Chapter 1

INTRODUCTION

In the last several decades, there has been an apparent increase in the prevalence of zoonotic diseases—diseases that people acquire from domestic or wild animals[1]. Japanese encephalitis (JE) is the most prevalent zoonotic viral encephalitis that affects people all over the world. The genus Flavivirus and family Flaviviridae include the Japanese encephalitis virus (JEV). The JEV virion has seven non-structural (NS) proteins, namely NS1, NS2A, NS2B, NS3, NS4A, NS4B, and NS, in addition to three structural proteins, namely nucleocapsid or core protein, non-glycosylated membrane protein, and glycosylated envelope protein[2][3]. Following a mosquito bite, the virus replicates in the skin before traveling to local lymph nodes. It has been shown that Langerhans dendritic cells in the skin aid in the reproduction of most *Flavivirus* infections, such as West Nile and dengue viruses[3]. After that, it causes a brief viremia by peripheral amplification before entering the central nervous system (CNS)[4]. Viral elements are deposited within the extra-neural cells during initial viremia. Connective tissue, lymphoreticular tissues, heart, smooth muscle, skeletal muscle, and endocrine and exocrine glands are important extra-neural sites of replication. The virus comes inside the central nervous system through blood[5]. There is a big deal of difference in the clinical presentation of many diseases depending on whether the virus enters cells in the CNS that are susceptible to it[6]. The symptoms may be slight or inapparent if the infection is restricted to extra-neural tissues; however, encephalitis results from the same pathogen infecting neural tissues. Most of the time, a JEV infection has no symptoms. Only one out of every 300 instances, on average, results in clinical symptoms. There is an incubation period of six to fourteen days before the first symptoms of infection manifest. Typically, it begins with a fever that is higher than 38°C, muscle aches, chills, vomiting, and headaches resembling meningitis. When children first come, they typically have gastrointestinal symptoms such as nausea, abdominal pains and vomiting, that resemble those of acute abdominal syndrome. There are four stages to the disease's progression[7][8][9]. Initially, there is the prodromal stage, marked by a sudden spike in temperature and headache, along with general symptoms including nausea, vomiting, anorexia, and malaise. Changes in consciousness ranging from minor clouding to comas are included in the second stage, known as the acute stage. Frequent convulsions might be focal or generalized, accompanied by neck stiffness and extremity paralysis. The later stage, in uncomplicated situations, is marked by better neurologic consequences and defervescence. The final stage is the sequelae stage, during which light instances fully recover, on the other hand, in severe cases, show improvement but retain neurological abnormalities[7][10].

Although not all mosquito species (family Culicidae) from the genera *Aedes, Anopheles, Armigeres, Mansonia, and Culex,* are equally capable of transmitting the virus, over thirty species are known to have the capacity to do so. Studies conducted in India have identified several other secondary vectors, such as *Anopheles subpictus, Anopheles. peditaeniatus, Mansonia. uniform , Culex whitmorei, Culex gelidus, Culex epidesmus,* and *Culex pseudovishnui*[11]. Not only do the susceptibility and competence differ amongst mosquito species, but they also covariate with genotypes. Due to the strong dependence on a range of biotic and abiotic environmental variables as well as the spatial scale of the study, the biology of arthropod-borne diseases, including JE, is complicated. Temperature, rainfall, and humidity are the most important factors, although wind and the length of sunshine are also important. The multiplication rate of insects is affected by temperature. This in turn controls the rate of infection of the salivary secretions and, thus, the chance of success in conveying the infection to a different host. Transmission is impossible if the infection takes longer to develop than the insect does to live. Another essential component of transmission is human act. When forests are cleared, species that spawn in tree-hole water are killed, but those that favor temporary, sunny ground pools (such as many Anopheles species that cause malaria) thrive. While many species use the marshy ponds created by wetlands drainage, certain species may benefit from the open channels[12].

