Chapter 5

Objective 2

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

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5.1. Introduction

The significance of food security and agricultural health are of the vital indicators for attaining SDGs (sustainable development goals) by 2020. A substantial increase in rice cultivation and production has occurred in recent decades as a result of cumulative population growth, especially in the regions where rice is a staple food. Rice cultivation techniques are being explored by agriculturalists and farmers to meet global food security needs. There is an expansion of rice-growing areas primarily in Asia and the African subcontinent[1]. Increasing agricultural production, like rice, in developing countries is dependent on enhancing prevailing cultivation practices, which impacts socio-economic development[2]. Water is a limiting factor in rice production in the conventional rice-growing areas of Asia. According to Guerra et al., (1998)[3], a standing water column of almost 700 to 1500 mm is indispensable for rice cultivation in a single cropping season. Water is lost during evapotranspiration (ET) while maintaining a saturated root zone during the growing season[4][3]. In developing countries, a huge amount of water is consumed in the urban and industrial sectors. This is again increasing the competition for water requirements in the agricultural sector. Regardless of water scarcity, rice cultivation is practiced as a ritualistic tradition to meet the food security as well as the economic security of people depending on rice[5]. This has resulted in overexploitation of water resources, leading to water shortages and environmental degradation. Governments must take appropriate action to ensure sustainable water management and to ensure equitable access to water resources. Practically it will be impossible to assure food security and economic security together without any scientific intervention, mostly in a region like India where there are diverse climatic conditions and population growth is evident in various geographical locations[6]. One possible way to make irrigation water more efficient is intermittent wet and dry conditions, rather than flooded conditions, aiming to avail only the saturated condition of soil during the growing stages of rice plants[7]. This method is widely known as the alternate wet and dry irrigation (AWDI) method. AWDI method is however widely practiced in China, and it has been gaining popularity in Bangladesh also because of its water saving potential particularly during Boro cultivation. Yao et al., (2012)[8] and Carrijo et al., (2017)[9] reported in their study that AWDI system has the potentiality to reduce the use of water by 23-33 %. Das et al., (2016)[10] reported that AWDI can improve quality of grain by lowering total As concentration . According to Tanner et al., 2018[11], this method can lower the amount of mercury in rice grain. Linquist et al., (2015)[12] observed that this can reduce the anthropogenic green house gas (GHG) emission up to 45–90 %. It also has the potentiality to improve water use efficiency (WUE)[13]. AWD irrigation in rice is also found to be efficient in declining insect pest by 92 % and disease infestation by 100 %[14][15]. From literature survey it is seen that AWDI can be very beneficial from sustainable point of view. But in contrast to grain yield, positive result is always not seen. For instance, Yang et al., (2004)[15]; Liang et al., (2016)[16] ; Jabran et al., (2016)[17] reported an improvement in total yield of grain under AWD system in contrast to the continuous flooding system. On the other hand Oliver et al., (2008)[18]; Chu et al., (2018)[19] and Lagomarsino et al., (2016)[20]; reported decrease in grain yield in AWDI system. Except for China, the practice of AWDI in other regions is very limited[21]-[23]. The fluctuation in yield after application of AWDI is due to difference in soil conditions as well as the local environment. It is greatly dependent on the variety of cultivars.

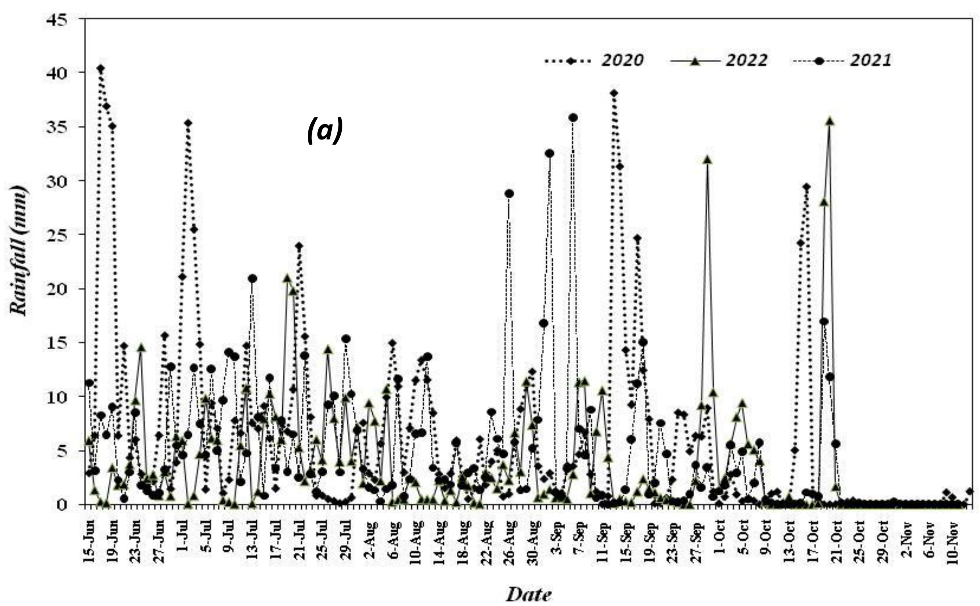
Comprehensive literature review shows that AWDI is not much popular in Indian agricultural system because farmers are not motivated towards experimenting or adopting newer farming techniques. The AWDI method may not be acceptable by farmers which they think that it can reduce the rice yield but studies illustrated that it does not cause any harm to crop yield; rather it can increase the crop yield up to certain extend. Rajendran et al.,(1995)[24] studied the potentiality of AWDI to control mosquito larvae in Tamil Nadu, India. They found an increase in yield also.

Success of AWDI largely depends on the variety of cultivars. Thus, the aim of the study is to examine the physicochemical improvements in soil environment due to application of AWDI at different growth phases of two most popular variety of rice. It will additionally help to optimize the timing of application of fertilizers such that maximum utilization of applied fertilizer could be achieved in rice yield.

5.2. Methodology

5.2.1. Description of experimental sites

Experiments were conducted in the North Bank Plain Agroclimatic Zone, Tezpur, Assam during monsoon, i.e., the rice growing season in Assam (June to November) for three consecutive seasons– 2020, 2021 and 2022. The North Bank Plain Agroclimatic Zone, Tezpur, Assam is located at 26˚ 30′35” and 27˚ 02’ 11” North Latitudes and 92˚19’30” and 93˚47′13” East longitudes with elevation between 73m to 75m. The study site experienced a high rainfall during the study period. The overall rainfall experienced by the study field in 2020 was 922.56 mm with a total of 134 numbers of rainy days. Similarly, in 2021and 2022 the total rainfall was 699.67 mm and 565.78 mm, and total numbers of rainy days were 131 and 126 respectively. The daily rainfall and number of rainy days per month is represented in the figure 5.2.1: (a),(b) experienced by the study site.



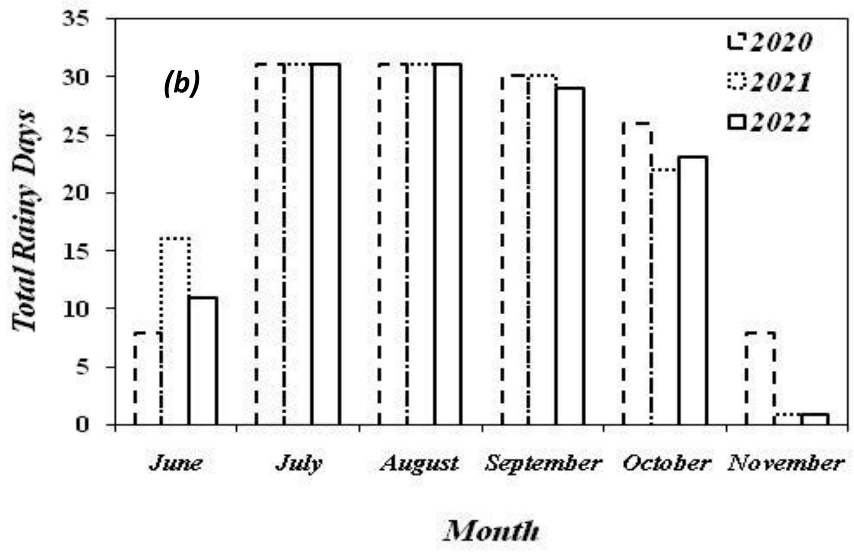


Figure 5.2.1: Distribution of (a) rainfall (mm) and (b) rainy days during the study period(2020-2022)

5.2.2. Description of rice varieties

High yielding rice varieties–Sali, B11 and Ranjit sub 1 were selected for this experiment. B11 is bacterial blight and blast resistant variety. It is a high tillering variety with maximum plant height of 110-115 cm and attains maturity within 110 to 115 days with moderately long grains. Ranjit sub 1 was developed by Assam Agricultural University in 2018, suitable for medium land. It is a submergence tolerant variety that can tolerate submergence up to 2 weeks. It is also suitable for low land and thus, it is a very popular and widely used rice variety in Sonitpur. The average plant height is 115 cm, and it attains maturity within 150-155 days with medium slender type of grains.

5.2.3. Experimental setup

The field was thoroughly ploughed, completely puddled to a depth of 15 cm, and leveled and 12 plots (7 m × 7 m = 14 m^2) were constructed, with a 0.5 m space between each plot. 35-day-old seedlings were transplanted into the experimental plots in June 2020, 2021, and 2022 at a 15x15 cm spacing (plant x row) (Figure 3.3). Two irrigation systems were tested in the experimental field in randomized block design with three replications of each variety. The treatments applied were–1) irrigation at the prescribed application rate (control), which is the traditional technique for both B11 and Ranjit sub 1, 2) controlled irrigation using AWD watering methods in both B11 and Ranjit sub 1.

5.2.4. Water management

In order to maintain 5±2 cm of standing water, irrigation water was applied in the field using the conventional farming method. Following the suggested package of practices for rice farming, there were a total of seven (mean) irrigation episodes over the crop-growing season.

Under AWDI treated plots, rice fields are treated with intermittent flooding and drying instead of keeping them in continuous submerged condition throughout the cropping season. To implement AWDI safely a "field water tube" is used to record the water level in the fields. A model field water tube was developed by International Rice Research Institute (IRRI), Philippines and Institute for Agro-Environmental Science (IAES) using polyvinyl chloride (PVC) water tube having diameter of 10–20 cm, that invigilates water level above the soil surface[25]. These tubes were designed using PVC pipes, having an approximate diameter of 10−20 and 30 cm in length, half of the tube was perforated and remained under the soil and the non-perforated end remains above the ground and water was supplied to individual plots by stable irrigation tubes in each plot. In AWDI rice treatment, irrigation was scheduled according to water levels inside the inserted tubes, i.e., water was applied when soil water reached 15 cm soil depth. Immediately after plantation, the water level was maintained at 5 cm above the soil surface up to 7 days in all the plots, in order reduce the transplanting shock. After 7 days of transplantation, excess water was drained out in AWDI and reirrigated up to 5 cm when crakes appear in soil and water level goes below 15 cm soil depth. However, during rainy days the drains were kept open to channel out the excess rainwater. Conventional method of irrigation was applied as it was practiced by the local farmers, where water table was constantly maintained at 5 to 7 cm, which is reirrigated when water table was seen below 5 cm [Figure 3.4 (a) and (b) of chapter 3, page no.53]. However, during panicle initiation stage the water level was maintained constantly at 5 cm level above soil surface, as it is a sensitive stage in relation to water stress. During the crop growing season there were 4 to 5 irrigation events in AWDI.

5.2.5. Soil physicochemical parameter analyses

In the experimental field with ordinary irrigation, field soils were gathered using a soil auger from three randomly selected places. A composite sample of almost half kg was created by quartering method. Following air drying in the shade, the soil samples were crushed and sieved using a 2 mm sieve. To analyze several soil physicochemical properties, the air-dried soil samples were utilized. After the AWDI treatment, soil samples were also taken at random from various points inside the AWDI experimental plots, ranging in depth from 0 to 15 cm, at various stages of crop growth. In order to preserve the soil moisture, each treatment's three copies of each soil sample were taken and transported to the lab in self-sealing plastic bags. The soil moisture content was determined using fresh soil samples weighing 20 to 30 g. The leftover soil was allowed to air dry for seven days before being sieved (2 mm) as previously mentioned and used for various parameter study.

