# CONTROL OF JAPANESE ENCEPHALITIS VECTORS BY ALTERNATE WET AND DRY IRRIGATION TECHNIQUE OF MONSOON RICE FIELDS: A CRITICAL ASSESSMENT IN SEVERELY AFFECTED AREAS OF SONITPUR DISTRICT, ASSAM, INDIA

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# Chapter 7

## SUMMARY AND CONCLUSION

In Sonitpur, the agricultural and tea garden areas provide ideal and conducive breeding conditions for mosquitoes, facilitating the spread and development of Japanese encephalitis (JE). The favorable physical conditions (rainfall, temperature, humidity, surface water, vegetation cover, etc.) and socio-economic conditions (poor surveillance activities and their coverage, improper planning and management in the health sector) have substantially contributed to the growth and diffusion of JE incidence in the district. Knowledge about the nature and ecology of the dispersal of JEV vectors needs to be increased. This present study mechanistically explores the eco-biology of JEV vectors and the mode and frequency of occurrence of Acute Encephalitis Syndrome (AES) and JEV infestations. We used linear regression to study the impact of environmental variables on JEV infestation by *Culex tritaeniorhynchus*, *Culex vishnui*, and *Culex pseudovishnui*.

From epidemiological data and experimental findings, it is confirmed that JEV infections were prevalent from April to November but highly significant in the hot-wet period, that is, July to September (summer season). Rainfall events, temperature, and humidity influenced the relative density of JEV vectors and JE and AES cases. Additionally, evaluation of the lag effect revealed that the climatic factors were positively associated with human JE cases and delayed JE infection by a lag period of 1–3 months known as the lag effect; regular monitoring of temperature, rainfall, and humidity will help in extending the period of JE infections. Therefore, this investigation successfully traced the causal agents, mode, and rate of occurrence of JE infection and confirmed the impact of meteorological factors on JE epidemics. It is emphasised that further research on JEV and JE vectors will support healthcare institutions and sensitise people about the eco- epidemiology of JE.

JEV infestation dominated near rainfed ricefields. JEV infestation was found to be concentrated in adult male residing near rice fields (15.66%). Modulations in temperature and rainfall patterns over the years shifted the breeding period of *Culex vishnui*. There is a tendency for a rise of JEV load in JE hotspot regions, especially near rice fields. Thus, comprehensive epidemiological investigations can help prevent a silent outbreak of JEV. This study revealed that monthly total rainfall was the most significant factor determining JEV transmission in the study area compared to the monthly minimum temperature. Therefore, high rainfall would enhance the growth of the virus in an amplifying host as well as vector and thus accelerate the transmission of JEV. *Culex vishnui* primarily depends on rainfall, which coincides with the inundation of the rice fields, compared to *Culex tritaeniorhynchus* and *Culex pseudovishnui*. However, transmission of JEV is very complicated, and detailed ecological and epidemiological studies are still needed to assess the local risk.

It is established that JEV vectors prefer to breed in rice fields where they get standing water, optimum temperature, humidity, and sunlight. The National Programme for Prevention and Control of Japanese Encephalitis/Acute Encephalitis Syndrome by the Government of India identified several risk factors for JE outbreaks, including the high density of Culex mosquitoes and paddy cultivation. Populations residing close to paddy fields are particularly susceptible to JEV infection due to the favorable breeding conditions for mosquitoes that these areas provide. This situation emphasizes the crucial link between agricultural practices and vector density, highlighting the need for effective control measures to mitigate the risks associated with JEV.

The AWDI can be applied in paddy fields to control mosquito vectors in their breeding habitats. This method is recognized as environmentally friendly and cost-effective, requiring no special arrangements for implementation. However, despite its benefits, Indian farmers often hesitate to adopt AWDI due to a lack of awareness regarding its advantages. It has been observed that the implementation of AWDI leads to a significant decrease in yield compared to traditional farming practices, raising concerns among farmers who primarily focus on yield-related benefits. A comparative study using the two commonly cultivated rice varieties, B11 and Ranjit sub 1, showed both positive and negative influences on yield due to the adoption of AWDI, necessitating further investigation into the parameters affecting these results.

The temporal changes in soil moisture content across three years clearly illustrate the impact of treatment on moisture levels, as evidenced by significant statistical findings ($p_T < 0.05$, LSD=0.209). The moisture content observed for B11 ranged from 24.34% to 39.13%. For Ranjit sub1, moisture content fluctuated between

18.14% and 27.24%. Irrespective of the treatment, soil moisture content demonstrated a notable decline during the flowering stage (P3), followed by a recovery during the maturation phase (P4). In the first year under AWDI treatment, the lowest moisture content recorded was 10.37% in B11 and 17.13% in Ranjit sub1 at growth phase 3 (P3). The second year exhibited a continued decline in soil moisture content through phase four (P4), reaching 22.41% in B11 and 21.27% in Ranjit sub1.The third year showed a decreased moisture content right after AWDI was implemented in phase two (P2), with values recorded at 20.2% in B11 and 19.02% in Ranjit sub1.The application of AWDI was crucial in regulating the water supply within the rice cultivation system, ensuring that only the physiological water needs were met. The observed fluctuations in soil moisture content throughout the growth phases across the three years could be attributed to varying amounts of rainfall experienced during the study period, as well as the timing of AWDI application. Throughout the study, variations in soil moisture content were influenced by the frequency and intensity of rainfall events. For instance, periods of extended dryness followed by substantial rainfall significantly affected soil moisture retention and availability, illustrating that the soil's response to rainfall is closely linked to prior moisture conditions and rainfall characteristics.

Thus, present study showed that using AWDI significantly reduces soil moisture supply, resulting in lower moisture content during specific growth phases, emphasizing the treatment's effectiveness while highlighting the influence of environmental factors like rainfall on overall moisture content dynamics.