The abundance of JE vectors is directly correlated with agricultural practices and agroclimatic characteristics, such as crop breed, drainage pattern, and fertilizer application[13]. The Japanese encephalitis mosquito subgroups *Culex tritaeniorhynchus, Culex vishnui,* and *Culex pseudovishnui* use transplanted rice fields as a larval home[14]. There are noticeable changes in the chemical and physical characteristics of ricefield water during the day and throughout the crop cycle[15]. In ricefields, the relative quantity of mosquitoes that spawn is greatly affected by these changes in physico chemical properties of soil and water[16]. Insect predators and phytoplankton are examples of biotic components that have a significant influence on the quantity of mosquitoes breeding in rice fields[16]. The water management strategy used in rice fields has an impact on it. The water in rice fields provides the ideal environment for JE vector breeding. It is responsible for the many-fold increase in vector density and the maximum number of JE cases, which were followed by a peak in mosquito density[17]. A four-year study on Japanese encephalitis (JE) cases in Taiwan revealed that the counties with the greatest concentration of rice fields had the highest number of infections[19]. In regions where dry farming had been implemented, there were fewer cases. When the JE epidemic struck Sri Lanka in 1986 and 1988, it was observed that most cases were recorded from pig farming and irrigation areas, while there were none from non-irrigated areas[20].

The best method to lower the incidence of JE in people is through vaccination, yet this does not change the JEV transmission cycle. On the other hand, immunizing animals—particularly pigs—would lessen the virus's ability to amplify, the frequency of mosquito infections, and ultimately the danger of human transmission. However, because pig immunization is expensive, logistically difficult, and sometimes ineffective in piglets, it is not typically used to prevent JE in pigs[21]. Space sprays are typically used in vector control operations during epidemics to instantly stop the spread of the virus by knocking down adult mosquitoes[6]. This is not cost-effective and could harm the environment if sprayed across large regions. Even though there are several vector management strategies in place, it is not feasible to develop a long-term, sustainable, economical, or environmentally friendly technology to lessen or completely eradicate JE vectors. The degree to which insects are susceptible to insecticides varies naturally. The target population is under selection pressure from insecticidal control, which helps the least vulnerable individuals survive. Eventually, these survivors give rise to strains that, even at high dosages, are physically resistant. Numerous physiological and metabolic mechanisms may be implicated. Cross-resistance to chemically related chemicals and even to families of chemically unrelated compounds is frequently conferred by resistance to one pesticide. In a rice-growing environment, the management of water by intermittent irrigation has been used to limit disease vector larvae. This is just an approach of alternately drying and watering the field. Managing water can only effectively reduce the aquatic stages of mosquitoes in areas where there is no shortage of water and where farmers cooperate[22].

In recent years, outbreaks of Japanese encephalitis (JE) have been documented in several regions of northeastern India. The mosquito species belonging to the *Culex vishnui* group are the main disease vectors in Assam. Pools, ditches, and paddy fields are examples of water features with lush flora where these mosquitoes grow. Three species—*Culex vishnui*, *Culex pseudovishnui*, and *Culex tritaeniorhynchus*—are members of this group. Certain areas of the Sonitpur district in Assam, especially the northern ones, like Dhekiajuli, North Jamuguri, Biswanath Chariali, Balipara, Gohpur, Behali, Bihaguri, and Rangapara along the border between Assam and Arunachal, are more susceptible to an outbreak of this disease when the monsoon arrives. The Assam government is putting these vector-borne diseases under control through a number of initiatives. The vaccination campaign against Japanese encephalitis (JE) for children aged one to fifteen has now reached eleven of the 27 districts. Nonetheless, health officials continue to receive reports of JE cases. As a result, areas afflicted by JE are increasingly becoming extremely concerned, and a thorough, methodical investigation of various vector management strategies in rice fields is required. Numerous studies on the JE vector and its mitigation are accessible in the literature. To stop JE from spreading, numerous initiatives are being implemented on a national and worldwide level. In order to stop the disease from spreading further, the government of Assam has also implemented all necessary precautions, including immunization campaigns, the distribution of mosquito nets, and the use of insecticides. According to the health department of the government of Assam, fogging is going on in full swing across the state periodically. Furthermore, the department is planning campaigns to raise public awareness. Because fewer people have access to government services outside of these locations and because the people there are illiterate, JE regulating procedures frequently become more difficult in rural areas. The vector usually grows because of the rice-irrigated areas next to rice-cultivated areas.

According to the report of Central Ground Water Board, 2019, net irrigated area of Sonitpur is almost 42,157 ha and rain fed area of the district is found to be 1,09,710 ha. The major crop of Sonitpur district is paddy and there are numbers of tea gardens in the district. Such conditions make this district susceptible to vector borne diseases.