Soil moisture content (MC) was estimated by gravimetric method which is the simplest and most widely used method for measuring moisture content of soil[26].Soil pH was measured by Handaled Thermo Scientific Multiparameter **S**ystem, Model-STARA3295, which had a single combined electrode. Soil organic carbon (SOC) was estimated using Modified Walkley and Black [27] titration method. Soil respiration was determined by using titration method, where cumulative respiration of both the aerobic and anaerobic microbe present in the sample was measured, that evolves due to microbial metabolism during the decomposition of organic matter present in soil[28]. Exchangeable potassium (K) was measured in a Flame photometer (Systronics Flame photometer 128 µC) following protocol suggested by Black, 1965[29].The estimation of available phosphorus was done by Olsen[30] extraction method when pH of the sample was more than 6 whereas for pH less than 6 the concentration was measured following Bray-Kurt's[31] method. Available soil nitrogen was measured by Alkaline permanganate method using Kel Plus Automatic Nitrogen estimation system (Kelplus, Kelvac VA) and distillation unit (Kelplus, Distyl-EM VA). Soil micronutrients i.e., the bio-available elements were analyzed following the diethylenetriamine pentaacetic acid (DTPA) extraction method of Lindsay and Norvell, (1978)[32] using Atomic absorption spectrophotometer (AAS) and ICP-AE. Water productivity index (WPI) and its calculation are described in methodology section of chapter 3.

5.2.6 Plant and yield related parameters

High yielding Sali rice varieties were grown in this investigation, B11 and Ranjit sub 1. The rice plants were regularly monitored starting from the first day of implantation and morphological characters were systematically observed and noted. Rice plant heights were measured in centimeters (cm) and were assessed from the base to the tip of the longest leaf of every rice plant.

Leaf Area Index (LAI) for each plant's individual leaves was computed by dividing total leaf area (m^2) by ground area (m^2) covered by plant. Leaf area (LA) of rice plant within $1m^2$ area was estimated from the length and breadth of each leaf[33]. The grain filling percentage was calculated by dividing the number of filled grains in a panicle by the total number of grains in the panicle[34]. Five randomly selected panicles from each of the three replications were used to count the total number of grains in each panicle. For each panicle, the grains that were filled and those that were not counted independently. Mature plants were removed from a 1 m^2 area in replicas of each treatment, taking care to avoid the border row. The grain weight was measured and stated in kilograms per hectare following threshing and cleaning[34]. Carbohydrate of grain was determined by phenol disulphonic method of total carbohydrate estimation[35]. Chlorophyll content was measured using spectrophotometric method[27]. The P and K content in plant sample was done by Flame photometric method. Total Nitrogen is estimated by Kjeldahl method as per procedure suggested by AOAC, 1995 and the crude protein was estimated by the following formula:

Crude protein content (%) = *Kjeldahl nitrogen content (%) × 6.25* ………………(31)

Uptake of nutrient by grain and straw was calculated by multiplying concentration (%) of particular nutrient of grain and straw with their respective yield[36] as described in section 3.2.1.9.7, page no. 65.

Micronutrients in plant were estimated by Atomic Absorption Spectro-photometric method of di-acid digestion[32]. Harvest index (HI) is a measure of the distribution efficiency of photosynthetic assimilates to grains, which positively correlated with grain yield nutrient harvest index (NHI) was computed using the formula given below[36]:

Nutrient harvest index (NHI) = $\frac{Uptake\ of\ perticular\ nutrient\ by\ grain}{Total\ uptake\ of\ the\ nutrient\ by\ biomas} \times 100$ ....(32)

5.3 Results and discussion

The study was carried out for three consecutive years, i.e. from 2019 to 2022. In this study, the investigation period was divided into four phonological stages (phases of growth) for the purposes –1) vegetative (phase 1/P1) phase, 2) late vegetative and panicle initiation phase (phase 2/P2), 3) flowering and grain filling phase (phase 3/P3) and 4) grain maturation and harvesting phase (phase 4/P4). The Calendar of agronomic practice in the experimental fields is listed below (Table: 5.1). Basic soil properties of the field are in the table: 5.2

Table 5.1.Calendar of agronomic practice in the experimental fields

Agronomic practice	First year(2020)	Second year(2021)	Third year(2022)
Plantation	23rd June	15th June	20th June
First AWDI	8th August	31st July	5th August
Second AWDI	20th September	12th September	17th September
Third AWDI	10th October	2nd October	7th October
Harvesting	21st November	11th November	16th November

Table 5.2. Basic soil physicochemical properties of experimental field during study period

Sl. No.	Parameters	Year		
		2020	2021	2022
1	**Soil Moisture Content (%)**	34.326±0.95	33.36±0.90	32.69±0.48
2	**Soil Organic Matter (%)**	3.75±0.55	3.65±0.58	3.85±0.62
3	**Available N (kgha^{-1})**	989.03±16.60	969.03±15.60	972.36±7.13
4	**Available P(kgha^{-1})**	24.81±1.56	24.11±1.66	23.78±0.52
5	**Exchangeable K (kgha^{-1})**	437.44±4.23	427.44±4.13	430.77±7.69
6	**Respiration (CO_2gm^{-1}hr^{-1})**	33.70±2.81	32.70±2.61	34.70±1.55
7	**pH**	6.8±0.10	6.4±0.10	6.07±0.67
8	**Cu (µgg^{-1})**	0.53±0.04	0.53±0.04	0.53±0.04
9	**Mn(µgg^{-1})**	0.34±0.01	0.31±0.02	0.29±0.03
10	**Zn (µgg^{-1})**	6.7±0.26	6.2±0.16	5.96±0.54
11	**Sand (%)**	52.34±0.67	54.04±0.93	53.15±1.03

12	**Silt (%)**	17.24±0.34	18.21±0.92	17.15±0.93
13	**Clay (%)**	22.45±0.23	27.13±0.25	28.25±0.56
14	**Bulk density(g cm-^{3})**	1.04±0.01	1.03±0.01	1.04±0.04
15	**Particle density(g cm-^{3})**	1.65±0.03	1.9±0.08	1.76±0.02
16	**Porosity (%)**	50.47±1.02	49.75±1.5	52.72±0.9

The results of physicochemical study of soil are discussed below:

5.3.1. Soil moisture content (MC) (%)

Temporal changes measured during the three years are shown in Figure 5.2.2. There was a significant effect of AWDI on MC of soil in these three years ($p_T<0.05$, LSD=0.209). Irrespective of treatment, soil MC ranged from 24.34% to 39.13% in B11 and from 18.14% to 27.24% in Ranjit sub 1 in the three years. Across the treatment after application of AWDI in both the varieties, sharp decline in soil MC was observed at flowering stage (P3). However, it started to regain some moisture at maturation phase (P4). Under AWDI, during the first year, the soil MC attained a minimum value of 10.37 % in B11, and 17.13% in Ranjit sub 1 during the growth Phase 3(P3) ($p<0.05$). In the second year, decline in soil MC continued till Phase 4 (P4) and measured 22.41% in B11 band 21.27% in Ranjit sub 1 ($p<0.05$). In the third year, decreased soil MC was observed immediately after implementation of AWDI i.e., in phase 2(P2). Soil MC measured 20.2% in B11 and 19.02% in Ranjit sub 1. By controlling the supply of water, the AWDI system ensures that only the physiological water requirements of rice are sufficed[37]. Thus, application of AWDI reduces the water supply and hence the soil MC. However, temporal fluctuation of soil MC in the four growth phases might be due to differences in amount of rain fall and timing of application of AWDI in the three years[38]

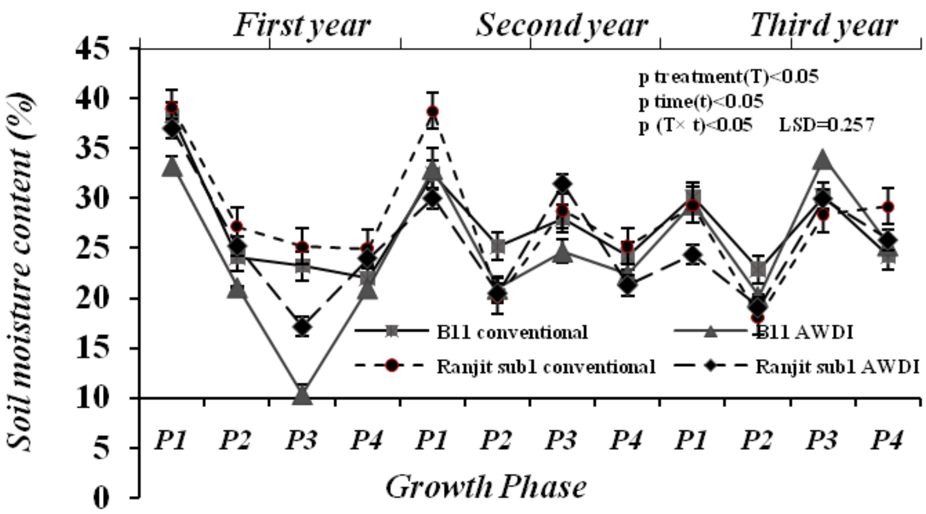


Figure 5.2.2.Variation of soil MC (%) during the growth period. Data are mean±standard deviation (n=3).b P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.2. Soil organic carbon (SOC) (%)

The pooled data of soil organic carbon is presented in figure 5.2.3. Irrespective of treatment the SOC content of the experimental fields ranged from 2.05% to 3.98% in 2020, from 1.98% to 3.48% in 2021 and from 2.9% to 3.87% in 2022 at different crop growth stages. The treatment effect was significant at $p_T < 0.05$ level (LSD= 0.37) in changing the organic carbon (SOC) status of soil. The organic matter content of the experimental field increased in the active vegetative growth phase and panicle initiation stages (P2). During late vegetative growth stage, the SOC at AWDI fields with Ranjit sub 1 were 3.86% in 2020, 3.48% in 2021 and 3.65% in 2022. However, a sharp incline of SOM was recorded at flowering and grain filling stage (P3) in B11. Across the treatment, the highest SOC content at flowering stage was recorded in B11 i.e., 3.98% in 2020 followed by 3.4% and 3.87% in 2021 and 2022 respectively ($p<0.05$, LSD=0.087, LSD= 0.053, LSD= 0.018). Relatively low SOC was observed at the grain maturation stage (P4) than flowering and grain filling stage (P3). SOC content is generally related to plant biomass. SOC increases as the biomass increases. Across the treatment, there was 2.98 % increase in SOC in B11 and 2.7% increase in Ranjit sub 1 in the first year (Figure 5.2.3). However, there is only 2.21% increase in B11 and 2.35% increase in Ranjit sub 1 in the field under traditional practice. In the second year, there was a 2.48% increase in SOC in both the variety under AWDI whereas; under

AWDI treatment there was 2.21% in B11 and 0.22% in Ranjit sub 1 under traditional practice. In the third year, under AWDI fields, there was a 0.60% and 0.25% increase in SOM in B11 and Ranjit sub 1. On the other hand there was 0.25% increase in B11 and 0.22% increase in Ranjit sub 1 in conventional practice (Figure 5.2.3). Interestingly SOC was more evident in B11 than Ranit sub1 with AWDI. Soil organic matter (SOM) content in rice fields fluctuates during different growth phases due to variations in microbial activity, plant growth and decomposition rates, with higher temperatures. Aerobic conditions generally leading to faster decomposition and lower SOM, while anaerobic, flooded conditions can slow down decomposition rate[39]. Therefore, the aerobic condition at latter part might be one of the reasons for increased decomposition activity consequently the low SOM content. During the active vegetative growth stage, different treatments significantly affect the SOM levels. Increased plant biomass during this phase correlates with higher SOM content, indicating that management practices that enhance biomass can lead to improved SOC [39].

