and subsurface groundwater level. Production function approach in valuing groundwater recharge shows that dry season agriculture depends on groundwater. Improved insitu water-saving by System of Rice Intensification (SRI) certifies that field irrigation requirement of SRI was lower than traditional irrigation according to 3-D finite element groundwater model (FEMWATER) studies.

Keywords: Rice, irrigation, groundwater recharge, system of rice intensification**Introduction**

Rice is the major staple food for world. Irrigated production systems provide 75 percent of the world's rice supply (Cantrell and Reeves, 2002; Qin *et al.*, 2006). However, there are numerous problems that threaten agriculture to fulfill human needs, including climate change; biodiversity loss; land degradation; depletion and pollution of water resources; rising production costs; decreasing number of farms and, linked with that, poverty and a decrease of the rural population (Beus *et al.*, 1990; Goodland, 1997; Rosset *et al.*, 1997; Thrupp, 2000; Ogaji, 2005; Peters, 2010; Lemke, 2012; Rivera-Ferre, 2013) [8, 28, 64, 48, 21, 54]. Agriculture has become the part and parcel of these issues (Goodland, 1997; Koohafkan *et al.*, 2012) [28]. Rice cultivation aids ground water recharge as 60 percent of the irrigation water is used by the plants; remaining 40 percent filters through soil recharging the aquifer below. Yet, this concept even misused and exploited (Constance, 2010) [19]. In this review paper, we aim to advance understandings of sustainable agriculture on social processes rather than mapping it as a technical paradigm. A literature review with the objective of identifying the ideas and aspects associated where focused to identify patterns and differences in adoption and application of these ideas. This in turn might benefit future work as every attempt to realize the significance is indispensable (Pretty, 1999; Giovanucci *et al.*, 2012; Matson *et al.*, 1997; Shi *et al.*, 2005; Tilman *et al.*, 2002) [50, 44, 25, 65]. Irrigation can mitigate salinization and water logging, in irrigated areas (Zhou *et al.*, 2016; Emna *et al.*, 2016; Singh, 2017a, b). FEMWATER is a three-Dimensional Finite Element Computer Model for simulating subsurface hydrological model for rice cultivation in monsoon region. FEMWATER is developed by Dr. Yeh and Dr. Hsin-Chi (Jerry) Lin to describe flow and transport through saturated-unsaturated porous media using Richards's equation (Lin *et al.*, 1997) [43].

Ground Water

Water by soil, pores, voids, interstices and crevices in rocks in underground zone of saturation is groundwater. Sub surface flow joins groundwater into surface bodies like rivers, streams.

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Aquifers inside saturated zone store groundwater which can be obtained by extraction and pumping. Rainwater is its the major source and it replenished within five years so that water table should remain same. Groundwater contributes 50 percent irrigation, 80 percent domestic use in rural areas and 50 percent water for urban and industrial areas. Groundwater is seen as static and dynamic components. Static resources are the aquifers zones below zone of fluctuation which does not replenish annually whereas dynamic resources are replenished annually. The Article 262 of Constitution and National Water Policy of 1987 aimed to limit the utilization of dynamic component and static resources in periods of drought. Annual water availability is predicted by annual aquifer recharge. When mining (over exploitation) of water occurs, it causes for drought or sea water ingress. The potential groundwater reservoirs lie in river basin alluvial formations of Punjab, Haryana, Uttar Pradesh Bihar, West Bengal and Assam. Hard rock formations are seen in south India where wells are used. Groundwater is explored by test drilling, electrical resistivity, electric and gamma ray logging. Net Ground Water Availability & Ground Water Draft (March 2013) ^[25] found that annual ground water replenished is 6.84 BCM. Artificial Recharge to Ground Water (AR) detailed 4312 check dams, 7181 sub-surface dykes, 10780 gully plugs and 10780 nalah bunds as AR structures with 4650 km² area with 1078 MCM (million cubic meter) recharged water (Michael, 1978) ^[45].