Therefore, those who live close to these locations are frequently at risk of contracting JE. Although, state government is trying its best to eradicate vector borne diseases, but practices are not implemented to control the growth and development of disease vectors in its breeding site i.e. agricultural areas. Alternate wet and dry irrigation (AWDI), is anticipated to be quite helpful in such conditions. In this technique, a short dry period is implemented in the field rather keeping it inundated throughout the cropping period. Thus it curtail the life cycle of vectors flourishing in the field. Moreover, scientific investigations and field trials showed that AWDI method is the most promising technique in fulfilling water requirement and increased grain yield[23][24].

The AWDI method is a very effective water management system which keeps the rice fields saturated by supplying optimal amount of water for growth and development of rice plants. AWDI reduces irrigation water use by 40%–45% in arid conditions without influencing the yield potential[25]. This technique also increases the water productivity at the field level by reducing seepage and percolation during the crop-growth period[26]. This method is increasingly practiced in parts of Africa and Asia (mostly in Japan and China)[27]. AWDI is a socio-economically feasible method that has the potential to remove reluctance of farmers to switch from conventional methods to innovative methods of crop cultivation which can reduce the water use[28]. Paddy fields are treated with alternating cycles of wetting and drying in AWDI, this pattern of hydration positively influences soil texture and water potential[26][29]. AWDI provide an aerobic condition for a considerable period of time that do not compromise with other vital physiological functions of the rice cultivars, thus, a key component of successful implementation of AWDI method is assortment of suitable rice cultivars. Drought resistant and aerobic cultivars are good combinations for sustaining AWDI, mixed breeding of drought resistance-aerobic and lowland rice cultivars may provide desirable crop yield[30]. Aerobic rice cultivars show significant yield with AWDI in diverse environmental backgrounds i.e. soils having distinctive physiochemical characteristics – soil pH, soil texture, water holding capacity and soil moisture. A gradual increase of pH from 6.4 to 7.1 was reported in a long-term field experiment of 12 seasons of aerobic rice cultivation in alluvial (clay) soil by IRRI, Philippines[31]. Soil texture also influences growth pattern and crop yield of rice cultivars, evident within 1 to 10 days of implementation of AWDI[32]. Soil organic carbon (SOC) is another important factor that determines the extent of soil aggregation, bulk density, structure and porosity; it was observed that SOC above 1% improved water holding capacity of soil and enhanced rice yield[33]. However, rice yield is not at par in alkaline soils having low SOC[34]. Best management practice and well-planned water conserving techniques combined with selection of good cultivars (having versatile phenotypes that can adapt in diverse growing conditions) will help in sustainable application of AWDI in varying climatic conditions. AWDI do not much affect the soil buffering capacity or leads to soil salinity, however, studies show that performance of AWDI is always better in acidic soil where soil pH is less than 6.5, AWDI also promotes deeper penetration of roots into unlike continuous flooding at a neutral pH[34][32]. In case of alkaline soil, AWDI shows better results in SOC >1%, and associates with some vital soil physical parameters such as bulk density, porosity, and aggregate stability because these influence the water holding capacity of soil in relation to SOC[33][34]. In saline soil (pH>8), higher percentage of exchangeable sodium leads to formation of an impermeable soil layer in AWDI method[35]. Higher percentage of exchangeable sodium also causes disintegration of soil structure[35]. Such soil condition may have an adverse effect on growth and development of rice plants in AWDI technique but not in continuous flooding system because of the shallow root systems[36]. It is also observed that AWDI increases the soil electric conductivity because of increased mineralization and dissolved ion concentration in some regions (depending on the soil physical properties)[37]. Soil redox potential is higher in AWDI than continuous flooding because of the oxidized condition in the fields[38]. AWDI additionally influences the soil microbial ecosystems, soil microbes flourish in aerobic condition in AWDI, moreover, aerobic condition improves nutrient mineralization and availability of nutrients in the rhizosphere; an anaerobic condition affects diffusion of air the soil microflora in continuous flooding[39]. It has been observed that AWDI cycle causes shifting of anoxic soil condition to oxic condition, thus it changes the soil aeration pattern and distribution of soil oxygen along with nutrient availability[38][40]. Increment of soil oxygen improves mineralization of soil organic matter and activity of soil microorganisms, and inhibits loss of soil nitrogen, and hence increases soil fertility[41][40]. Number of AWDI cycle in one crop season is depends on the texture of the soil[32]. For example, in sandy loam soil, AWDI fulfills in a short duration until the stage of drying, but in clayey soil, it requires more time to achieve the drying stage[42][43]. However, a detailed mechanism of influence of soil texture on performance of AWDI has not been reported[44]. AWDI is an environment friendly approach of water conservation as well as vector borne disease control method; it is a cost-effective approach because it does not require any high-end sophisticated equipment for field investigations[45][46].