The application of AWDI during the early vegetative stage has shown beneficial effects on soil pH dynamics. Initially, the soil pH was slightly acidic in both varieties of the studied crops, gradually shifting towards neutral to basic conditions in later growth phases. This transition indicates that AWDI may facilitate a more optimal environment for plant development by promoting a favorable soil pH. The application of AWDI did not significantly change soil pH values ($p_T>0.05$), suggesting that this irrigation technique may help maintain a stable pH level rather than causing drastic fluctuations. Stabilizing pH is crucial, especially in preventing the extreme saturation often associated with continuous flooding, which can lead to detrimental anaerobic soil conditions. Intermittent drying associated with AWDI promotes the oxidation of organic matter, thereby enhancing nutrient availability and contributing to a pH alignment towards neutrality. AWDI has been observed to improve microbial activity within the soil, which is an essential factor for practical nutrient cycling. Increasing microbial populations can improve soil structure and fertility, fostering an environment conducive to plant growth. This positive microbial response contributes to achieving a more stable and suitable pH environment for crops. The irrigation method not only supports plant water needs but also plays a role in improving soil health.

The soil organic matter (SOM) analysis presented in the provided data encapsulates the variations observed over three years (2020-2022) within different treatments and growth stages. The significance of the treatment effects, as indicated by the P-value of less than 0.05, reinforces the importance of managing soil organic matter content for enhanced agricultural productivity. The SOM content exhibited noticeable fluctuations across the years. In 2020, SOM ranged from 2.05% to 3.98%. In 2021, it ranged from 1.98% to 3.48%. In 2022, the range was from 2.9% to 3.87%.The active vegetative growth phase and panicle initiation stages (P2) increased SOM content primarily due to heightened plant biomass. In the late vegetative growth stage under the AWDI field in Ranjit sub1, SOM is 3.86% (2020), 3.48% (2021), and 3.65% (2022). In the Flowering and grain-filling stage (P3), the highest SOM content was recorded in B11 at 3.98% (2020), with subsequent values of 3.4% and 3.87% in 2021 and 2022, respectively. A comparative analysis reveals that SOM content was lower at the grain maturation stage (P4) than at both the flowering and grain filling stages (P3). An increase in SOM appears to correlate directly with plant biomass; thus, enhanced biomass generally leads to increased SOM levels.

The yearly increase in SOM across different treatments shows 2.98% in B11 and 2.7% in Ranjit sub1 in the first year. Under traditional practice, 2.21% were in B11 and 2.35% in Ranjit sub1. In the second year, both varieties exhibited a 2.48% increase in SOM under AWDI treatment, contrasting with 2.21% (B11) and 0.22% (Ranjit) under traditional practices. The third year saw lesser increments of 0.60% under AWDI, 0.25% under traditional practice in B11, 0.25% under AWDI, and 0.22% under traditional practice in Ranjit sub1. The results underscore that SOM increases more pronouncedly in B11 than in Ranjit sub1 under AWDI treatment. Different treatments significantly affect soil organic matter (SOM) levels during the active vegetative growth stage. Increased plant biomass during this phase correlates with higher SOM content, indicating that management practices that enhance biomass can improve SOM.

At the panicle initiation stage, treatments significantly influence SOM levels. For instance, the SOM content increased notably under AWDI treatment, with values reaching 3.86% in Ranjit sub 1 during 2020. This suggests that appropriate treatment applications can substantially improve SOM during critical growth phases, resulting in more robust plant growth and productivity. The late vegetative growth stage also exhibited significant variations in SOM influenced by different treatments. Higher biomass production at this growth stage typically results in increased SOM levels, further supporting the notion that practices promoting plant growth benefit SOM enhancement. The AWDI treatment, in particular, produced remarkable increases in SOM compared to traditional methods, demonstrating the effectiveness of modern agronomic practices. The flowering stage sees significant changes in SOM as influenced by treatments. It was observed that the highest SOM content in treatment B11 peaked at 3.98% during this period, while traditional practices yielded lower SOM levels. This increased SOM during flowering is beneficial as it enhances root development and nutrient uptake, which are crucial for sustaining plant health and productivity during later growth stages. Significant changes in SOM are recorded during the grain-filling stage, driven by the effectiveness of different treatments. B11 treatment again demonstrated the highest increase in SOM, showcasing the variability in plant response to different agronomic practices. However, SOM levels were lower during this stage compared to the flowering phase, indicating a possible decline in SOM as crop development transitions toward maturity. SOM content was generally lower during grain maturation than in previous stages, revealing the intricate relationship between plant developmental phases and SOM dynamics. In both B11 and Ranjit sub1 varieties, only slight increases in SOM were observed under traditional practices, highlighting that they might be less effective in maintaining SOM during maturity than other treatments.

Overall, a clear association exists between the selected treatments and SOM increases throughout various growth stages. Higher SOM levels correlate with improved biomass production, root development, and, ultimately, better crop yields, showcasing the importance of tailored soil management practices in agriculture. This comprehensive assessment of soil organic matter dynamics is crucial for refining agricultural strategies to enhance soil health and productivity. Continued monitoring and management of SOM will benefit sustained farming practices and improved crop yields.