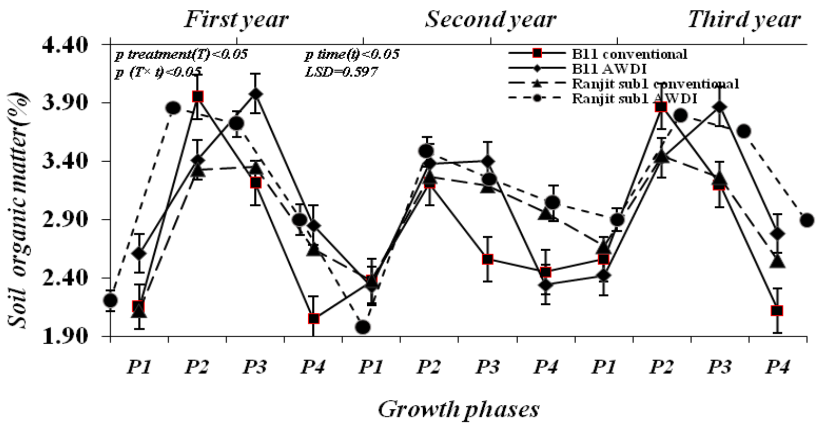


Figure 5.2.3.Variation of soil organic carbon content (%) during the growth period. Data are mean±standard deviation (n=3).P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.3. Respiration (CO_2gm^{-1} hour^{-1})

Soil respiration ranged between 17.98 and 48.34 CO_2 gm^{-1} hour^{-1} during the study period. Significant increase in the rate of soil respiration was observed due to application of AWDI (p_T <0.05, LSD= 0.26) (figure 5.2.4). Soil respiration was found to be more effective in Ranjit sub 1 due to application of AWDI (p_T <0.05, LSD= 0.06). A maximum rate of respiration was observed at P2 in conventionally cultivated field, but in the AWDI fields, maximum rate of respiration was observed during P3(p_t <0.05) (Figure 5.2.4). AWDI allows a brief soil drying period, which can increase the availability of oxygen, especially in the root zone. Increased oxygen availability can stimulate respiration in plant roots and the surrounding soil microorganisms. Soil microbial activity is closely linked to respiration rates. Alternating wet and dry conditions may influence the composition and activity of soil microorganisms, which in turn can affect plant respiration (Kassam , 2011)[40]

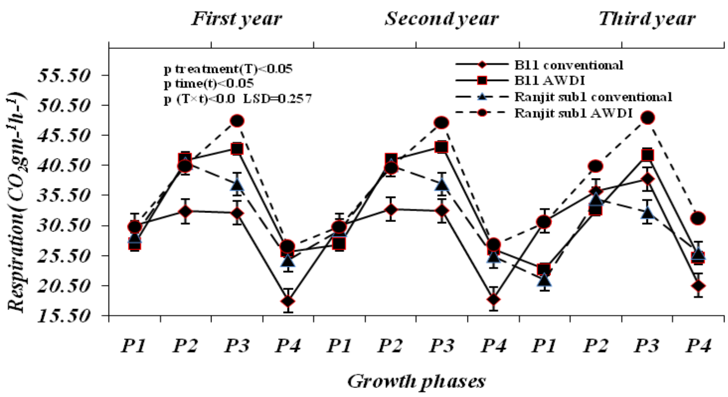


Figure 5.2.4. Variation of soil respiration (CO_2gm^{-1} $hour^{-1}$) during the growth period. Data are mean±standard deviation (n=3).P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.4. Soil pH

During the early vegetative stage, the soil was slightly acidic in both the variety which turned to neutral to basic in later phases. There was no significant change in pH value due to application of AWDI (p_T>0.05) (Figure 5.2.5). AWDI may help to maintain a stable pH level by preventing the extreme saturation that often characterizes continuous flooding conditions. This stabilization occurs because intermittent drying can promote oxidation of organic matter, thereby enhancing the nutrient availability and potentially aligning the soil pH towards neutrality[41]. AWDI contributes to a more favorable soil pH balance as compared to conventional irrigation methods. By enhancing the microbial activity and facilitating effective nutrient cycling, AWDI helps to achieve a more stable and suitable pH environment for plant growth. Ongoing research continues to investigate the long-term implications of this irrigation method on soil health and productivity.

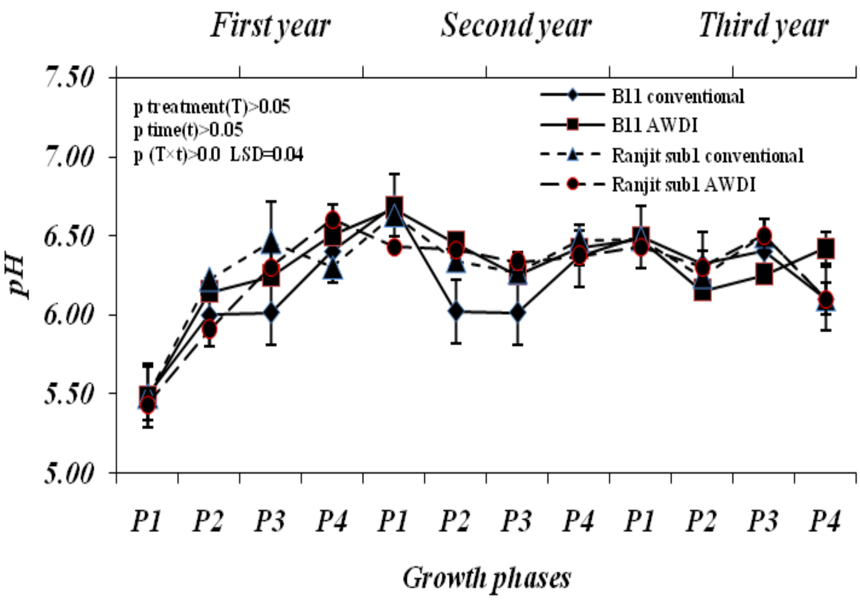


Figure 5.2.5.Variation in soil pH during the growth period. Data are mean±standard deviation (n=3).P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.5. Available Nitrogen (kg ha^{-1})

Soil mineral nitrogen recorded at different growth stages is represented in the Figure 5.2.6. AWDI showed a significant effect on soil NO_3-N during crop growth period. However, soil NO_3-N content resulting from treatment showed similar pattern of variation during the entire rice growing season. Increased soil NO_3-N content was recorded in phase1 which might be due to the application of nitrogenous fertilizers. Irrespective of treatment soil NO_3-N ranged from 428.53 to 975.26 kg ha^{-1} in B11and 429.11 to 975.26 kg ha^{-1} in Ranjit sub 1, which decreases gradually towards later phases. But fluctuation in NO_3-N content was recorded due to effect of AWDI. A significant decrease in NO_3-N content was observed at Phase 2 which later increased in phase3 and again decreased in the phases. A similar pattern was observed in the consequent years. Under control, i.e., conventional irrigation, average NO_3-N content ranged between 423.84 to 868.3 kg ha^{-1} in B11 and 444.77 and 1350.79 kg ha^{-1} in Ranjit sub 1 in 2021, similarly, 438.4 to 942.30 kg ha^{-1} in B11 and 429.41 to 1246.02 kg ha^{-1} in Ranjit sub 1 in 2022. Nitrogen exists in the soil mainly in the organic fraction from which it is continuously mineralized to and immobilized from mineral (ammonium and nitrate) forms by microbial transformations. Under anaerobic conditions, nitrates may be lost as gaseous dinitrogen, or in very strongly reducing conditions, these are converted to ammonium forms. Mineralization responds rapidly to drying but the resulting nitrates are at risk of loss by leaching unless actively absorbed by the roots. Thus, in systems that are frequently wet and dry, there is increase in available N but at the same time there is potential for significant loss of N by leaching and denitrification[42].

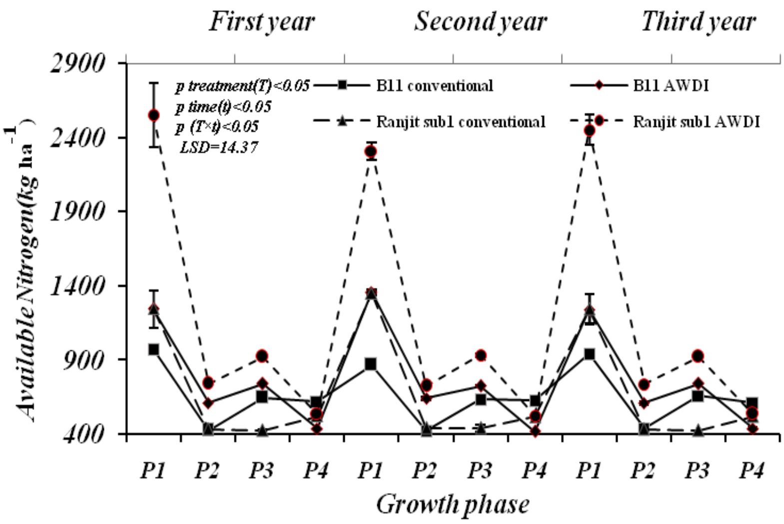


Figure 5.2.6.Variation of soil Available Nitrogen (kg ha^{-1}) during the growth period. Data are mean±standarderror (n=3).P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.6. Soil availablePhosphorus (kg ha^{-1})

The pooled data of available soil phosphorus are presented in Figure 5.2.7. Irrespective of treatment, P content ranged between 25.34 kg ha^{-1} to 36.24 kg ha^{-1} in 2020, 23.01 to 32.3kg ha^{-1} in 2021 and 24.14 to 32.63 kg ha^{-1} in 2022 in B11. In Ranjit sub 1 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. Significant increase in P content at each stage were observed but pooled data indicated a significant decrease in P availability due to application of AWDI (p_T <0.05, LSD=0.37).This is mainly due to the changes in soil moisture levels that influence phosphorus solubility and mobility[41]. The alternating wet and dry conditions can lead to increased soil aeration, which can facilitate the transformation of phosphorus into less available forms, contributing to decreased phosphorus availability. While this irrigation strategy can reduce phosphorus availability due to chemical transformations and microbial interactions, it also encourages practices that require careful management of fertilizer inputs to maintain crop yield. Understanding these dynamics is essential for optimizing irrigation strategies and ensuring sustainable rice production.

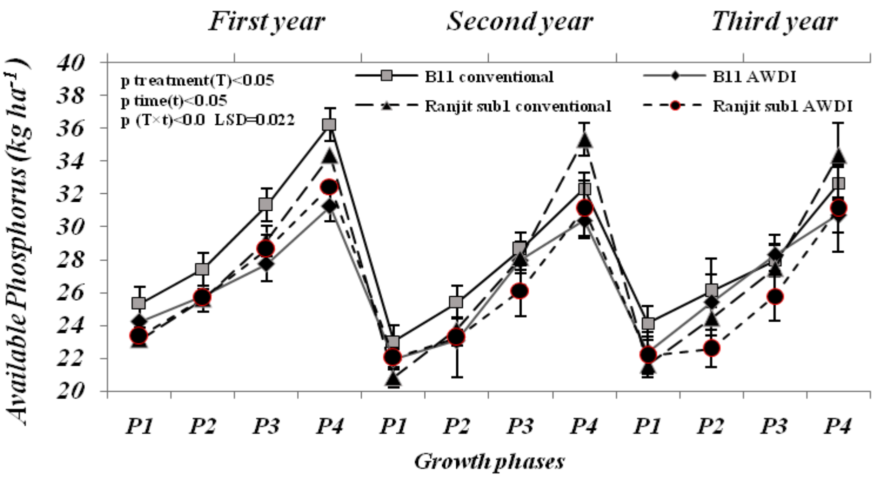


Figure 5.2.7.Variation of soil Available soil Phosphorus (kg ha^{-1}) during the growth period. Data are mean±standard error (n=3).P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.7. Potassium (K) content (kg ha^{-1})

Soil K content recorded at different crop growth stages are presented in Figure 5.2.8. AWDI did not show any significant effect on soil K content during the cropping period ($p_T>0.05$, LSD= 18.33). Across the phases, higher content of K was recorded in Phase 1 which gradually decreases towards Phase 3 but increased in Phase 4 ($p_T<0.05$). This may be due effect of moisture content on K availability. Higher soil moisture usually means greater K availability. AWDI limits the moisture content[43]. AWDI influenced soil K availability through several mechanisms, including changes in soil moisture dynamics, nutrient transport, and microbial activity[44]. During the soil wetting phases, soil moisture is replenished, promoting K solubility and making it more available for plant uptake[45]. Conversely, during the drying phases, soil moisture levels decrease, which can lead to increased K fixation due to higher soil plasticity and changes in the electrochemical environment.

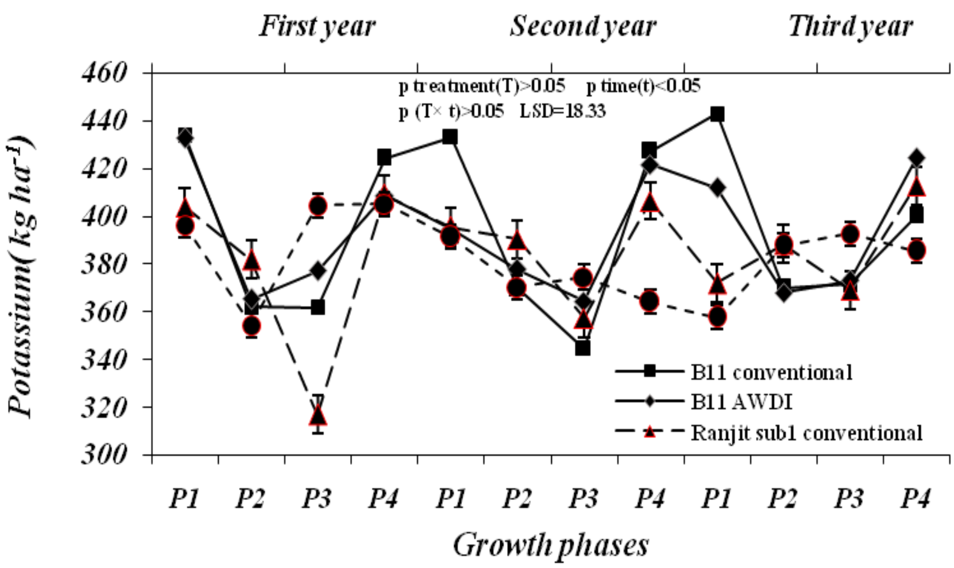


Figure 5.2.8. Variation of soil Potassium content (kg ha^{-1}) during the growth period. Data are mean±standarderror (n=3).P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.8. Soil micronutrients

The results of micronutrient study of soil are discussed below.