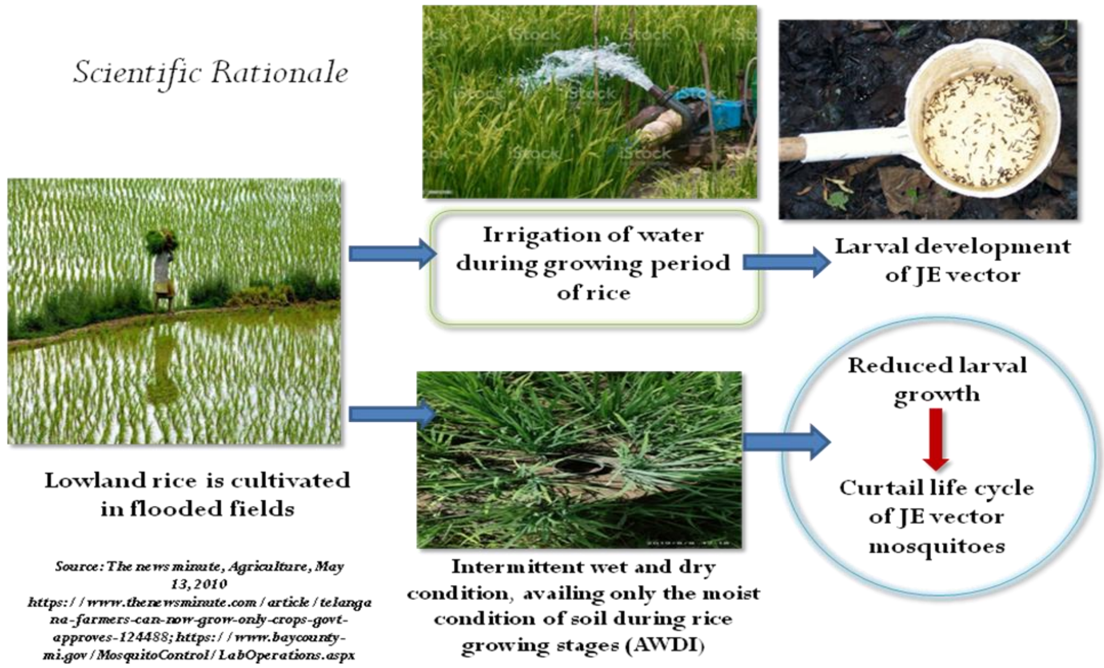

Figure 1.1. Scientific rationale of the study – implementation of AWDI involving local varieties of rice and curtailing growth of JE vectors

When assessing risk in regions that are prone to JE, meteorological and human factors are crucial. In order to reduce the morbidity and mortality rate linked to JE, this will alert the healthcare system to guarantee the best possible planning and resource allocation. Thus viral encephalitis has turned out to be a major worldwide catastrophe that has destroyed numerous economies and claimed many lives. It has been an important topic among researchers nowadays all around the world and numerous strategies required to fight the virus is being developed. Many nations are conducting extensive research to better understand the virus and develop countermeasures. Due to intense efforts, JE has been all but eradicated in the majority of nations within the past 40 years following vaccination. The only appropriate method to lower the frequency of disease is through personal protection since treatment techniques are lacking. The only known preventive method for JEV transmission is mosquito control. Much more extensive JEV research is required, including the creation of potent antiviral medications and vaccination plans. In locations where JE is common, vaccination is required. Avoiding overusing vaccines is advised to prevent the virus from becoming resistant to medications that are given regularly. International immigration and emigration points should conduct quarantine checks in order to prevent the spread of viruses among visiting foreign nationals. A vector control program ought to be created in such a way as to effectively manage the danger posed by vectors. In order to raise awareness among the local population and confront them with hygiene management and preventive measures, general awareness camps should be held in rural areas. It is imperative that scientists, molecular biologists, physicians, drug developers, policy officials, and the local populace work together to implement a systematic and combinatorial strategy. This situation must be addressed with a sense of urgency. AWDI techniques are used in this study to identify the knowledge gaps in understanding how environmental factors modulate JE vector populations as well as rice grain quality and production.

Under these perspectives, a three-year (2020-2022) long field experiment was conducted with monsoon rice to evaluate the efficiency of AWDI technique in providing a holistic ecosystem service for sustaining rice productivity, improving soil quality, experimenting water use efficiency, and controlling the growth of JE larval population in a typical alluvial tract under rice based cropping system. In this study the variability in one response of two rice cultivars to AWDI technique has also been assessed for the first time.