Artificial groundwater recharge

The addition of water to saturation zone expressed in mm³ year⁻¹ is recharge. Augmentation of ground water reservoir by natural surface water movement. Artificial recharge addresses issues to enhance aquifer recharge. Aquifers act as "warehouse" for storing water with advantages of being free from inundation of large surface area, loss of cultivable land, displacement of local population, substantial evaporation losses and sensitivity to earthquakes. Aquifers which absorb large quantities of water and release them slowly are ideal that its conductivity is high vertically and low horizontally. Artificial recharge is followed in areas where ground water levels are declining regularly basis with aquifer desaturation or salinity ingress. It has advantages like removal of contaminants by natural cleansing processes and facilitates the water use. Mitigation of the groundwater quality deterioration in shallow coastal aquifers was initiated through groundwater recharge in Cochin (Rajendran, 2002) ^[52]. Local farmers observed that rainfall recharge accounts for about 82 percent of the annual recharge. Bohlke (2002) ^[10] reported that groundwater recharge effects dissolve aquifer chemical concentrations. Water pumped equals the recharge but not exceeds in surface recharge. It exceeds in deep aquifers where source and sink is distant. Recharge is already more in coastal area to prevent sea water intrusion. In recharge operation, water is made to stand in field or suitable structures can be constructed to divert water to spread water. The main methods include recharging in basin, furrow, ditch, wells or pits. Basin method provides maximum area of recharging with contours preventing water runoff where ground water is irregular. Water from main canal is diverted to parallel shallow flat bottomed furrows in furrow method. Wells and pits are used in areas where the water bearing stratum is overlain by impermeable layer. Water leaches inside topsoil and becomes interflow at impermeable layer and never joins water table. It is usually done in urban areas where large basins can't be made (CGWB, Central Ground Water Board, 2000) ^[16].

Wetlands

Wetlands are areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty including areas of marine water, the depth of which at low tide does not exceed six meters. It may also incorporate riparian and coastal zones adjacent to the wetlands and islands or bodies of marine water deeper than six meters at low tide lying within the wetland. Centre for Ecological Sciences (2013) stated that wetlands prevent flooding by holding water much like a sponge. They help keep river levels normal and filter and purify the surface water. Wetlands accept water during storms and whenever water levels are high and slowly release water when water levels are low. The richness and usefulness of the wetlands was first brought to the notice of the world by Ramsar Convention on Wetlands in 1971 ^[41]. Groundwater recharge is considered as main hydrological regulating functions of wetlands. Abraham (2015) found that wetlands have an important influence on the recharge or discharge of groundwater. Groundwater recharge refers to the movement of surface water down through the soil into the zone in which permeable rocks and overlying soil are saturated. Groundwater discharge, in contrast, refers to the movement of groundwater out into the soil surface. Wetland areas where groundwater is discharging are referred as seepage wetlands because they are places where the water seeps slowly out into the soil surface. Kokkal *et al.* (2008) claimed that *Kol, Kuttanad* and *Pokkali* paddy systems are classified under Coastal Wetlands with 1.27 lakh ha. With 157 units under natural and artificial this further highlights the importance of the topic. Kuttanad with major paddy cultivated area of Kerala has unique wetland topography has been included under Ramsar sites by understanding their importance.

Groundwater recharge through rice

Outflows from paddy field are reused downstream through drainage canals or recharge aquifers has been proven through several studies. (Tuong, 1999 ; Belder *et al.*, 2004; Bouman *et al.*, 2001; Cabangon *et al.*, 2000 ; Guerra *et al.*, 1998; Harnpichitvitaya *et al.*, 2000) ^[35, 7, 12]. Zulu *et al.* (1996) ^[71] confirmed that average drainage water reuse was about 14–15 percent in rice irrigation system. Chieng (2003) claimed that multi-functionality of rice fields to recharge the groundwater and water supply to wetlands from field outflows. Chopra (1997) and Gopikuttan (2004) found that paddy lands perform as feeders of aquifers and retain ground water level of the area. They act as the water reservoirs of the state by recharging ground water. When water moves from wetland down into underground aquifer it becomes cleaner. It may be drawn for human consumption or flow laterally underground until it rises to another wetland. Recharge is also beneficial for flood storage-because the runoff is temporarily stored underground, rather than moving swiftly downstream and overflowing. Paddy fields are not just production centers of food grain but a unique wetland ecosystem that delivers a series of ecological services such as retaining water, helping seepage and recharging groundwater and providing natural drainage paths for flood waters. If the average water level in a paddy field is one foot, one hectare will hold 3 million litre of water. This percolates down and replenishes groundwater. Losing paddy fields and wetlands will threaten the state's water security. M.S. Swaminathan, who headed the National Commission for Farmers says, "The country needs over 100 million tons of rice to meet the demand by 2030. Therefore, all traditional rice farming systems should be conserved for

rice cultivation.” Paddy fields help to recharge underlying aquifers (Sakthivadivel, 2007) ^[57]. Kaushal (2009) claimed that optimal rainwater conservation is done naturally in paddy fields.