5.3.8.1. Zinc (Zn) content (µg g^{-1})

Pooled data of Zn content is reported in the Figure 5.2.9. AWDI effects were found to be significant ($p_T<0.05$, LSD=0.18) in changing Zn status of the field soil. A significant decrease in Zn content was observed in both the varieties due to application of AWDI. Lower Zn content was observed at P3 in ($p_T<0.05$) in both the variety. Zn content ranged between 6.03 to 9.04 µg g^{-1} during different growth phases. One of the primary factors affecting Zn availability in soil is pH. Higher pH (above neutral) levels can lead to reduced Zn availability due to the precipitation of Zn as insoluble compounds[46]. This suggested that AWDI could enhance Zn availability during certain growth stages, particularly when field drying stimulates favorable pH conditions. Soil texture can also influence Zn retention and mobility during AWDI treatment. Sandy soils may have lower Zn retention, while clay soils can hold Zn more effectively[46].

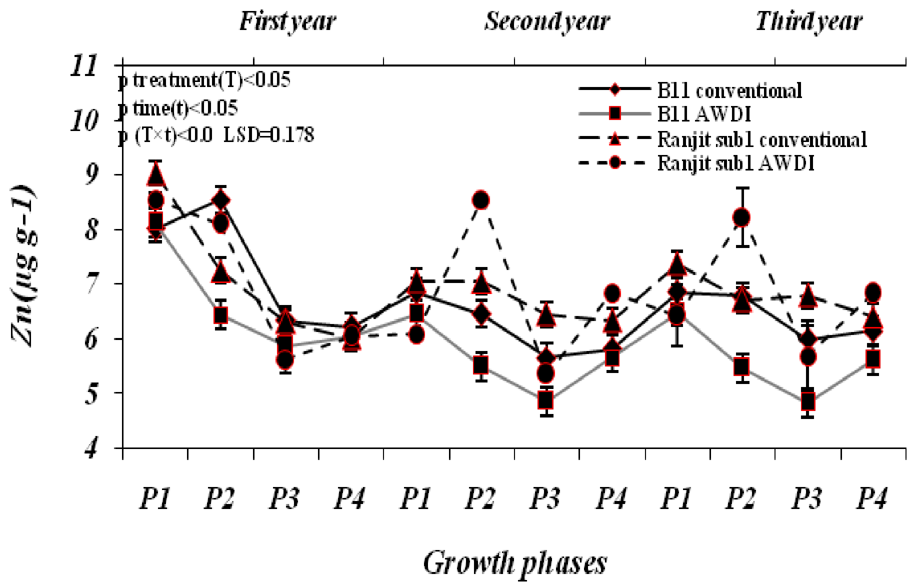


Figure 5.2.9.Variation of soil Zn content(µg g^{-1}) during the growth period. Data are mean±standard deviation (n=3).P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.8.2. Copper (Cu) content (µg g^{-1})

Cu content of soil was significantly affected by time and method of irrigation. A significant decrease in Cu content was recorded in both the varieties due to implementation of AWDI (P_T<0.05, LSD= 0.03) (Figure 5.2.10). Irrespective of AWDI, Cu content ranged from 0.38 to 0.58 µg g^{-1}in 2020, 0.39 to 0.57µg g^{-1}in 2021 and 0.35 to 0.67µg g^{-1}in 2022 in B11. In Ranjit sub 1 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. Soils with elevated organic matter (OM) content often exhibit reduced availability of Cu due to the strong binding and immobilization capacities of organic matter. Organic matter has a high affinity for Cu, making it less accessible for plant uptake[47]. This immobilization can significantly affect the bioavailability of Cu in the rhizosphere, especially in agricultural contexts where organic residues are applied to the soil. Soil microorganisms play a crucial role in Cu cycling within these high-OM environments. Certain bacteria and fungi can facilitate the mineralization process, breaking down Cu-bound minerals or organic matter and converting them into forms that plants can absorb. Conversely, some microbial activities can lead to increased Cu immobilization, further limiting its availability for plant uptake, which has implications for crop growth and health[47].

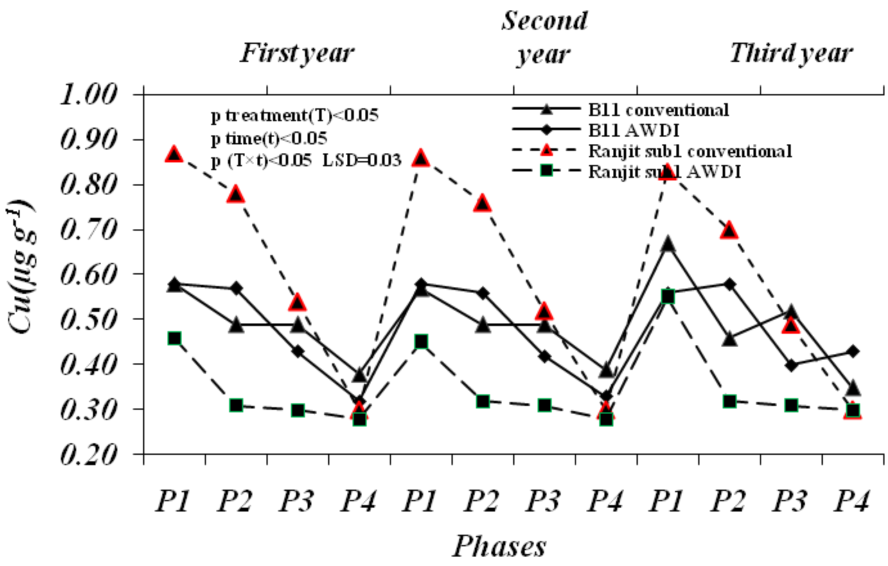


Figure 5.2.10.Variation of soil Cu content (µg g^{-1}) during the growth period. Data are mean±standarderror (n=3).P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.8.3. Manganese (Mn) content(µg g^{-1})

Mn content was significantly affected by application of treatment (AWDI) in first two years ($p_T<0.05$, LSD= 0.01) but not in the third year ($p_T>0.05$, LSD= 0.36). An improvement in Mn content was observed in B11 ($p_T<0.05$) but no significant effect of treatment was recorded under Ranjit sub 1 ($p_T<0.05$, LSD= 0.02). Irrespective of treatment Mn content ranged from 0.01 to 0.34 µgg^{-1} in B11 in 2020, 0.01 to 0.34 in 2021 and 0.03 to 0.57 in 2022. Whereas in Ranjit sub 1 it ranged between 0.01 to 0.2 µgg^{-1} in 2020, 0.034 to 0.34 in 2021 and 0.38 to 0.47 in 2022. However, in phase 4, Mn content was found to be below detection limit of the instrument in all the three years (Figure 5.2.11). Soil OM can impact manganese levels because OM can bind to Mn and affect the cycling of essential nutrients. Soils with high OM may have higher levels of plant-available Mn[48]

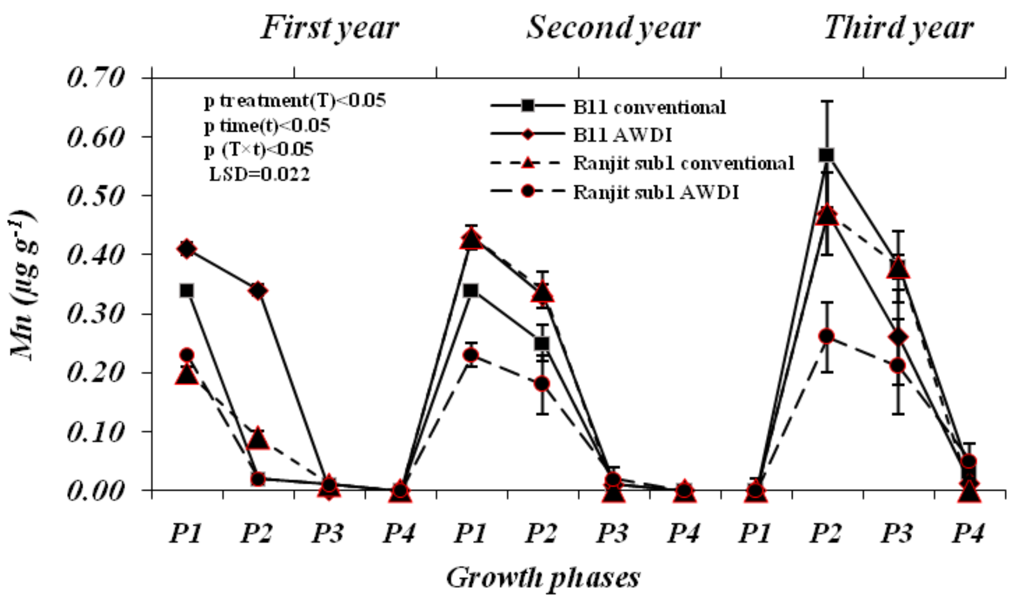


Figure 5.2.11.Variation of soil Mn content (µg g^{-1}) during the growth period. Data are mean±standard deviation (n=3).P1, vegetative phase; P2, late vegetative and panicle initiation phase; P3, flowering and grain filling phase; P4, grain maturation and harvesting phase

5.3.9. Attribute related to growth and development of plant

5.3.9.1. Leaf area index (LAI)

Pooled data of LAI is presented in the Figure 5.3.1. LAI was recorded during the late vegetative growth phase as maximum LAI was attained at the flowering stage after which it started to decline. Irrespective of AWDI, the LAI ranged between 4.70 to 6.65 in B11 and 4.43 to 5.34 in Ranjit sub 1 during the study period. A decreased LAI was evident in both the varieties in all the three years (p_T<0.05, LSD=0.27). Maximum LAI was recorded in B11.

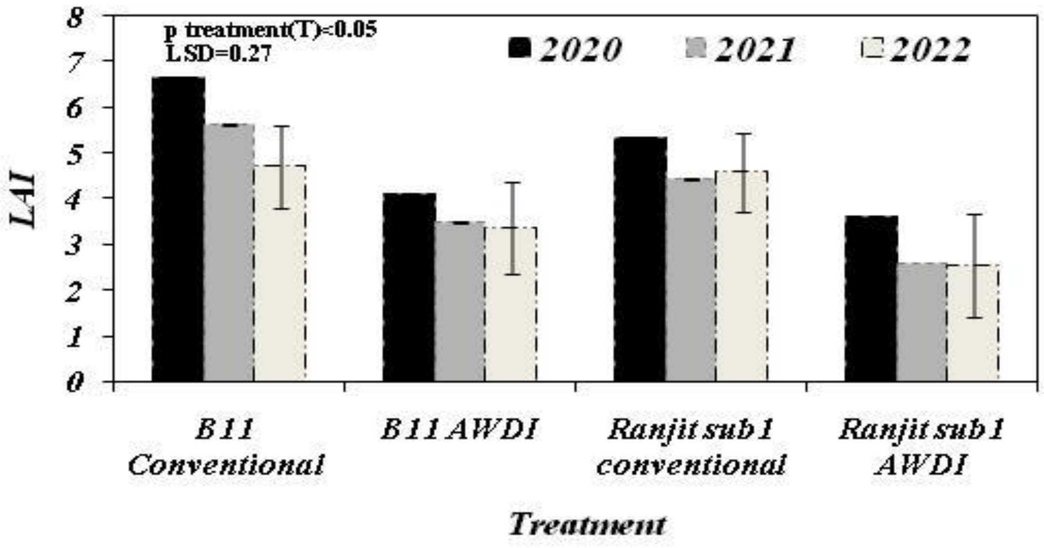


Figure 5.3.1 Temporal variation of Leaf Area Index of rice plant under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean (LAI, leaf area index)

5.3.9.2 Chlorophyll content (mg g^{-1})

Chlorophyll content was not significantly influenced by AWDI (p_T>0.05, LSD= 0.002). However, the chlorophyll content ranged between 0.01 to 0.07 (mg g^{-1}) during the study period. Pooled data of chlorophyll content is presented in the Figure 5.3.2. Decreased chlorophyll levels can indicate biotic stress such as drought[49]. In our study, it seemed that plants did not experience water stress due to limitation of water in AWDI. Evidently, rice plants in AWDI did not experienced water stress during the entire growing season[8]. AWDI involved alternating wet and dry cycles, the soil was aerated during the dry cycle which can led to better oxygen availability for root respiration and overall plant health[50]. Adequate oxygen levels are essential for efficient chlorophyll synthesis. AWDI can maintain optimal soil oxygen levels, thus promoting healthy chlorophyll synthesis and improving overall plant growth[50].