The data presented for nitrate nitrogen reflect the variations in soil mineral nitrogen, particularly the nitrate-nitrogen component ($NO_3$-N), across different growth stages of crops. This report emphasizes the significant impacts of various treatments and environmental factors on the soil $NO_3$-N content throughout the rice growing season. The analysis shows that the treatment significantly influenced soil $NO_3$-N levels, demonstrating a consistent pattern of variation during the entire crop growth period. Notably, the highest recorded soil $NO_3$-N content occurred at phage 1, which can be attributed to applying nitrogenous fertilizers. Under AWDI, for B11, $NO_3$-N levels fluctuated between 428.53 to 975.26 kg $ha^{-1}$; for Ranjit sub1, the levels ranged from 429.11 to 975.26 kg $ha^{-1}$. Despite this initial boost, soil $NO_3$-N content gradually decreased towards the later phages. Additionally, fluctuations in $NO_3$-N content were noted, influenced by the effect of the AWDI. The data further illustrate some specific trends. A significant decrease in $NO_3$-N content was observed in phage 2. This decrease was followed by an increase in phase 3, after which another decrease occurred in the subsequent phases. These patterns were also consistent in the following stage, underscoring a recurring trend in the nitrogen dynamics.

Applying nitrogenous fertilizers and managing irrigation are critical factors affecting nitrate-nitrogen dynamics in soils. The evidence highlights the necessity of monitoring these variables to optimize crop growth and nitrogen utilization efficiently. This study also focused on available soil phosphorus content over three consecutive years, from 2020 to 2022, across different treatments and crop varietals. Irrespective of treatment, P content ranged between 25.34 kg $ha^{-1}$ to 36.24 kg $ha^{-1}$ in 2020, 23.01 to 32.3 kg $ha^{-1}$ in 2021, and 24.14 to 32.63 kg $ha^{-1}$ in 2022 in B11. In Ranjit sub1 in the first year, it was recorded between 23.12 to 34.32 kg $ha^{-1}$; in the second year, 20.83 to 35.32 kg $ha^{-1,}$ and in the third year, it ranged between 21.59 to 34.32 kg $ha^{-1}$ at different crop growth stages. A significant increase in phosphorus content was observed at each crop growth stage, indicating the responsiveness of soil phosphorus to differing agricultural practices. The availability of phosphorus showed a statistically significant change due to the application of AWDI, with a p-value of less than 0.05 ($p_T<0.05$) and the LSD noted at 0.37. Climatic factors such as rainfall and temperature fluctuations significantly impact phosphorus levels through their effects on soil moisture and microbial activity. Increased rainfall can cause runoff and erosion, leading to nutrient losses, including phosphorus. Temperature changes influence microbial processes in the soil, which can alter phosphorus availability and cycling.

In summary, the data indicate that the B11 and Ranjit Sub1 varietals exhibit variable phosphorus availability, which is influenced by numerous factors, including treatment application. These findings underscore the importance of phosphorous management in optimizing soil fertility and crop yield.

The treatment applied to the soil did not result in any statistically significant changes in potassium content during the cropping period, indicated by the p-value ($p > 0.05$). This suggests that the variations observed were likely due to natural fluctuations rather than the imposed treatments. The LSD value is reported as 18.33. This metric is essential for determining the minimum difference required to deem the treatments statistically different. The analysis indicates that, on average, the potassium content was highest in Phase 1. From Phase 1 to Phase 3, there is a gradual decline in potassium content. However, contrary to this declining trend, potassium levels are observed again in Phase 4, signifying a potential recovery or nutrient accumulation at this later stage of crop growth. This change is statistically significant ($p_T < 0.05$), indicating that the increase in potassium content in Phase 4 is noteworthy.

In current study, treatment applications did not significantly affect soil potassium content and notable trends were observed throughout the growth phases, highlighting a seasonal pattern of potassium availability. Continued monitoring and further analysis might be beneficial to understand better the implications of these trends on crop health and yield. During Phase 4, the increase in potassium content can be attributed to enhanced crop uptake, as plants continue to assimilate potassium from the soil solution even during maturation. This uptake is crucial for the development of seeds and overall plant health, contributing to elevated potassium levels observed at this stage. The decomposition of crop residues can also significantly increase soil potassium levels during Phase 4. As organic matter breaks down, it releases potassium into the soil, enriching the nutrient supply available for the current crop. Weather conditions, particularly moisture availability, significantly affect potassium dynamics in the soil. Adequate rainfall during Phase 4 may have enhanced the movement of potassium to plant roots, facilitating better nutrient absorption and higher potassium concentrations. Applying potassium fertilizers during the cropping period can contribute to increased potassium content in the soil. Research indicates that adding potassium fertilizers can raise exchangeable potassium levels significantly, positively impacting soil fertility and bolstering plant uptake. The interaction between potassium and other nutrients, particularly phosphorus, can influence potassium availability. Balanced fertilization strategies that include phosphorus may also promote better potassium uptake by crops during Phase 4, leading to improved potassium levels in the soil.

The treatment effects on soil zinc content were significant, with a p-value of less than 0.05. The LSD was determined to be 0.18. Both varieties examined showed a significant decrease in zinc content due to the application of AWDI. A notably lower zinc content was recorded at P3 for both varieties, with a significance level of $p_T < 0.05$. Throughout various growth phases, the zinc content in the soil ranged from 6.03 to 9.04 µg $g^{-1}$.

The application of AWDI has significantly reduced soil zinc levels.Varieties experienced a similar decline, indicating a potential systematic response to the treatment. Monitoring specific growth phases (notably P3) is crucial for understanding the extent of zinc depletion.

The soil's copper (Cu) content was significantly influenced by both time and the irrigation method. The findings indicate a notable decrease in copper content as a result of the implementation of AWDI, with statistical significance determined by a threshold of ($P < 0.05$) and a LSD value of 0.03. Irrespective of treatment, Cu content ranged from 0.38 to 0.58 µg $g^{-1}$ in 2020, 0.39 to 0.57 µg $g^{-1}$ in 2021, and 0.35 to 0.67 µg $g^{-1}$ in 2022 in B11. In Ranjit sub1, Cu content ranged between 0.30 to 0.87 µg $g^{-1}$ in 2020, 0.30 to 0.86 µg $g^{-1}$ in 2021, and 0.30 to 0.83 µg $g^{-1}$ in 2022. This data illustrates the fluctuation of copper levels in soil over three years, highlighting the impact of irrigation methods on metal content in soil. Further investigation may be necessary to explore the underlying mechanisms contributing to these variations. However, it is established that soils with higher OM content may have low copper availability because

OM can immobilize copper quickly. Soil microorganisms also influence copper cycling; some microbes can aid in mineralizing copper from minerals or organic matter and make them available for absorption, while others can directly promote copper immobilization.