AWDI facilitates rice fields with intermittent wet and dry condition, availing only the moist condition of soil during rice growing stages. For half of the world population mostly Asian subcontinents, rice is the staple food and availability of fresh water for rice cultivation is decreasing day by day, while demand for rice is increasing[24]. In India, especially Assam, lowland rice cultivation is traditionally popular and there has been a growing demand for rice production due to increasing population and rise in economic standards of farmers. It has been observed that extensive lowland rice cultivation is leading to dearth of fresh water for irrigation and has affecting overall rice grain yield in various regions of Assam including Sonitpur. This thesis work is focused on application of AWDI technique in commonly practiced low land rice cultivation in Gotlong village, under Bihaguri near Tezpur University, that helps in keeping the rice fields saturated with water during the growing phase and increases rice grain yield at maturity. Literature review shows that lowland rice yield by using ADWI method is higher than conventional irrigation methods, and irrigation is performed with a minimum amount of fresh water[47]. The main goal of the study is to manage freshwater consumption and increase lowland rice yield by applying AWDI method in the study area. This thesis work has helped in identifying the environmental factors that influence grain quality and yield in relation to nutrient content and their effect on cultivable land by applying AWDI method.

Research Gap

On outlook of the scarcity of data and facts the following grey areas have been identified:

1. Identification of most important JE vector in the study area.
2. Epidemiological evaluation of JE affected cases and characterization of the major JE vector species
3. Although AWDI as water saving method is well documented in other countries, physico chemical change of soil and water environment of rice field due to application of AWDI method need focused research efforts.
4. Reports AWDI as a vector control tool in JE prone area of Assam is scarce in the literature

Key questions

Grounded on the above stated research lacunae, the following key questions were formulated

1. What are the local JE vectors that breed in rice agro-system?
2. Are the breeding opportunities created in the irrigated area likely to contribute significantly to the overall vector abundance and disease transmission level?
3. Is AWDI effective against the target vector?
4. Is AWDI compatible with local agricultural practices?

Considering these variables, the current study was designed with the following hypothesis and study objectives.

Hypothesis 1: Occurrence of JE is confined to rural agricultural areas. Temperature, humidity and rain fall pattern influences the growth and development mosquito vector. Thus it influences the transmission of the disease.

Objective 1: Epidemiological profiling of Japanese Encephalitis (JE) disease and evaluation of environmental factors influencing JE vector ecology in the targeted study area.

Hypothesis 2: Application of alternate wetting and drying technique lowers water consumption while increasing productivity.

Objective 2: Application of eco-technical AWDI practices in indigenous rice cultivation systems to mitigate vector breeding across spatiotemporal scales.

Hypothesis 3: Application of alternate wetting and drying technique in low land rice field can reduce the growth of adult mosquitoes.

Objective 3: Efficiency evaluation of AWDI as a vector management strategy in rice agro ecosystems.

Research Plan

The complete study has been categorized into three major phases, as described below:

Phase 1: The first phase encompasses the study of mosquito density which will reveal the most abundant mosquito vector of JEV in the study area. Furthermore, the study also includes the spatiotemporal scenario of occurrence of the disease in that locality.

Phase 2: The framework of the second phase assesses the effect of environmental factors on growth and development of three most important vectors of Japanese Encephalitis which favors to breed in paddy cultivation.

Phase 3: The third phase is application of AWDI in rice field. It's influence on yield quality and soil and water environment. It also assesses AWDI as vector control strategy.

References

[1] Sun, C. Q., Fu, Y. Q., Ma, X., Shen, J. R., Hu, B., Zhang, Q., Wang, L. K., Hu, R., and Chen, J. J. Trends in temporal and spatial changes of Japanese encephalitis in Chinese mainland, 2004–2019: A population-based surveillance study. *Travel Medicine and Infectious Disease*, 60, 102724, 2024. https://doi.org/10.1016/j.tmaid.2024.102724

[2] Chambers, T. J., Hahn, C. S., Galler, R., and Rice, C. M. Flavivirus genome organization, expression, and replication. *Annual Review of Microbiology*, 44, 649–688, 1990 https://doi.org/10.1146/annurev.mi.44.100190.003245

[3] Johnston, L. J., Halliday, G. M., and King, N. J. Langerhans cells migrate to local lymph nodes following cutaneous infection with an arbovirus. *The Journal of Investigative Dermatology*,114(3),560–568,2000. https://doi.org/10.1046/j.1523-1747.2000.00904.x

[4] Monath, T. P., Cropp, C. B., and Harrison, A. K. Mode of entry of a neurotropic arbovirus into the central nervous system. Reinvestigation of an old controversy. *Laboratory Investigation; A Journal of Technical Methods and Patholog*, 48(4),399–410, 1983.