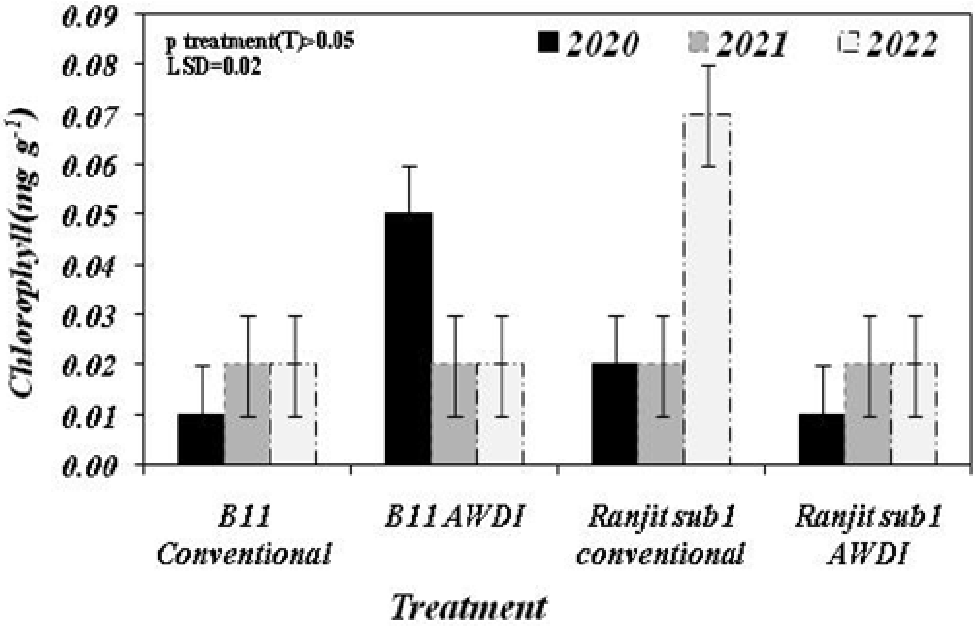


Figure 5.3.2.Temporal variation of chlorophyll (mg g^{-1}) of leaf under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.9.3. Plant height (cm)

The plant height recorded at different crop growth stages are presented in Figure 5.3.3. The plant height in treated plants ranged from 102 to 110 cm in B11 and 96 to 98 cm in Ranjit sub 1 whereas in conventional method it ranged between 121 to 130 cm in B11 and 102 to 113 cm in Ranjit sub 1. A significant decreased plant height in AWDI treatment during crop growth was noticed (p_T<0.05, LSD= 1.06), because AWDI promotes less vegetative growth and more reproductive growth.

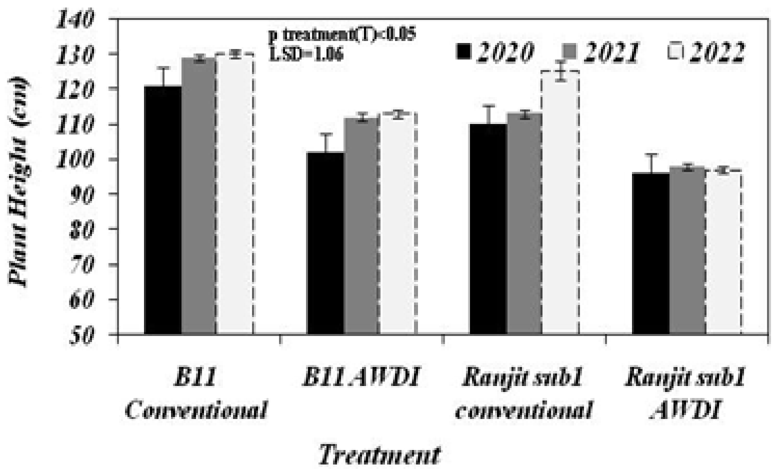


Figure 5.3.3. Temporal variation of plant height (cm) under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.10. Yield and yield related parameters

5.3.10.1. Grain yield (kg ha^{-1})

The average grain yield recorded in conventional tillage ranged from 3067.02 kg $ha^{-1}$to 4033.33 kg ha^{-1} in B11 and 3050 to 4100 kg ha^{-1} in Ranjit sub 1. In AWDI, yield ranged between 4066.11 to 5633.33 kg ha^{-1} in B11 and 5068.75to 5716.66 kg ha^{-1} in Ranjit sub 1. ANOVA analysis revealed that there is significant increase in grain yield withAWDI method in both the varieties ($p_T<0.05$, LSD=55.36). When compared to traditional irrigation, the key component that that affected rice grain production under AWD was the intensity of the soil drying phase in the AWD cycle. Earlier research demonstrated that there is a decrease in rice grain yield during AWD with more severe drying conditions of soil[9][51]-[53]. However, recent studies show that AWDI can increase the grain yield. One such result was reported by Wang et al., (2020)[54] where AWDI resulted in maximum yield of 7808.38 kg $ha^{-1}$of rice grains which agrees with the present study. Thus, Arouna, (2023)[55] recognized AWDI as the most popular water saving technology for rice production in terms of yield as well as water saving potential. Although higher number of fertile tiller and increased grains per panicle is directly related to increased grain yield[56], the exact mechanisms by which AWD increases yield under moderate soil dryness are not identified yet, further research on it will help to differentiate between the relative impacts of AWDI on grain-filling and vegetative development. In terms of yield, the crop growth stage is an important parameter, AWD cycles depend on the existing soil moisture and the exact time of irrigation[37]. Even though AWD is regarded as the most promoted water-saving economic and eco-friendly technology, it is not broadly practiced in India, probably due to the complex interactions between agricultural and socioeconomic systems and lack of strong institutional support[55].

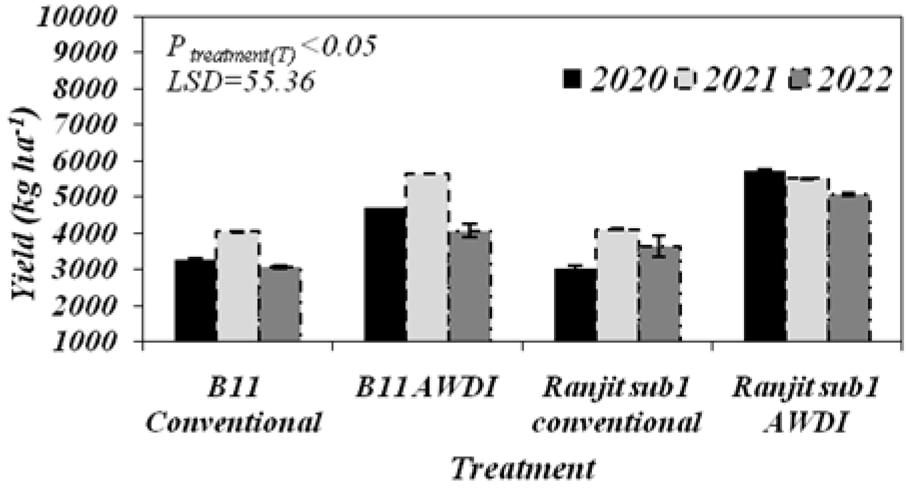


Figure 5.4.1. Temporal variation of grain yield (kg ha^{-1}) under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.10.2. Grain filling (%)

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[57]. Present outcomes agreed with the findings of Chu et al., (2018)[58]. AWDI implications increased rate of grain filling significantly, attributed to increased photosynthetic rate (flag leaf), root oxidation activity, and activity enzymes that govern sucrose-to-starch conversion[37].

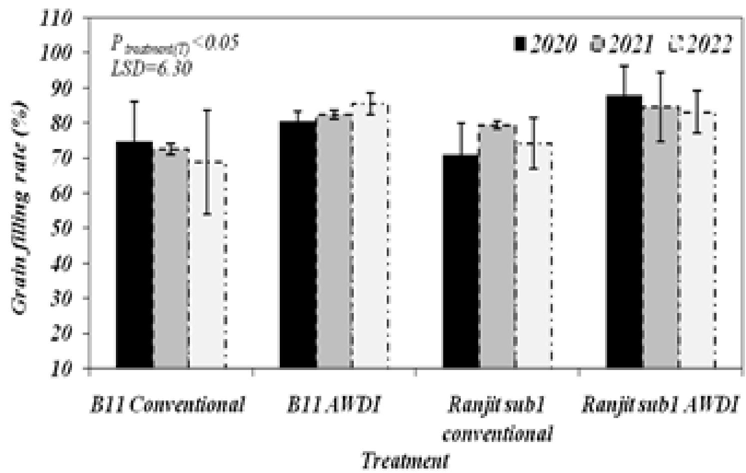


Figure 5.4.2. Temporal variation of grain filling (%) under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.10.3. Sterile spikelet(%)

The most interesting and positive finding of the study was that AWDI approach can lead to decreased spikelet sterility when managed properly. Pooled data of sterile spikelet percentage showed no significant difference among the treatments ($p_T<0.05$, LSD=3.34). It ranged between 21.04 to 24.60 % in B11 under conventional practice and 18.33 to 23.95 in Ranjit sub 1, in the present study. While across the treatment it ranged between 17.12 to 17.58 % in B11 and 14.25 to 19.96% in Ranjit sub 1. Thus, there was 30.70% decrease in spikelet sterility in B11 due to treatment effect in 2020 ($p_T<0.05$, LSD=2.42). Similarly, 16.03% in 2021($p_T<0.05$, LSD=3.70) and 18.63% in 2022($p<0.05$, LSD=3.44) decrease in sterility was evident in B11 due to AWDI (Figure 5.4.3). In the case of Ranjit sub 1,22.26 to 26.97 % decrease in spikelet sterility was evident($p<0.05$). Previous studies also have shown that AWDI can significantly decrease panicle sterility compared to continuous flooding, as the roots receive sufficient oxygen during the drying phases[59]. Furthermore, the AWDI technique facilitates improves microenvironment conditions, such as temperature and soil microbial activity, which are essential for reproductive development[60].· Additionally, it was discovered that panicle transpiration resistance enhanced the fertility of rice spikelets during flowering under water stress [57].

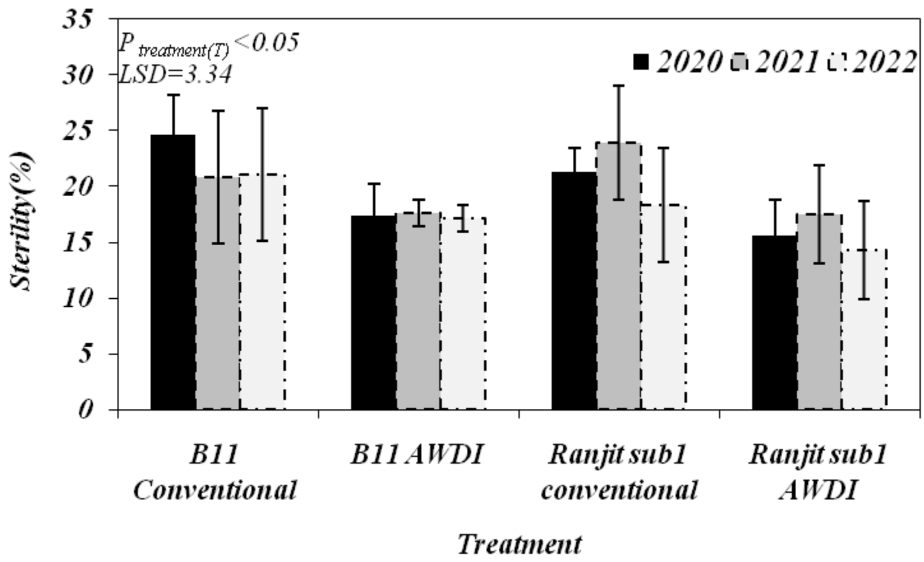


Figure5.4.3. Temporal variation of sterile spikelet under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.10.4 Tiller number

Under AWDI, an average of 2.67 to 5.33 tillers was recorded in the study period (Figure 5.4.4). However, ANOVA analysis did not show any significant difference in tiller numbers ($p>0.05$, LSD = 1.01) (Figure 5.4.4).