This report provides a detailed analysis of the manganese (Mn) content affected by the application of treatment (AWDI) over three years. The data indicates variable effects of the treatment on different varieties and years, with notable statistical implications. The application of treatment (AWDI) significantly influenced Mn content in the first two years ($p<0.05$, LSD= 0.01). However, there was no significant impact recorded in the third year ($p>0.05$, LSD= 0.36). An improvement in Mn content was explicitly noted in the B11 variety ($p<0.05$). Conversely, no significant effect of treatment was observed under the Ranjit sub1 variety ($p<0.05$, LSD= 0.02). Irrespective of treatment, Mn content ranged from 0.01 to 0.34 µg $g^{-1}$ in B11 in 2020, 0.01to 0.34 in 2021, and 0.03 to 0.57 in 2022. Whereas in Ranjit sub1 it ranged between 0.01 to 0.2 µg $g^{-1}$ in 2020, 0.034 to 0.34 in 2021 and 0.38 to 0.47 in 2022. In phase 4, the Mn content was consistently found to be below the detection limit of the instrument for all three years of the study.

The lack of significant impact on manganese (Mn) content in the third year could stem from changing soil conditions that affect Mn availability. Factors such as soil pH, moisture, and organic matter content can influence how much Mn is accessible to plants. For instance, higher soil pH might reduce Mn solubility, making it less available despite treatment application. Soil OM content can impact manganese levels because OM can bind to manganese and affect the cycling of essential nutrients. Soils with high OM content may have higher levels of plant-available manganese. Plant uptake of nutrients, including Mn, can also vary over time due to physiological changes in the plants. By the third year, the plants may have reached a physiological state that affects their ability to absorb Mn efficiently. Additionally, if earlier Mn treatments were sufficient, this might lead to less necessity for uptake in subsequent years. Environmental conditions such as rainfall and temperature fluctuations could influence both soil moisture and nutrient availability during the third year. The third year might have experienced conditions that were less favorable for nutrient absorption, wet soils that can induce deficiencies. Understanding the interplay of these factors can aid in addressing the reasons behind the diminished effect on Mn content observed in the third year.

The study on soil respiration yielded a range in the values of carbon dioxide ($CO_2$) emissions, specifically between 17.98 and 48.34 $CO_2$ per gram per hour throughout the study period. There was a statistically significant increase in the rate of soil respiration attributable to the application of AWDI with a p-value of less than 0.05. The LSD value was 0.26, indicating a meaningful effect. The Ranjit Sub1 exhibited notably higher soil respiration rates when AWDI was applied, again with a p-value of less than 0.05 and LSD value of 0.06. In conventionally cultivated fields, the maximum rate of soil respiration occurred at P2. In contrast, fields treated with AWDI revealed that the peak rate of respiration was observed during P3, maintaining a significance level of $p<0.05$. These results suggest that the application of AWDI not only enhances soil respiration but also that different cultivars may respond uniquely to such applications.

Further investigation into the underlying mechanisms and long-term effects of AWDI on soil health may provide additional insights. Soil composition plays a crucial role in influencing soil respiration rates, with factors such as soil depth and nutrient levels being significant contributors. In conventional cultivation, the respiration rates are influenced by organic matter decomposition, while the AWDI management enhances respiration through improved microbial and root activity. Soil moisture is another significant factor affecting soil respiration rates. Optimal moisture levels can enhance microbial activity, resulting in increased respiration rates, whereas insufficient moisture limits activity and consequently reduces rates. Conversely, excessive moisture can lead to low oxygen availability, inhibiting decomposition processes. Microbial activity is a critical determinant of soil respiration rates, with higher respiration typically observed in conventional systems compared to AWDI systems. Conventional practices often lead to increased carbon loss to the atmosphere as microbes prioritize maintenance over growth due to less favorable conditions. In contrast, AWDI promotes higher microbial biomass and efficiency, which can enhance soil health. The amount of root biomass significantly impacts soil respiration, with increased root biomass correlating with higher respiration rates. Healthy plants contribute to this effect by enhancing microbial activity through root exudates that serve as food sources for soil microbes, which ultimately increases $CO_2$ emissions from the soil. Management practices associated with cultivation methods also impact soil respiration. Conventional methods, often involving continuous flooding, can negatively affect soil properties and microbial activity, thus reducing respiration. In contrast, AWDI promotes aerobic conditions, which improve microbial growth and enhance soil respiration rates by increasing dissolved oxygen levels and stimulating enzymatic activities related to nitrogen transformations.

The study presented compelling evidence showing that significantly higher K uptake occurs in rice plants under AWDI conditions, with a statistical significance of for varying data points. The maximum observed uptake in 2022 showed further improvement, with LSD value of 1.33. This implies that the AWDI method optimizes nutrient absorption, which is critical for rice cultivation, particularly under conditions of limited water availability. AWDI has been helpful in increasing root proliferation in rice plants, which is critical for enhanced nutrient and water uptake from the soil. Studies similar to this one have documented increased root growth rates due to the application of AWDI, linking improved soil aeration to enhanced root dry weight. This relationship suggests that effective irrigation strategies not only promote root growth but also facilitate overall plant health by allowing for more efficient absorption of essential nutrients.