[5] Dropulić, B., and Masters, C. L. Entry of neurotropic arboviruses into the central nervous system: an in vitro study using mouse brain endothelium. *The Journal of Infectious Diseases*, 161(4),685–691, 1990.

[6] Tiwari, S., Singh, R. K., Tiwari, R., and Dhole, T. N. Review article Japanese encephalitis : a review of the Indian perspective. *Brazilian Journal of Infectious Diseases*, 16(6),564-573, 2012. https://doi.org/10.1016/j.bjid.2012.10.004

[7] Solomon, T., Kneen, R., Dung, N. M., Khanh, V. C., Thuy, T. T., Ha, D. Q., Day, N. P., Nisalak, A., Vaughn, D. W., and White, N. J. Poliomyelitis-like illness due to Japanese Encephalitis Virus. *Lancet*, 351,1094–7, 1998. https://doi.org/10.1016/S0140-6736(97)07509-0

[8] Solomon, T., Vaughn, D. Clinical features and pathophysiology of Japanese

encephalitis and West Nile virus infections. In: McKenzie JSB, AD, Deubel V, editors. Japanese encephalitis and West Nile viruses. *New York: Springer-Verlag,* 171–194, 2002. DOI: 10.1007/978-3-642- 59403-8_9

[9] Solomon, T., Dung, N. M., Kneen, R., Thao, leT. T., Gainsborough, M., Nisalak, A., Day, N. P., Kirkham, F. J., Vaughn, D. W., Smith, S., and White, N. J. Seizures and raised intracranial pressure in Vietnamese patients with Japanese encephalitis. *Brain: A Journal of Neurology*, *125*(5),1084–1093,2002. https://doi.org/10.1093/brain/awf116

[10] Diagana, M., Preux, P. M., and Dumas, M. Japanese encephalitis revisited. *Journal Of The Neurological Sciences*, *262*(1-2),165–170,2007. https://doi.org/10.1016/j.jns.2007.06.041

[11] Goddard, J., Varnado, W.C., and Harrison, B. An annotated list of the mosquitoes (Diptera: Culicidae) of Mississippi. *Journal of Vector Ecology*, 35,79-88, 2010. https://doi.org/10.1111/j.1948-7134.2010.00062.x

[12] Goddard, J., Waggy G., Varnado, W.C. and Harrison, B. A. Taxonomy and ecology of the pitcher-plant mosquito, Wyeomyia smithii, in Mississippi. Proceedings of Entomological. Society Wash. 109,684 688, 2007. https://onlinelibrary.wiley.com/ doi/ pdf/10.1111/j.1948-7134.2010.00062.x

[13] Phukan, A. C., Borah, P. K., and Mahanta, J. Public health Japanese Encephalitis in Assam, Northeast India. *Southeast Asian Journal of Tropical Medicine and Public Health,* 35(3), 618-622, 2004.

[14] Sunish, I. P., and Reuben R. Factors in influencing the abundance of Japanese encephalitis vectors in ricefields in India - II . Biotic. *Medical and Veterinary Entomology*, 154(16),1-9, 2002. https://doi.org/10.1016/j.fcr.2013.08.016

[15] Roger, P. A. and Kurihara, Y. Flood water biology of tropical wetland rice fields. *Proceedings of the First International Symposium on Paddy Soil Fertility, December,University of Chiang Mai, Thailand*, 275-300, 1988.

[16] Sunish, I. P., and Reuben, R. Factors influencing the abundance of Japanese

encephalitis vectors in ricefields in India--I.Abiotic. *Medical and veterinary entomology*, *15*(4), 381–392, 2001. https://doi.org/10.1046/j.0269-283x. 2001. 00324.x

[17] Kanojia, P. C., Shetty, P. S., Geevarghese, G. A long-term study on vector abundance and seasonal prevalence in relation to the occurrence of Japanese encephalitis in Gorakhpur district, Uttar Pradesh. *Indian Journal of Medical Research*, 117-104, 2003.