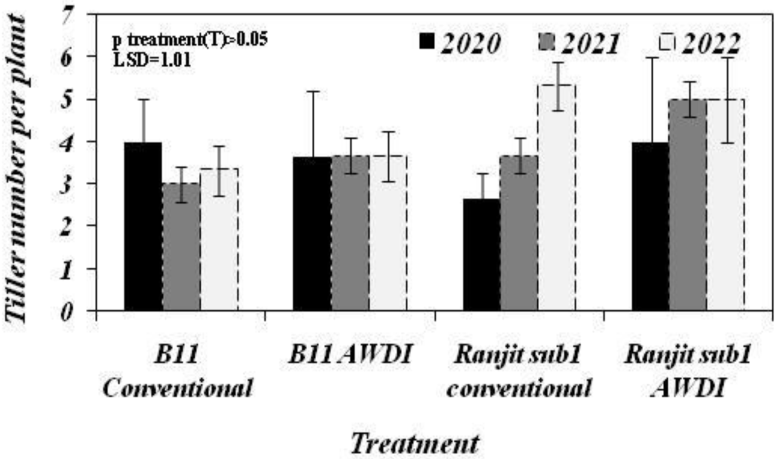


Figure 5.4.4. Temporal variation of tiller number under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.11. Grain quality

5.3.11.1. Protein content in grain

The pooled data of protein percentage is presented in the Figure 5.4.5. AWDI was significantlyinfluenced the protein content of grains ($p_T<0.05$, LSD=2.40). In the study, the protein content of the B11 variety of grains ranged from 6.64% to 8.45%. This range indicateda relatively moderate level of protein concentration. Conversely, the Ranjit sub 1 variety exhibited a higher protein content, with values varying from 10.68% to 16.06%. Across the treatments, the protein content ranged between 11.50 to 20.36 in B11 while 13.29 to 19% in Ranjit sub 1. The substantial difference between these two varieties underscores the impact of genetic and environmental factors on protein accumulation in grains.This comparative analysis shows that while both varieties benefited from the treatments, Ranjit sub 1 consistently maintained higher protein levels than B11. The findings imply a strong potential for Ranjit sub 1 as a valuable crop for protein augmentation in food products, while also suggesting the potential for optimizing treatment strategies for both varieties to maximize their nutritional benefits. Increased protein content of grain may be due to increased nutrient uptake by plant. Doung et al., 2024[61] have indicated that rice varieties grown under AWD conditions can achieve higher protein levels due to enhanced nutrient uptake which is corroborative with the present study[61].Similar finding was stated by Jabran et al., (2017)[62] in their research.The intermittent drying and re-flooding cycles appear to stimulate better nutrient availability in the soil, positively influencing protein synthesis in the rice plant[63]

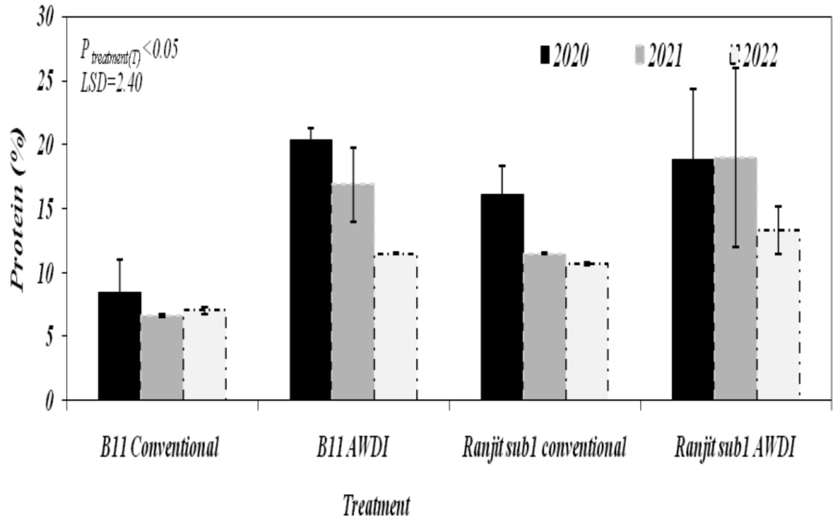


Figure 5.4.5. Temporal variation of protein content (%) under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.11.2. Carbohydrate in grain (mg ml^{-1})

Carbohydrate content of grains in the present study ranged between 20.6 to 28.36 mg ml^{-1} in B11and 22.1 to 29.2 mg ml^{-1}. ANOVA analyses revealedthat plant grown with AWDI had higher grain carbohydrate content than plants grownwithconventional method of irrigation ($p<0.05$, LSD= 0.76) (Figure 5.4.6). It was more evident in Ranjit sub 1 than B11. AWDI encourages deeper root growth, allowing better access to nutrients and water that are critical for starch biosynthesis during the grain filling period[64]. This intermittent supply of water tends to promote metabolic activities in rice grains, enhancing the synthesis of starch and other carbohydrates[65].

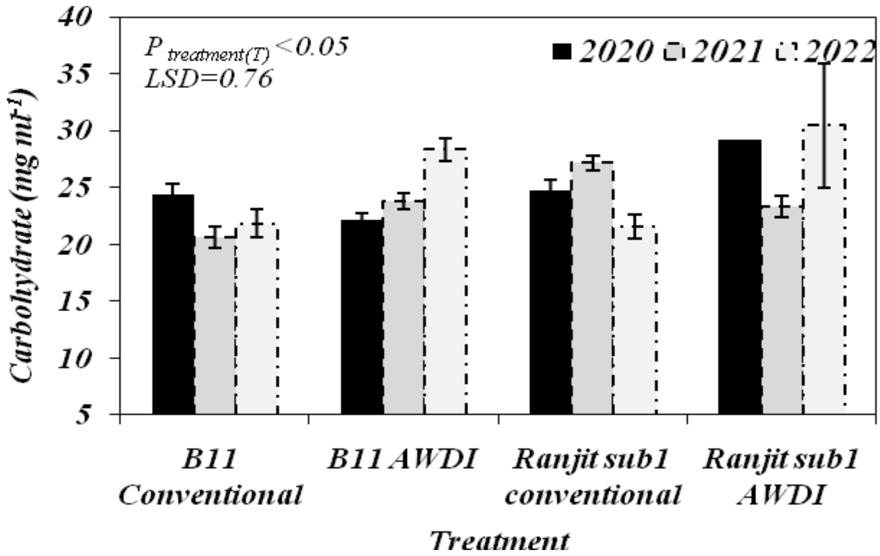
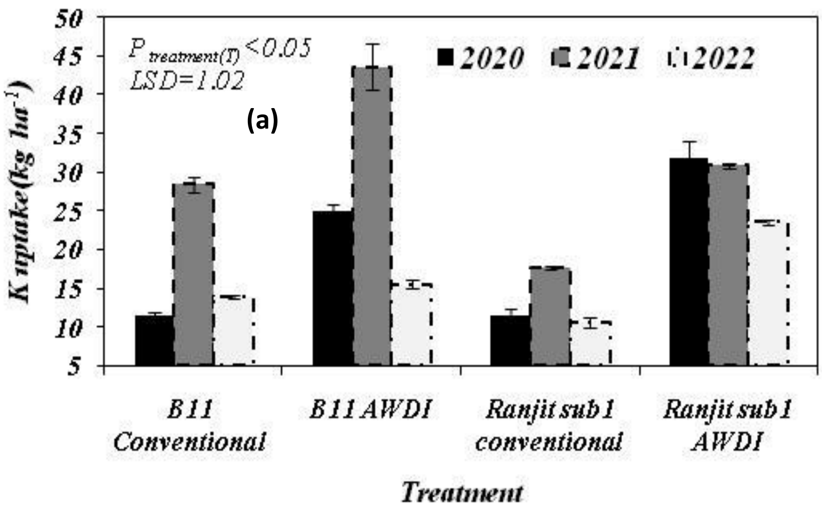


Figure 5.4.6.Temporal variation of Carbohydrate content in grain (mg ml^{-1}) under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.12. Nutrient uptake (N,P and K) by crop

5.3.12.1. Potassium uptake (kg ha^{-1})

Remarkable differences in K uptake were observed in the present study involving AWDI (p_T <0.05,LSD=1.02) (Figure 5.4.7). Significantly higher K uptake was noticed in the rice plants under AWDI. Maximum uptake was evident in 2022 (p_T<0.05, LSD=1.33). Increasing rates of available K in AWDI notably enhanced the root production of rice plants to soak up the nutrients and water[36]. Sandhu et al., 2017[66] reported increased root proliferation due application of AWDI. Soil aeration by AWDI and high root dry weight together implied more uptake of water and nutrients from the soil through to the root system[66]. Moreover K uptake is dependent on total soil input of K through fertilizer and plant biomass[36].Thus, higher K uptake may be due to availability of soil K in theplant residue of the previous years[36]. Higher Kuptake may be indicative of increased availability of soil K. HI for K ranged between 71 to 0.87 in B11 and 0.63 to 0.87 in Ranjit sub 1 in the present study. However,significant increase of HI for K (KHI) was observed due to application of AWDI. KHI is dependent on nutrient uptake by crop[67] which is evident through correlation analysis (r= 0.342, p<0.05).



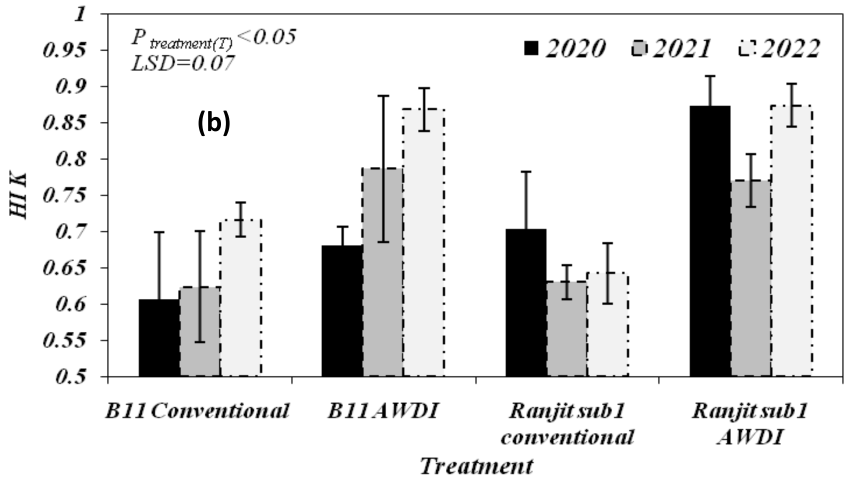


Figure 5.4.7.Temporal variation of (a) potassium uptake (kg ha^{-1}) (b) potassium harvest index under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.12.2. Phosphorus (P) uptake (kg ha^{-1})

P uptake was significantly increased in both rice varieties under different irrigation practices (p_T<0.05, LSD=0.01)[Figure 5.4.8(a)]. Irrespective of treatment, P uptkae ranged between 62.83 to 84.27kg ha^{-1} in B11 and 52.50 to 97.56 kg ha^{-1}in Ranjit sub 1. Across the treatments, higher P uptake was observed in Ranjit sub 1 which ranged between 144.95 to 179.32 kg ha^{-1}in contrast to 95.79 to 151.13 kg ha^{-1}in B11 under AWDI. Increased availability and effective absorption of nutrients from the soil, as well as the movement of absorbed nutrients from roots to shoots and grains, are credited with this, which in turn enhanced plant growth and grain yield. These outcomes concurred with those of Chowdhury, (2014)[69] and Ramakrishna, (2007)[68]. Irrespective of AWDI, Phosphorus harvest index (PHI) ranged between 1.17 to 1.79 in B11 and 1.28 to 2.01 in Ranjit sub 1 in conventional irrigation; on the otherhand, PHI ranged between 1.48 to 2.41 in B11 and 2.04 to 2.60 in Ranjit sub 1 under AWDI treatment. Significant differences in PHI was evident across the treatments in the present study ($p< 0.05$, LSD= 0.05) was observed. However higher HI for P (PHI) was observed in Ranjit sub 1 than B11. PHI is dependent on nutrient uptake by crop[67] which is evident in correlation analysis of P uptake and PHI ($r= 0.709$, $p<0.01$)[Figure 5.4.8(b)].