N uptake varied significantly among different crop variants, with the B11 variant showing a range of 84.35 to 107 kg $ha^{-1}$, while the Ranjit sub 1 variant displayed a broader range of 64.53 to 113.35 kg $ha^{-1}$ before treatment. Following treatment with AWDI, these values increased substantially, with B11 reaching between 98.32 to 193.58 kg $ha^{-1}$ and Ranjit sub 1 rising to 118.12 to 208.91 kg $ha^{-1}$.

This increase in N uptake can be attributed to the enhanced root development, which facilitated better nutrient absorption from the soil and improved transportation from roots to shoots and grains. The substantial improvement in N uptake likely stems from enhanced and healthier root growth emanating from applied supplements. Healthier roots promote greater soil exploration, resulting in better availability of nitrogen and other essential nutrients. Moreover, these abundant roots encourage efficient absorption, enabling plants to secure necessary carbohydrates and nutrients for growth and reproduction. The results are consistent with findings from previous studies where root health was significantly correlated with nutrient uptake

The measured P uptake values in the rice varieties indicate a considerable range. For the variety B11, phosphorus uptake was observed between 62.83 to 84.27 kg $ha^{-1}$, while Ranjit sub1 showed a higher uptake range of 52.50 to 97.56 kg $ha^{-1}$under the same irrigation methods. Notably, across the treatments, Ranjit sub1 demonstrated consistently higher phosphorus uptake, ranging from 144.95 to 179.32 kg $ha^{-1}$ compared to B11's uptake of 95.79 to 151.13 kg $ha^{-1}$ under AWDI practices.

The enhanced phosphorus uptake in Ranjit sub1 can be attributed to its superior root growth compared to B11. Healthy and extensive root systems contribute to increased availability and efficient absorption of nutrients from the soil. Additionally, effective transport mechanisms ensure that these absorbed nutrients are conveyed efficiently from the roots to the shoots and grains, subsequently leading to improved plant growth and grain yields.

The analysis of nutrient uptake, particularly of zinc (Zn), copper (Cu), and manganese (Mn), reveals significant variability among different treatments when employing alternating wet and dry irrigation (AWDI). The outcomes underscore the complex relationship between irrigation methods and nutrient availability in rice plants.

Notable decrease in Zn uptake was exhibited by ANOVA analysis across various treatment groups ($p_T < 0.05$, LSD = 0.60), contradicting findings from other studies, such as those by Wang et al. (2014), who reported increased Zn uptake under AWDI conditions. The present study observed that Zn uptake ranged from 0.36 to 0.54 kg $ha^{-1}$ in the B11 rice variety, while the Ranjit sub1 variety reported a range from 0.44 to 0.64 kg $ha^{-1}$.

Across all treatments, Zn uptake for B11 was observed between 0.29 to 0.44 kg $ha^{-1}$, and between 0.39 to 0.55 kg $ha^{-1}$ for Ranjit sub1. Such outcomes suggest that the AWDI methodology significantly influences Zn bioavailability and uptake rates in rice.

The decrease in Zn uptake could be attributed to the temporary water stress that rice plants experience during dry cycles inherent to AWDI, leading to reduced nutrient availability in the soil. Furthermore, as soil pH increases in aerobic conditions, the overall nutrient availability diminishes, adversely affecting the uptake of Zn and potentially other micronutrients. This relationship highlights the critical balance between irrigation techniques and optimal nutrient conditions for rice cultivation.

Similar patterns of nutrient uptake were observed for Cu, with significant differences noted in ANOVA results ($p_T< 0.05$, LSD = 0.09). Irrespective of the irrigation treatment, Cu uptake was predominantly higher in the Ranjit sub1 strain compared to B11. Notably, the harvest index (HI) of Cu also demonstrated a significant decrease related to the treatment effects ($p_T < 0.05$, LSD = 0.18), indicating a possible correlation between nutrient uptake and irrigation management. These findings imply that the availability of Cu in the soil may be substantially influenced by water management practices.

Regarding Mn, a significant decrease was observed in uptake ($p_T < 0.05$, LSD = 1.90), with corresponding declines in the HI of Mn due to treatment effects associated with AWDI. The decreased uptake of Mn appears to be related to its availability in the soil, reinforcing the trend seen with both Zn and Cu. Statistical analysis showed a robust correlation ($r = 0.846$, $p< 0.01$) between Mn uptake and overall nutrient availability, further emphasizing the critical role of soil management practices

The implications of applying AWDI practices in rice cultivation encompass significant challenges in nutrient management, specifically concerning the availability and uptake of essential micronutrients like Zn, Cu, and Mn. The variations in nutrient uptake suggest a need for careful monitoring and adjustment of irrigation methods to optimize crop health and yield. Future research may focus on developing strategies that enhance nutrient availability under AWDI conditions to mitigate the adverse effects on micronutrient uptake in rice crops.

The application of AWDI has shown an increase in yield across both B11 and Ranjit sub1 varieties. While traditional irrigation yields range from 4066.11 kg $ha^{-1}$ to 5633.33 kg $ha^{-1}$ for B11, and 5068.75 kg $ha^{-1}$ to 5716.66 kg $ha^{-1}$ for Ranjit sub1, the ANOVA analysis indicates a statistically significant increase ($p_T<0.05$, LSD=55.36) in yields when employing AWDI. This increase is attributed primarily to the controlled drying phase inherent to the AWD cycle, which optimizes irrigation efficiency and enhances growth.

The study underscores the importance of understanding soil moisture dynamics in managing potassium availability effectively. By recognizing how phases of moisture influence K solubility and uptake, agricultural practices can be optimized to enhance crop yield and nutrient efficiency. Future investigations should continue to focus on the direct relationship between moisture levels and potassium dynamics to develop precise management strategies for soil fertility.