[18] Barzaga, N. G. A review of Japanese encephalitis cases in the Philippines (1972–1985). *Southeast Asian Jpurnal of Tropical Medicine and Public Health*, 20,587–592, 1989.

[19] Jennifer Keiser, Michael F. Maltese, Tobias E. Erlanger , Robert Bosc, Marcel Tanner , Burton H. Singer, J. U. Effect of irrigated rice agriculture on Japanese encephalitis, including challenges and opportunities for integrated vector management. *Acta Tropica*, 95(1),40-57, 2005.

[20] Amerasinghe, F. P. Irrigation and mosquito-borne diseases. *Journal of Parasitology*, 89,14-22, 2003.

[21] Erlanger, T. E., Weiss, S., Keiser, J., Utzinger, J., and Wiedenmayer, K. Past , Present , and Future of Japanese Encephalitis. *Emerging Infectious Diseases, www.cdc.gov/eid*, 15(1),1-7, 2009.

[22] Kabilan, L., Rajendran, R., Arunachalam, N., Ramesh, S., Srinivasan, S., Samuel, P. P., and Dash, A. P. Japanese encephalitis in India: an overview. *Indian Journal of Pediatrics*, *71*(7), 609–615, 2004. https://doi.org/10.1007/BF02724120

[23] Li, Y. H., Barker, R., Loeve, R., Li, Y.,Tuong, T. P. Li, Y. H., Barker, R., Loeve, R., Li, Y., and Tuong, T. P. Water saving irrigation for rice. Proceedings of an International Workshop on Water Saving Irrigation for Rice, March 23–25, 135-144, 2001. https://econpapers.repec.org/RePEc:iWt:cOnprc:h02923.

[24] Talukdar, O., Bhattacharya, S. S., and Gogoi, N. Alternate wet and dry irrigation

technology as a sustainable water management and disease vector control tool. *Environmental Quality Management*, 33(1), 23-42, pp 20, 2022. DOI: 10.1002/tqem.21935

[25] Bhuiyan, S. I., and Tuong, T. P. Water use in rice production: Issues, research opportunities and policy implications. Inter-Center Water Management Workshop. International Irrigation Management Institute. *World Health Organization*, 1995. https://cir.nii.ac.jp/crid/1570009750096822 .

[26] Ishfaq, M., Farooq, M., Zulfiqar, U., Hussain, S., Akbar, N., Nawaz, A., and Anjum, S. A. Alternate wetting and drying: A water-saving and ecofriendly rice production system. *Agricultural Water Management*, 241,106363, 2020.

[27] Van der Hoek, W., R. Sakthivadivel, M. Renshaw, J.B. Silver, M.H. Birley, and Konradsen, F. Alternate Wet/Dry Irrigation in Rice Cultivation: A Practical Way to Save Water and Control Malaria and Japanese Encephalitis? In: *Int. Water Management Inst*, Res. Rep., 2001.

[28] Tuong, T. P., Bouman, B. A. M., and Mortimer, M. More rice, less water—integrated approaches for increasing water productivity in irrigated rice based systems in Asia. *Plant Production Science*, 8, 231–241, 2005. https://doi.org/10.1626/pps.8.231.

[29] Shao, C.G., Deng, S., Liu, N., Yu, E.S., Wang, H.M., and She, L. D. Effects of controlled irrigation and drainage growth, grain yield and water use in paddy rice. *European Journal of Agronomy*, 53, 1–9,2004 https://doi.org/10.1016/j.eja.2013.10.005 .

[30] Xiang J, Haden VR, Peng S, Bouman B. A. M, Visperas R. M., and Huang J, C. K. Improvement of N availability, N uptake and growth of aerobic rice following soil acidification. *Soil Science Plant Nutrition*, 55,705–714, 2009. DOI:10.1111/j.1747-0765.2009.00407.x.

[31] Murphy, B. W. Impact of soil organic matter on soil properties—a review with emphasis on Australian soils. *Soil Research*, *53*, 605-635, 2015. Retrived from https://www.semanticscholar.org/paper/Impact-of-soil-organic-matter-on-soil-

properties%E2%80%94a-Murphy/e3714d3112be19901c87ec4d71fcdd87b5e6cf3b

[32] Sandhu, N., Subedi, S. R., Yadaw, R. B., Chaudhary, B., Prasai, H., Iftekharuddaula, K., Thanak, T., Thun, V., Battan, K. R., Ram, M., et al. Root traits enhancing rice grain yield under alternate wetting and drying condition. *Frontiers in Plant Science*, 2017. DOI:10.3389/fpls.2017.01879

[33] Abrol, I. P., Bhumbla, E. R., and Meelu, O. P. Influence of salinity and alkalinity on properties and management of rice lands. *Soil Physics and Rice*, International Rice Research Institute, Los Baños, Philippines , 430, 1985.