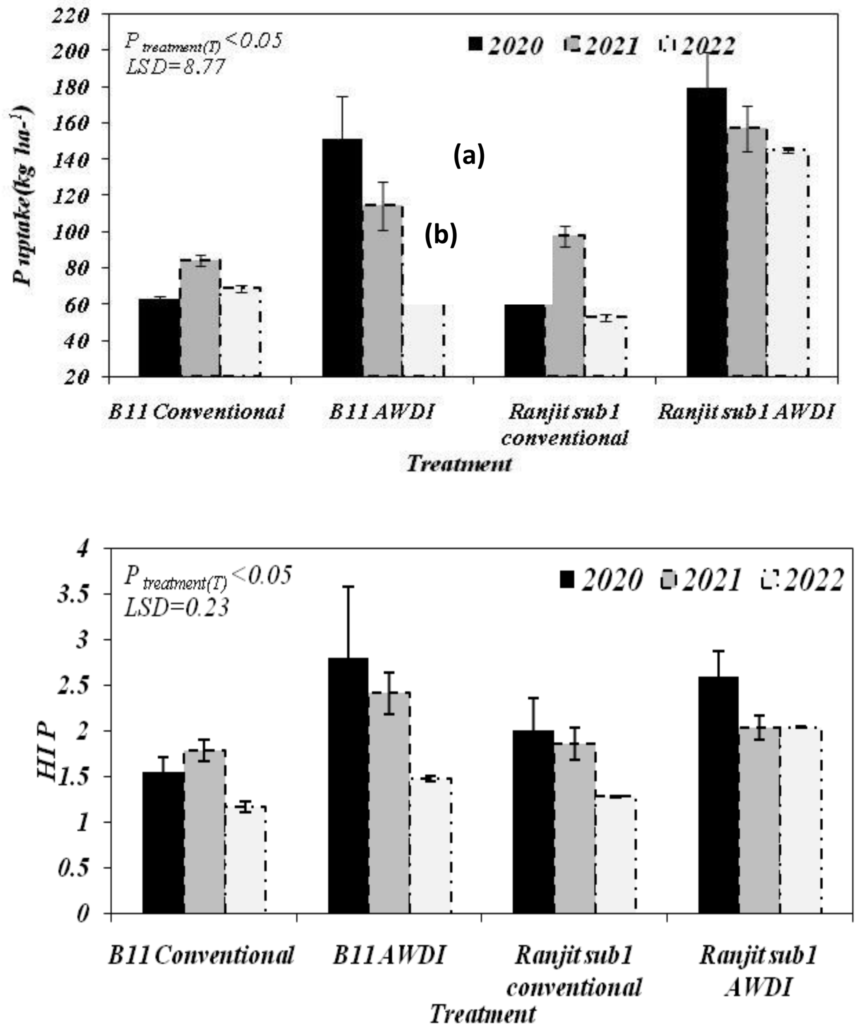
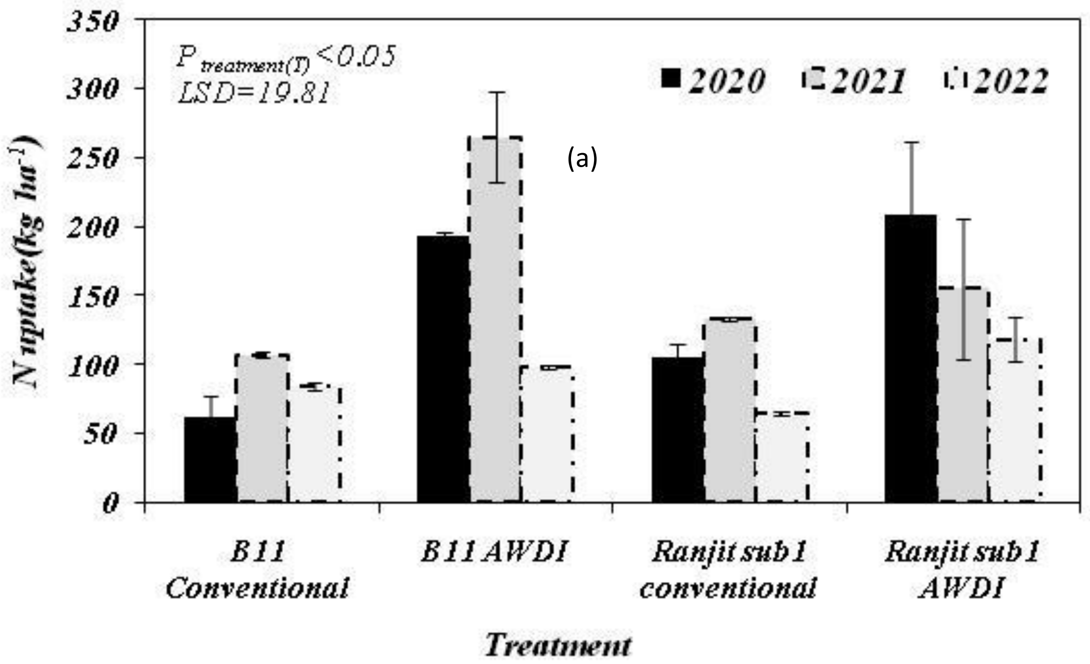


Figure 5.4.8. Temporal variation of (a) phosphorus uptake (kg ha^{-1}):(b) phosphorus harvest index under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.12.3. Nitrogen (N) uptake(kg ha^{-1})

There was asigninificant improvement in nitrogen uptake due to application of AWDI (p_T<0.05, LSD=19.81). Irrespective of treatment, N uptake ranged between 84.35 to 107 kg ha^{-1} in B11 and between 64.53 to 113.35 kg ha^{-1} in Ranjit sub 1 which increased to 98.32 to 193.58 kg ha^{-1} in B11 and 118.12 to 208.91 kg ha^{-1} in Ranjit sub 1 (Figure5.4.9). Increased availability and efficient absorption from the soil, as well as the movement of nutrients from the root to the shoot and grains, may be the cause of noticeably higher N uptake. Panda et al., (1997)[70], Ramakrishna, (2007)[68], and Chowdhury et al., (2014)[69] all reported similar outcomes. Across the treatment maximum N uptake was recorded in B11. Increase HI for N (NHI) was evident due to treatment effect (p<0.05, LSD= 0.50). Maximum NHI of 4.7 was evident in Ranjit sub 1 due to treatment. NHI is dependent on grain filling rate as well as with nutrient uptake by plant[71]. Srtong correlation of NHI with nutrient uptake was evident through correlation analysis (r=0.536, p<0.01) (Table 5.3).



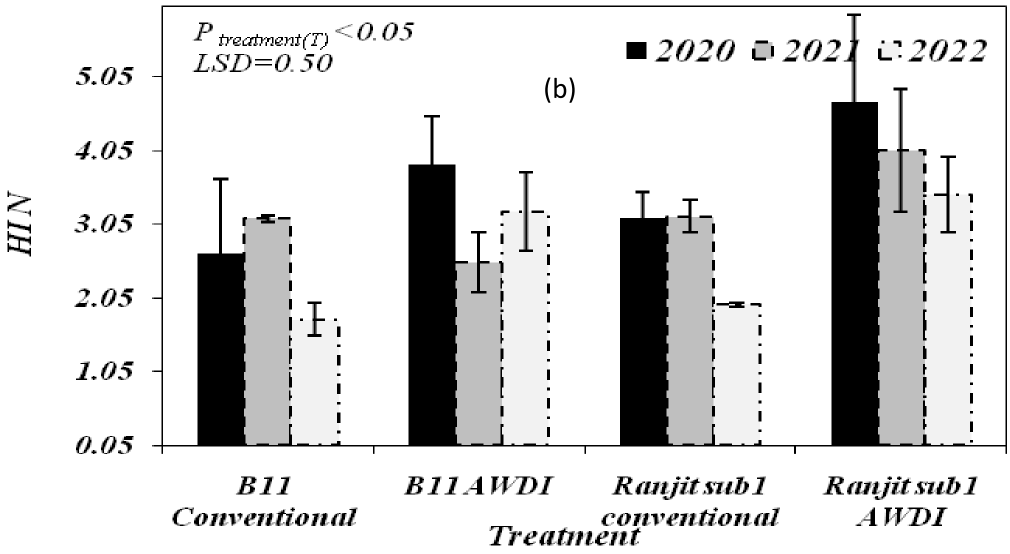


Figure 5.4.9.Temporal variation of (a) Nitrogen uptake(kg ha^{-1}) (b) nitrogen harvest index under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

Table 5.3.Pearson's Correlation coefficient (r value) for different parameters

Parameters	Grain filling rate	WPI	K Uptake	KHI	P Uptake	PHI	N uptake
WPI	0.555**						
K Uptake	0.489**	0.892**					
KHI	0.290	0.504**	0.342*				
P Uptake	0.499**	0.843**	0.959**	0.322			
PHI	0.340*	0.619**	0.630**	0.293	0.709**		
N uptake	0.395*	0.760**	0.833**	0.196	0.757**	0.682**	
NHI	0.430**	0.504**	0.368*	0.180	0.402*	0.431**	0.536**

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

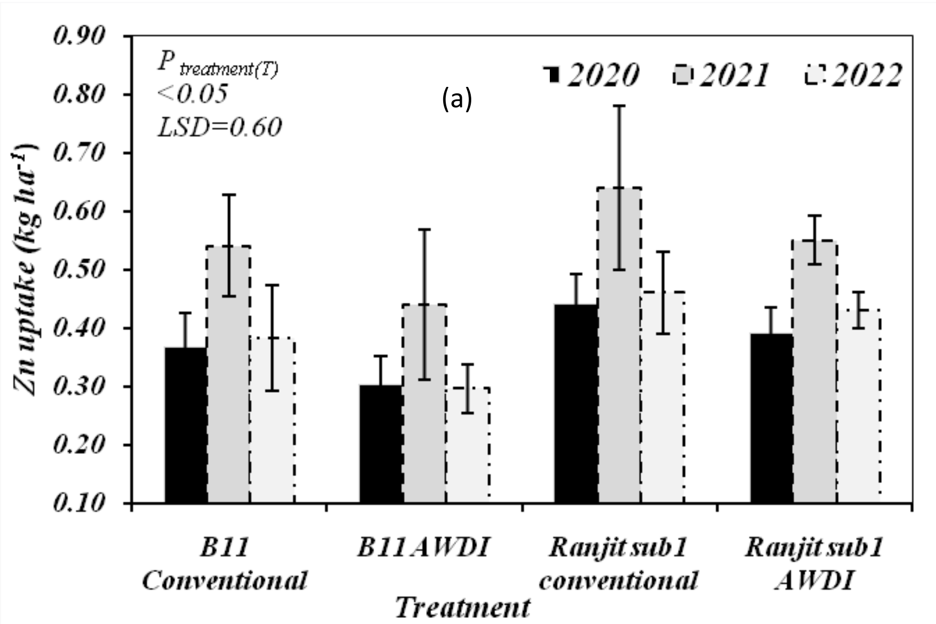
WPI, water productivity index; KHI, nutrient harvest index of potassium; PHI, nutrient harvest index of phosphorus NHI nutrient harvest index of nitrogen

5.3.13. Micronutrient uptake

AWDI can influence the soil moisture dynamics, which in turn can impact active nutrient uptake. Dry periods may limit nutrient uptake, while wet periods can promote effective uptake of nutrients. Zn, Cu and Mn are the micronutrients essential for vital physiological processes in rice plants. They can interact with each other in terms of uptake and utilization. For example, excess of one micronutrient can interfere with the uptake of another. The shift in cultivation practice from continuous flooding to aerobic soil (AWD) condition causes variations in soil aeration, soil water contents, and nutrient availability due to mineralization[37].

5.3.13.1. Zn uptake (kg ha^{-1})

A significant decrease in Zn uptake was revealed by ANOVA analysis among different treatment (p_T<0.05, LSD=0.60).This result was not corroborative with the findings of Wang et al., 2014[72], where they found an increase of Zn uptake in the rice plants under AWDI. Irrespective of treatment, Zn uptake ranged between 0.36 to 0.54 kg ha^{-1} in B11 and from 0.44 to 0.64 kg ha^{-1} Ranjit sub 1 in present study. Among treatment Zn uptake ranged between 0.29 to 0.44 kg ha^{-1} in B11 and from 0.39 to 0.55 kg ha^{-1} in Ranjit sub 1 [Figure5.4.10(a)]. Significant decrease in HI of Zn was evident by ANOVA analysis (p_T<0.05, LSD=0.15)[figure.5.4.10(b)] AWDI involved alternating wet and dry cycles in rice fields. During dry cycles, the soil moisture levels decreased, which led to temporary water stress in the rice plants. This affected nutrient availability in the soil. Decrease in Zn uptake and ZnHI may be attributed to nutrient availability of soil which decreases as the pH of soil increases during aerobic condition[37].