Infiltration, percolation & puddling

Infiltration is the movement of water into the soil surface (International Rice Research Institute, 1965). Percolation is the movement of water within the soil matrix by gravity pulling the water downward (Huang *et al.*, 2003). Percolation rate controls infiltration rate. Rate of percolation is controlled by soil grain size. Smaller the grains mean smaller the pores so more the frictional resistance to water and hence less hydraulic conductivity. Low hydraulic conductivity means low infiltration rate. Puddling is the process of working saturated or near saturated soils into mud. It is one of the most basic tasks in irrigated paddy field to control weed growth, increasing nutrient availability. Percolation rate of soil is governed more by the water passage ways it contains (root channels or structural cleavage) than by the character or volume of the pore space (Slateob and Byers, 1931; Bouma, 1978) ^[11]. Fujihara *et al.* (2013) and Yamada (2010) ^[69] reported that the ponding water in the plots disappeared even when puddling was conducted carefully during little rainfall and percolations increased during the later periods of rice growth. Absence of drought stress was found by higher rice yield of non-puddled fields than puddled ones. Bhattacharya (2010) found that surface irrigation increases production during monsoon gaps and non-monsoon period with adequate drainage is assured, that the additional water gets recharged underground. Soil salinity under puddling soils was higher than that without puddling (El-Henawy 2013). Soil bulk density were higher under puddling soil than those without puddling (Saffan, 1975; Adachi, 1990; Aggarwal *et al.*, 1995; Behera *et al.*, 2007; Gorgy, 2010; El-Henawy, 2013) ^[56, 2, 3, 6, 31]. Values of rice yield without puddling were higher than those under puddling (Elias, 1969; Saffan, 1975; Sharma, 1985; Ebada, 1992; Gorgy, 1995; El-Henawy, 2013) ^[56, 32, 56]. Puddling is one of the most tedious and expensive agricultural practice which destroys soil aggregates which reduces root growth and distribution (Elias, 1969; Saffan, 1975; Alva and Petersen, 1979; Gorgy, 2010) ^[56, 32, 56]. Values of soil pH under puddling soils were higher than that without puddling. (Ebada, 1992; Gorgy, 1995) ^[22, 31]. Infiltration rate (IR) was significantly affected by puddling (Gorgy, 2010) ^[32]. Puddling disperses clay-skins aggregates and compresses the subsoil (Grant, 1964). Puddling causes dispersion of soil particles and flocculation which reduce macro pore volume in the compacted, anthropogenic horizon (plough sole or tillage pan) (Adachi and Inoue, 1988; Adachi, 1990 Wopereis, 1993; and Aggarwal *et al.*, 1995) ^[2]. Puddling lowers soil hydraulic conductivity (DeDatta and Kerim, 1974 Adachi and Inoue, 1988; and Naklang *et al.*, 1996). Puddling decreases water percolation rate under field and laboratory conditions, (Mousavi *et al.*, 2009; Adachi and Inoue, 1988; Wopereis, 1993) ^[2]. Percolation rate increased rice grain yield by 21percent over no percolation (De Datta, 1981; Sharma *et al.*, 1985). Razavipour *et al.* (2014) reported the inverse relationship between clay content and percolation in soil. Water moves out of the root zone by uptake through the crop, and through seepage and percolation beyond the root zone which causes recharge (Wicham, 1978) ^[68]. Soil texture has a strong influence on the magnitude of seepage and percolation losses (Wicham, 1978) ^[68]. Increased bulk density reduces percolation losses of water through no puddled soils

(Ghildyal, 1969) ^[26]. Janssen (2010) ^[39] reported that the results demonstrate that percolation losses increase in the order of continuous soil saturation, continuous flooding, mid-season drainage and intermittent irrigation, mid-season drainage and continuous flooding. Derr *et al.* (1969) reported that the percent silt and coarse fragments of subsoil were positively correlated with percolation rate whereas percent clay was negatively correlated.

Conclusion

Ground water can be made available sine die only through artificial recharging. Ground water recharging is best done by wetlands. Paddy fields effectively acts as artificial wetlands which not only recharges ground water but also provides food. Puddling in paddy fields should be done optimally to balance the yield and ground water recharge for attaining sustainability in both aspects

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