Moreover, significant improvements in harvest indices for potassium, phosphorus, and nitrogen were recorded, reflecting the AWDI's positive influence on nutrient efficiency within the crop ecosystem. Yet, while increases in micronutrient uptake (such as zinc and copper) were anticipated, the findings showed an unpredicted decline in zinc and copper uptake, possibly due to soil pH effects during aerobic conditions created by AWDI.

Significant increase in grain filling was evident due to treatment effect ($p_T<0.05$, LSD=6.30). Irrespective of treatment, grain filling ranged between 68.85 to 74.62 % in B11 and 70.97 to 79.38 % in Ranjit sub 1 with maximum grain filling rate in Ranjit sub 1 rice ecosystem (Figure 5.4.2). There was approximately 8 to 24 % increase in grain filing percentage in B11 and 6 to 24% increase in grain filing percentage in Ranjit sub 1 due to AWDI ($p_T<0.05$). Grain filling rate is directly related to spikelet sterility. Present outcomes agreed with the findings of Chu et al. (2018)[58]. AWDI implications increased grain filling rate significantly which is attributed to increased root oxidation activity, photosynthetic rate (flag leaf) and activity of sucrose-to-starch conversion enzymes[37]. ·This report presents an overview of key metrics observed during a recent study focusing on grain filling percentage, total filled grains, sterile spikelets, and tiller number. The statistical analyses employed include ANOVA to determine significant differences across treatments.

The mechanisms through which AWDI boosts grain yield—especially under moderate soil dryness—remain largely unexplained. However, established relationships indicate that a higher number of fertile tillers and increased grains per panicle directly correlate with enhanced grain yields. Current inquiries suggest a need for more detailed research to elucidate the interactions between grain-filling processes and vegetative development under AWD conditions.

The treatment of AWDI significantly improved grain filling in rice varieties, as indicated by substantial statistical results. In particular, the grain filling rates demonstrated an increase ranging from approximately 8% to 24% for the B11 variety and 6% to 24% for the Ranjit sub 1 variety under AWDI conditions ($p_T<0.05$). The maximum grain filling rates were particularly evident in the Ranjit sub 1 ecosystem, which exhibited grain filling percentages between 70.97% and 79.38%. This increase is crucial as grain filling rate is directly correlated to spikelet sterility, with AWDI managing to decrease sterility significantly, showcasing its efficiency in enhancing rice crop productivity

The reduction in spikelet sterility was noteworthy, ranging from 30.70% to 26.97% over the years due to AWDI. The study's findings affirm previous research, which posited that AWDI not only decreases panicle sterility but also facilitates superior root development through improved oxygen availability during drying phases. Moreover, the AWDI technique has been shown to enhance the microenvironment essential for reproductive development, thus contributing positively to plant health and yield.

Protein content varied significantly between the two rice varieties under study, reflecting the nutritional benefits gained from AWDI treatment. The B11 variety's protein concentration ranged from 6.64% to 8.45%, which is comparatively lower than the Ranjit sub 1 variety, where protein levels were recorded between 10.68% and 16.06%. This difference underscores the varying genetic potentials of rice varieties. Furthermore, both varieties exhibited increased protein levels due to better nutrient uptake facilitated by AWDI. Enhanced nutrient availability resulted from the intermittent drying cycles which stimulated higher nutrient uptake, corroborating findings from previous studies.

Carbohydrate analysis further revealed advantages linked to AWDI practices. Grain carbohydrate content ranged from 20.6 mg/ml to 29.2 mg/ml for the different varieties, with significant increases noted at $p<0.05$ for AWDI applications. This enhancement in carbohydrate synthesis can be attributed to deeper root systems that AWDI encourages, which allows rice plants better access to essential water and nutrients needed during the crucial grain filling period.

The data collected on the Leaf Area Index (LAI) during the late vegetative growth phase offers insightful analysis on the growth performance of two rice varieties: B11 and Ranjit sub1. The maximum LAI was observed during the flowering stage, after which there was a noticeable decline.Irrespective of treatment, the LAI ranged between 3.37 to 4.11 in B11 and 4.43 to 5.34 in Ranjit sub1 during the study period. The findings indicate a statistically significant increase in LAI for both rice varieties over the three-year study period, with a p-value less than 0.05 and LSD of 0.27. This suggests that the variations observed are of practical significance rather than due to random sampling error. Notably, irrespective of treatment conditions, Ranjit sub1 consistently exhibited the highest values of LAI.

This study underscores the superiority of the Ranjit sub1 variety in terms of its LAI, providing valuable data for further agricultural research and potential cultivation practices. The increased LAI in both varieties highlights the importance of careful management during the late vegetative growth phase, particularly approaching the flowering stage.

The observation suggests that there was no significant change in chlorophyll content due to treatment effects, as indicated by a p-value greater than 0.05 and LSD value of 0.002. The chlorophyll content fluctuated between 0.01 to 0.07 mg $g^{-1}$ during the study period, reflecting a possible stabilization in chlorophyll levels throughout the treatments.

It appears that the plants did not experience water stress due to limited water availability in the AWDI system. This irrigation method involves cycles of alternating wet and dry conditions, which can benefit plant health by increasing soil aeration during dry periods. In general, aeration of soil during the drying phases is critical for ensuring proper oxygen availability to roots, which is essential for root respiration and overall plant vitality. Sufficient oxygen levels in the root zone facilitate efficient chlorophyll synthesis, underscoring the importance of the AWDI strategy in promoting plant health.

The recorded plant heights at various crop growth stages reveal notable differences based on the treatment applied. In the B11 variety, plant height ranged from 102 cm to 110 cm. In the Ranjit Sub1 variety, plant height ranged from 96 cm to 98 cm.