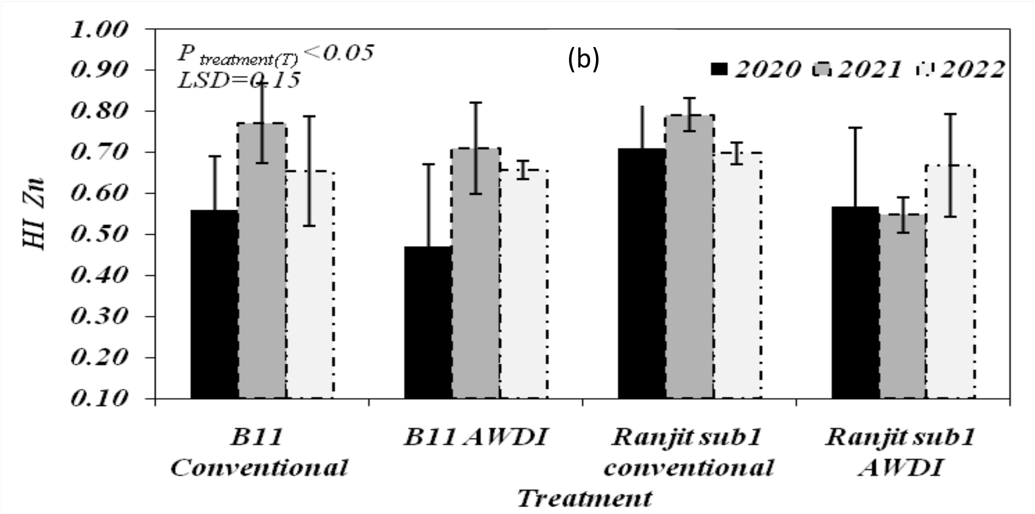
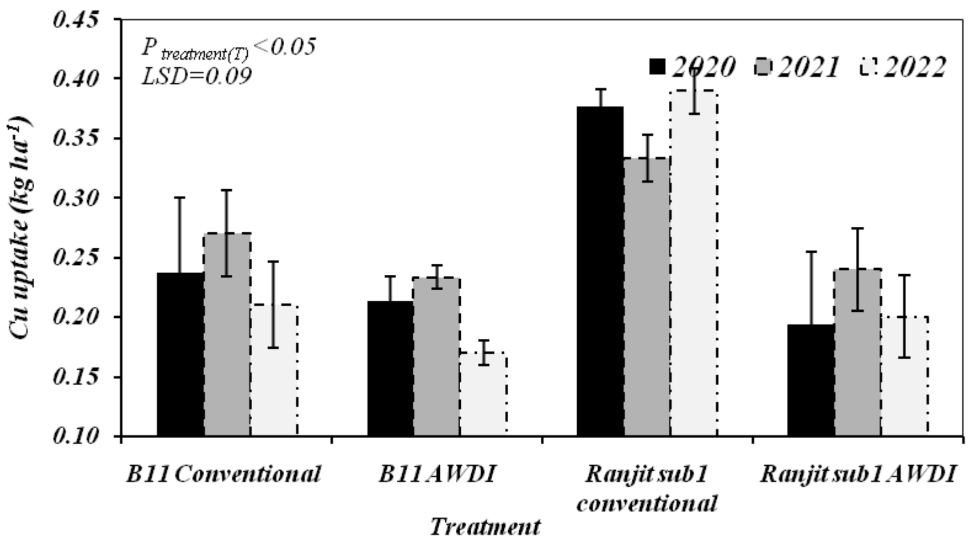


Figure 5.4.10. Temporal variation of (a) Zinc uptake (kg ha^{-1}) (b) Zinc harvest index under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.13.2. Cu uptake (kg ha^{-1})

Significant difference in Cu uptake was evident (p_T<0.05, LSD=0.09). Decrease in Cu uptake may be attributed to nutrient availability of soil[37]. However irrespective of treatment Cu uptake was high in Ranjit sub 1 than B11. HI of Cu also found to be decreased due to treament effect (p_T<0.05,LSD=0.18) which is positively correlated to nutrient uptake (Table 5.4) (Figure 5.4.11). Decrease in Cu uptake and Cu HI may be attributed to nutrient availability of soil[37].



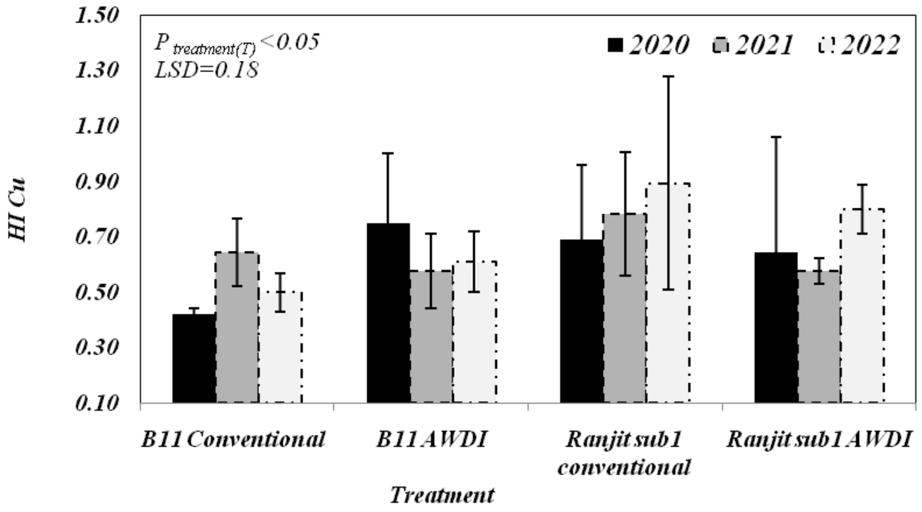
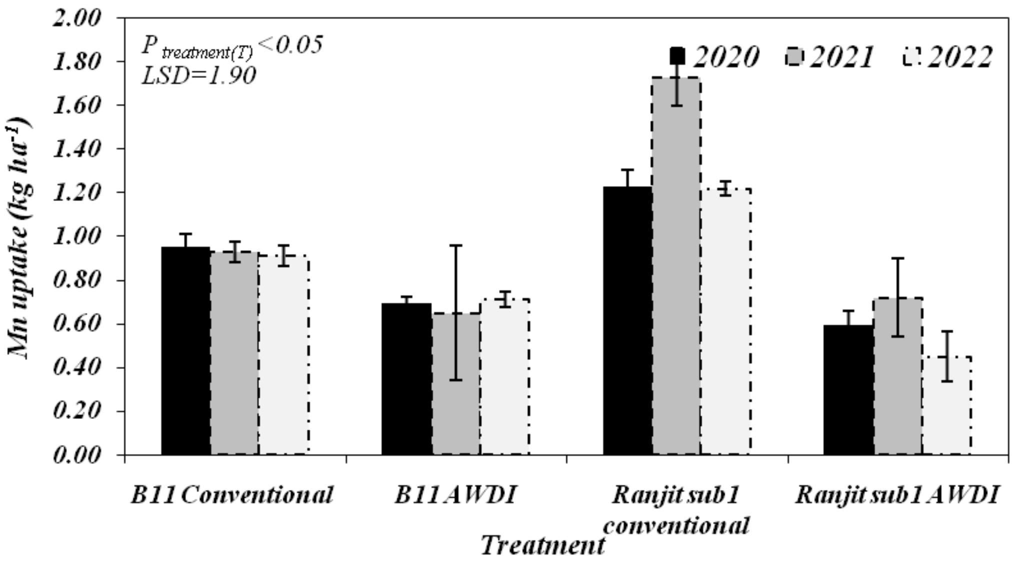


Figure 5.4.11. Temporal variation of (a) Copper uptake (kg ha^{-1}) (b) Copper harvest index under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.13.3. Mn uptake

A significant decrease in Mn uptake was evident (p_T <0.05, LSD= 1.90) HI of Mn was also found to be decreased due to AWDI (p_T <0.05, LSD=0.11) (Figure 5.4.12). Decrease in Mn uptake and Mn HI may be attributed to Mn uptake (r=0.846,p<0.01) and nutrient availability of soil of soil[37] (Table 5.4)



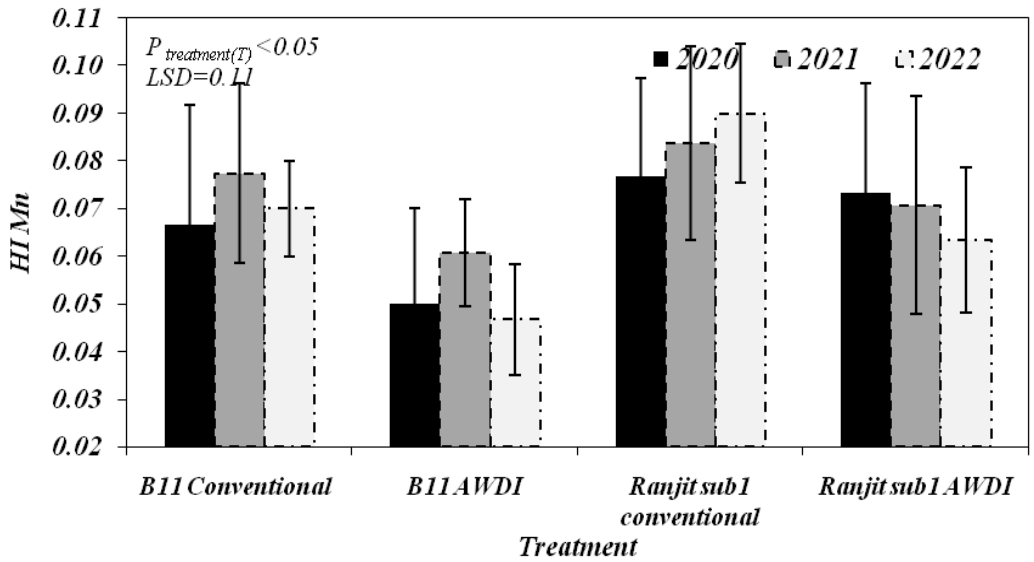


Figure 5.4.12.Temporal variation of (a) Manganese uptake (kg ha^{-1}) (b) Manganese harvest index under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

5.3.14. Water productivity index (WPI)

A significant increase in WPI was noticed in present study (p_T <0.05, LSD= 2.85) (Figure 5.4.13). For the B11 rice variety, an increase in WPI was observed ranging from 28.33% to 56.12%, indicating a substantial improvement in water use efficiency during the study period. In the case of the Ranjit sub 1 variety, the enhancement was even more pronounced, with WPI values increasing between 56.68% and 64.59%. These improvements highlight the potential of specific rice varieties to thrive under varying environmental conditions by maximizing water use. Similar result was reported by Zhang et al.,[73] and Bwire et al.,[71]. A positive correlation was (r=0.555, p<0.01) established between the rate of grain filling and WPI. This correlation suggests that as the grain filling rate improves, the water productivity also enhances. The strong statistical relationship indicates that optimizing grain filling might be an effective strategy for improving overall water productivity in rice cultivation, possibly leading to better yields and resource management. In order to prevent any induced water stress that could impair rice productivity, irrigation water application in paddies with AWD conditions must be done as soon as water lowers the necessary soil depth[71].

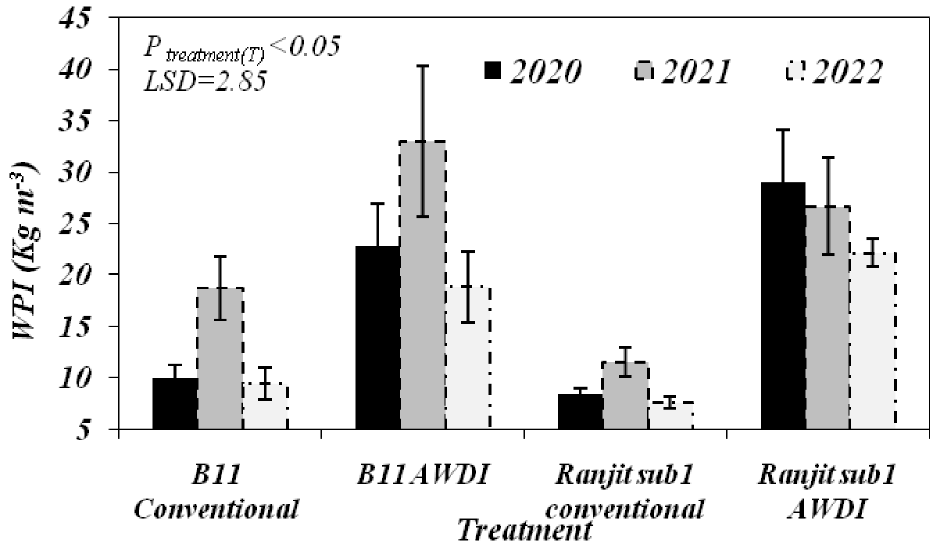


Figure 5.4.13. Temporal variation of water productivity index under two different agricultural practices in two different varieties. Vertical bars represent standard error of mean

Table 5.4. Pearson's Correlation coefficient (r value) for different parameters

Parameters	Grain filling rate	WPI	CuHI	Cu uptake	MnHI	Mn uptake	Zn HI
WPI	0.555**						
CuHI	0.387*	0.171					
Cu uptake	0.322	0.375*	0.184				
MnHI	0.291	0.400*	-0.038	0.388*			
Mn uptake	0.157	0.111	-0.061	0.319	0.846**		
Zn HI	0.307	0.263	0.020	0.209	0.275	0.183	
Zn uptake	0.207	0.331*	-0.059	0.346*	0.761**	0.775**	0.098
**. Correlation is significant at the 0.01 level (2-tailed).							
*. Correlation is significant at the 0.05 level (2-tailed).							

WPI, water productivity index; CuHI, nutrient harvest index of copper;MnHI, nutrient harvest index of manganese; Zn HI, nutrient harvest index of zinc

5.4. Conclusion

According to this study, high-performing rice varieties are crucial for increasing agricultural sustainability. Various areas face water scarcity problems, especially the cultivation of rice, which consumes a lot of water. WPI improvements are essential to address these problems. Farmers can increase their output and possibly achieve more sustainable agricultural water management, which is beneficial to the environment and the economy if these strategies are put into practice. Recently, abiotic concerns such as ammonia toxicity, nutritional deficits, and soil pH have gained attention. Majority of recent studies on the yield stability of the AWDI approach have been carried out at IRRI farms, and the findings may vary depending on the location. The sustainability of AWDI must be investigated in a variety of settings with varying soil fertility, water availability, and physical and chemical characteristics [74].

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