[34] Carrijo, D. R., Lundy, M. E., Linquist, B. A. Rice yields and water use under alternate wetting and drying irrigation: a meta-analysis. *Field Crops Research*, 203, 173–180, 2017. https://doi.org/10.1016/j.fcr.2016.12.002 .

[35] Yang, C., Yang, L., Yang, Y., Ouyang, Z. Rice root growth and nutrient uptake as influenced by organic manure in continuously and alternately flooded paddy soils. *Agricultural Water Management*, 70,67–81,2004. https://doi.org/10.1016/j.agwat. 2004.05.003.

[36] Nhan, P.P., Hoa, L.V., Qui, C. N., Huy, N. X., Hữut, T., Macdonald, B. C., and Tường, T. Increasing profitability and water use efficiency of triple rice crop production in the Mekong Delta, Vietnam. *The Journal of Agricultural Science*, 154(6), 1015–1025, 2016. https://doi.org/10.1017/S0021859615000957

[37] Xiao, W., Ye, X., Yang, X., Li, T., Zhao, S., and Zhang, Q. Effects of alternating wetting and drying versus continuous flooding on chromium fate in paddy soils. *Ecotoxicology and environmental safety*, 113, 439–445, 2015. https://doi.org/10.1016/j.ecoenv.2014.12.030 .

[38] Kassam, A., Stoop, W., and Uphoff, N. Review of SRI modifications in rice crop and water management and research issues for making further improvements in agricultural and water productivity. *Paddy and Water Environment*, 9(1),163-180, 2011.

[39] Timsina, J., Connor, D. J. Productivity and management of rice-wheat cropping system: issues and challenges. *Field Crop Research*, 69, 93–132, 2001. https://doi.org/10.1016/S0378-4290(00)00143-X .

[40] Ye, Y., Liang, X., Chen, Y., Liu, L., Gu, J., Guo, R., and Liang, L. Alternate wetting and drying irrigation and controlled-release nitrogen fertilizer in late-season rice. Effects on dry matter accumulation, yield, water and nitrogen use. *Field Crops Research*, 144,212–224, 2013. DOI: 10.1016/j.fcr.2012.12.003

[41] Dong, N. M., Brandt, K. K., Sorensen, J., Hung, N. N., Hach, C. V., Tan, P. S., and Dalsgaard, T. Effects of alternating wetting and drying versus continuous flooding on fertilizer nitrogen fate in rice fields in the Mekong Delta, Vietnam. *Soil Biology and Biochemistry*, 47, 166–174, 2012. https://doi.org/10.1016/j.soilbio.2011.12.028

[42] Linquist, B.A., Anders, M.M., Adviento- Borbe, M.A.A., Chaney ,R.L., Nalley, L.L., Da Rosa, EF., Kessel, C. Reducing green house gas emissions, water use and grain arsenic levels in rice system. *Global Change Biology*, 21(1),407-417, 2015. https://doi.org/10.1111/gcb.12701

[43] Rabha, B. Status of irrigation in assam for seasonal paddy cultivation. *The International Journal of Analytical and Experimental Modal Analysis*, 11(10),1341, 2019.

[44] Talukdar, K.C. and Beka, B. C. Cultivation of summer rice in the flood plains of Assam An assessment of economic potential on marginal and small farms,. *Agricultural Economics research Review*, 18(1),21-38, 2005.

[45] Victor, T.J. and Reuben R. Effects of organic and inorganic fertilisers on mosquito populations in rice fields of southern India. *Medical and Veterinary Entomology*, (14),361-368, 2008.https://doi.org/10.1046/j.1365-2915.2000.00255.x

[46] Zhang, Y., Tang, Q., Peng, S., Xing, D., Qin, J., Laza, R.C. and Punzalan B.R. Water use efficiency and physiological response of rice genotypes under alternate wetting and drying conditions. *The scientific world journal*, 2012.

[47] Bouman, B. A. M., Humphreys, E., Tuong, T. P., and Reuben, B. Rice and water. *Advances in Agronomy*, 92(04), 187–237. 2007. https://doi.org/10.1016/S0065-2113(04)92004-4.