In the B11 variety, plant height varied between 121 cm and 130 cm. In the Ranjit Sub1 variety, plant height ranged from 102 cm to 113 cm.A significant decrease in plant height was observed in the AWDI treatment during crop growth stages, with a statistical significance marked at ($p<0.05$) and LSD of 1.06. This reduction in height may indicate a shift in the growth patterns of the plants, characterized by reduced vegetative growth coupled with increased reproductive growth. This information suggests that the different treatment methods influence plant height significantly, which could have implications for crop management and yield outcomes. Further analysis may be required to explore the underlying factors contributing to these growth responses.

The data indicates that AWDI treatment results in a shorter plant height compared to conventional methods, likely due to enhanced reproductive growth at the expense of vegetative growth. This finding highlights the importance of considering growth stages and treatment effects in crop management practices aimed at optimizing yield and plant development.

The implementation of AWDI has resulted in notable advancements in water productivity indices (WPI) for rice cultivation, particularly observed in different varieties of rice. The B11 variety exhibited an increase in WPI ranging from 28.33% to 56.12%, showcasing significant improvement in water efficiency during cultivation. This increase indicates that the B11 variety can benefit substantially from optimized irrigation practices, which not only enhance water conservation but also contribute to overall agricultural sustainability. In comparison, the Ranjit sub 1 variety demonstrated an even more pronounced improvement in its water productivity indices, with increases ranging from 56.68% to 64.59%. This higher percentage suggests that the Ranjit sub 1 variety is particularly responsive to AWDI practices, underscoring its potential as a viable choice for farmers aiming for improved water use efficiency. Such advancements in WPI are crucial for addressing the challenges of water scarcity in agricultural practices, especially in regions reliant on rice as a primary crop. A significant correlation has been established between grain filling rates and water productivity. This relationship emphasizes that enhancing grain filling through effective water management strategies, such as those employed in the AWDI system, could lead to optimal yields. It implies that careful management of water resources not only conserves water but also positively impacts the crop's developmental processes, ultimately improving the economic viability of rice cultivation. The findings regarding the improvements in WPI as a result of implementing AWDI can potentially guide future agricultural practices. By adopting such efficient irrigation methods, farmers can maximize their yields while minimizing water usage, making rice cultivation more sustainable in the long term. The relationship between water management and enhanced yield illustrates the critical need for integrated water use strategies tailored to specific crop varieties within varying environmental conditions. This information underscores the importance of ongoing research and adaptation of irrigation practices in order to optimize crop outputs. As climate change continues to affect water availability, adopting innovative methods like AWDI will be essential for ensuring food security and sustainable agricultural practices in rice cultivation. The current findings highlight AWDI’s role in improving not only rice grain filling and quality but also underline its potential in enhancing nutritional content and water efficiency. Proper management of this irrigation technique could significantly improve productivity across various rice cultivars, thereby contributing positively to food security and agricultural sustainability.

The evaluations of various water quality parameters indicated significant relationships between dissolved oxygen levels, nitrate nitrogen concentrations, inorganic phosphorus, temperature, total dissolved solids (TDS), salinity, pH, leaf area index (LAI), and larval density of *Culex* mosquitoes. The findings highlight the dynamic interactions between agricultural practices and aquatic ecosystem health, particularly regarding mosquito populations.

The mean concentration of dissolved oxygen ranged from 6.82 to 5.78 mg $L^{-1}$, reflecting a stable but slightly declining trend in oxygen levels. A statistically significant positive effect on dissolved oxygen was observed in 2021 ($p<0.05$) across different varieties, though a minor reduction was noted in treatment B11 in 2022. The decrease in dissolved oxygen may be attributed to diminished photosynthetic activity following canopy development. Furthermore, there was no significant correlation between dissolved oxygen levels and *Culex* larval densities ($p> 0.05$; $r = 0.26$), suggesting that other environmental factors might be more influential.

The mean concentration of nitrate nitrogen ($NO_3$-N) varied between 3.62 and 5.82 ppm, with significant differences across treatments ($p<0.05$). Strong positive correlations between $NO_3$-N concentration and mosquito larval stages were observed ($r = 0.919$, $p < 0.01$), indicating that heightened nitrate levels can promote mosquito population growth. Nutrient release into water bodies typically occurs through microbial activity during land preparation, highlighting the ecological implications of appropriate fertilizer management practices.

ANOVA results revealed significant decreases in phosphorus levels due to treatment effects, ranging from 0.42 to 0.75 ppm ($p< 0.05$). A positive correlation ($r = 0.865$, $p < 0.05$) was reported between inorganic phosphorus levels and aquatic mosquito phases, indicating that elevated phosphorus concentrations may facilitate mosquito population growth. Management practices, particularly AWDI, effectively limited phosphorus release, emphasizing the importance of sustainable agricultural techniques to mitigate adverse impacts on aquatic ecosystems.

Mean water temperature varied between 19.26°C and 25.86°C, significantly influencing aquatic ecosystems. A correlation coefficient of 0.441 ($p < 0.05$) highlighted the positive impact of temperature on immature organism abundance. Factors such as air temperature and solar radiation primarily drive floodwater temperature, which has substantial implications for the growth of different algal species.

The average TDS ranged from 24 to 36.30 ppm, with higher concentrations in B11 treatments compared to Ranjit sub1. Statistical analysis indicated significant decreases in TDS levels due to the treatments ($p<0.05$, LSD values: 2.69 in 2021, 0.73 in 2022). A strong correlation ($r = 0.879$, $p<0.01$) between TDS and larval density indicated that higher mineral content could support aquatic life, particularly mosquito larvae.

Salinity levels during the study ranged from 0.31 to 0.92, with significant declines observed due to treatment interventions ($p< 0.05$). Notably, salinity positively influenced larval abundance ($r = 0.707$, $p< 0.05$), reinforcing previous findings about salinity's role in mosquito breeding conditions across varying agricultural practices.

The pH values of paddy field water remained alkaline, ranging from 7.23 to 7.88, with no statistical significance in seasonal differences ($p>0.05$). Importantly, the study reported no correlation between pH levels and larval presence, indicating that other factors may influence mosquito populations more significantly than pH alone.

LAI values ranged between 2.68 and 4.28, demonstrating variations in light interception by crops, which affect growth rates. Statistical analysis revealed a significant impact of treatments on LAI ($p<0.05$), with AWDI methods leading to notable decreases in LAI, particularly during the reproductive stage of rice growth. Despite variations, no significant relationship was observed between LAI and Culex larvae.

The observed Average Larval Density (APD) of *Culex* has shown variability, ranging from 2.42 to 9.12 larvae per dip, indicating significant fluctuations in larval populations across different treatments and environmental conditions. This fluctuation highlights the dynamics of *Culex* populations influenced by various factors, which can be crucial for controlling mosquito breeding sites. Statistical analyses have confirmed a significant decrease in larval density under treatment conditions, with a significance level ($pT< 0.05$) and LSD values of 0.88 for 2021 and 0.69 for 2022, indicating that the treatments implemented effectively reduced *Culex* larval populations across the studied regions.

In the year 2021, significant reductions in larval density were documented: a 61.38% reduction at the B11 treatment site and a 69.77% decrease at Ranjit sub 1. The subsequent year (2022) further demonstrated effectiveness, with reductions of 68.31% at B11 and 72.57% at Ranjit sub 1. These findings suggest that different ecological contexts of the B11 and Ranjit sub 1 sites may influence treatment effectiveness. The analysis of variance (ANOVA) revealed that the treatment effects were significantly more pronounced at the B11 site compared to Ranjit sub 1.

A significant positive correlation was identified between larval densities and several environmental factors, including nitrate nitrogen ($NO_3$-N), temperature, total dissolved solids (TDS), salinity, and phosphorus. This correlation underscores the importance of environmental conditions in determining *Culex* larval population dynamics. The influence of these factors could provide insight into tailoring control measures that are more effective depending on the environmental context.

The APD for specific *Culex sp*. during the study period varied. Notably, *Culex tritaeniorhynchus* showed a reduction of 45.16% in B11 and 64.91% in Ranjit sub 1 in 2021, while for 2022, reductions included 64.70% in B11 and 56.61% in Ranjit sub 1. Furthermore, significant reductions were seen in *Culex pseudovishnui*, with an impressive decrease of 86.58% in B11 in 2021 and 78.86% in 2022. *Culex vishnui* also displayed notable reductions of 75.12% in B11 in 2021 and 66.97% in 2022, highlighting the variable response of different *Culex sp.* to intervention measures.

The effectiveness of these treatments aligns with findings reported by Cao et al. in 2012 in Jiangsu province, where a 72.14% reduction of *Culex tritaeniorhynchus* was noted due to irrigation practices. The current study observed that after periods of drought, as fields were reflooded, *Culex* larvae were still able to survive in residual water pools despite reduced activity to migrate. This behavior may explain why complete eradication of *Culex* larvae from AWDI fields was not achieved, emphasizing the necessity for comprehensive management strategies that account for environmental retention of water.

Significant changes in the overall breeding index (BI) of mosquito larvae were observed as a result of treatment effects, with a statistical significance indicated by $p<0.05$, LSD=0.01. The study particularly noted a significant decrease in breeding index for the species *Culex tritaenorhynchus*, *Culex vishnui*, and *Culex pseudovishnui*, where the thresholds were $p<0.05$ and LSD values were 0.79, 0.82, and 0.19 respectively. Moreover, the effect of treatments was found to be more pronounced in the rice variety Ranjit sub 1 compared to B11, which further demonstrated statistical significance with $p<0.05$. These findings suggest that the larval populations may be influenced by the type of treatment applied and the specific characteristics of the rice varieties used in the study.

The correlation analysis indicated that the breeding index of larvae had a significant positive relationship with several environmental variables. Parameters including nitrate (NO3), temperature, total dissolved solids (TDS), salinity, and phosphorus levels showed strong correlations at a confidence level of less than $p<0.01$.

Additionally, there was a notable positive correlation with plant height observed at a $p=0.05$ level. These relationships suggest that higher levels of these environmental factors may contribute to increased larval breeding activity, highlighting the need for managing such factors in mosquito control efforts.

The implementation of AWDI resulted in a marked decrease in salinity, TDS, temperature, and nitrate content in the water bodies under observation. This reduction in key environmental parameters may contribute to the observed decline in larval populations, particularly in Ranjit sub 1, which experienced a more significant effect than B11. This observation further supports the hypothesis that proper management of water quality is crucial in controlling the breeding of mosquitos, particularly in agricultural settings.

The findings emphasize the importance of both treatment strategies and hydrological management in mitigating mosquito populations. By tailoring mosquito control measures to account for the effects of environmental factors such as salinity, temperature, TDS, and nutrient concentrations, including $NO_3$ and P, it may be possible to enhance the effectiveness of control programs. Additionally, the differential impacts observed between rice varieties underline the potential for using agricultural practices not only for crop productivity but also for integrated pest management strategies.

Significant treatment effects on the breeding index of various *Culex sp*. were documented in the report, with a noticeable improvement in lowering larval populations when specific interventions were applied. The correlation with environmental factors highlights actionable insights for future mosquito control strategies in agricultural contexts, emphasizing the potential roles of both biological and physical water quality management techniques. Further studies are suggested to explore the long-term efficacy of such interventions and the mechanistic pathways influencing breeding indices in mosquito populations.