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IMPACT OF AEROBIC RICE CULTIVATION ON GROWTH AND PRODUCTIVITY OF *INDICA* AND *JAPONICA* CULTIVARS

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Abstract

An experiment was carried-out to examine the effects of aerobic rice cultivation on different growth, yield and its related characteristics. The study was laid out at the experimental field RE-5, Tsukuba International Center, Japan International Cooperation Agency, Japan. The main objectives of the experiment were to save the irrigation water and acquire optimum/higher yields under aerobic cultivation as compared to traditional lowland cultivation. To achieve these objectives, two *Indica* and one *Japonica* cultivars were selected to examine under both the conditions on two-factor split plot design with three replications. Under aerobic conditions, ~59% of the total irrigation water was saved and ~72% water was saved at freshwater level except rainfall as compared to lowland conditions. The *Indica* cultivar IR-50 showed higher grain yields (6.3ton/ha) under aerobic conditionsas compared to lowland (5.2ton/ha) and also retained higher panicle and spikelets number under aerobic conditions. On the other hand, the *Japonica* cultivar Fukuhibiki retained higher yields (5.2ton/ha) under lowland compared to aerobic conditions (4.9ton/ha). Whilst, an upland cultivar NERICA-10 retained higher grain yields (4.6ton/ha) under aerobic cultivations as compared to lowland (3.7ton/ha). Interactions were significant among all the cultivars underaerobic and lowland conditions, whereas IR-50 had higher nitrogen absorption under aerobic conditions than rest of the cultivars. Hence, nitrogen absorption positively sustains the grain yields and total dry mass accumulations. It is, therefore, concluded that lowland and upland cultivars are not only adaptive to aerobic conditions but also a great amount of irrigation water may be saved.

Key words: Aerobic rice, *Indica*, *Japonica*, Irrigation, Grain yield, Nitrogen absorption.

Introduction

Rice (*Oryza sativa* L.), a major food crop for more than half of the world's population, is cultivated worldwide in more than 95 countries, and about 90% of the world's rice is produced and consumed in Asia (Liu *et al.*, 2019). By the year 2025, it is predicted that two million hectares of Asia's irrigated dry-season rice and thirteen million hectares of its irrigated wet-season rice will experience physical water shortage and most of the approximately twenty-two million hectares of irrigated dry-season rice in South and Southeast Asia will experience economic water shortage (Tuong & Bouman, 2002). There are signs that declining water quality and declining resource availability are threatening the sustainability of the irrigated rice-based production system in Asian continent. In this regard, ways must be established to decrease water use in rice production. In lowland rice, losses of irrigation occur by seepage, percolation and evaporation when the soil is submerged; the production of lowland rice requires higher quantity water (Bouman & Tuong, 2001). Grain crops, such as wheat and maize, in contrast are grown on non-puddled, aerated soils. Irrigation water is applied when the soil becomes too dry, and the quantity of applied water is sufficient to bring the soil to field capacity or saturation level. Irrigation water saving and increases in water productivity might be possible if paddy could be grown under aerobic soil conditions such as wheat and maize (Bouman *et al*., 2002). Aerobic rice has been identified as a water-saving, environmentally friendly, and cost-effective technology for rice production (Patel *et al.*, 2010; George, 2018).

In early 1970s, investigation on alternate wetting and drying method of water saving technology was started and, in these days. It is getting renewed attention by scientists (Bouman & Tuong, 2001). The fundamental requirements of implementing this technology seem to be in place in current scenario; the adoption of this water saving technology has been slow other than China (Li, 2001). The big challenge is to identify the environmental and socio-economic conditions that encourage lowland farmers to adopt this particular technique to save fresh water reservoirs (Bouman, 2001; Kadiyala *et al*., 2012) also suggest that paddy can grow aerobically under irrigated conditions just like upland crops such as wheat and maize. On the other hand, rice crop is very sensitive and difficult to grow under limiting water conditions (Anjum *et al.*, 2011; Sokoto and Muhammad, 2014).

Aerobic rice cultivation is an Alternate Wetting and Drying (AWD) technology**,** which is a water saving technology that lowland rice farmers can apply to reduce their water use in irrigated fields. In AWD irrigation water is applied to flood the field after a certain number of days have passed following the disappearance of ponded water. Hence, the field is alternately flooded. Lowland rice in Asia is mostly transplanted or direct seeded into puddled, lowland paddy fields. The available amount of water for irrigation is increasingly getting scarce. The prevailing situation has given a wakeup call to develop and popularize innovative water saving technologies to produce more rice from every drop of water. The objectives of this research are to save irrigation water, get optimum yield and test the adoptability of different *Indica* and *Japonica* cultivars under aerobic conditions. Considering above issues, an experiment was designed to investigate the effects of water conditions on growth and productivity of rice. Hence, irrigation water was applied as determined by considering the disappearance of irrigation water and dryness of soil surface as aerobic and control was fully flooded by withholding 5-10 cm irrigation water till full maturity.

Materials and Methods

The experiment was carried-out during the rice season, 2014 at the experimental field (RE-5) of Tsukuba International Center, Japan International Cooperation Agency. Two *Indica* (IR-50 and NERICA-10) and one *Japonica* (Fukuhibiki) rice varieties were selected to examine the effect of aerobic cultivation. Split Plot Design with three replications was practiced for investigation. Three blocks were made and both the aerobic and lowland conditions were separated with the installation of hard and soft plastic sheets (up to 30cm depth or hard pan) to prevent the entrance and seepage of irrigation water. Aerobic rice cultivation technology is based on the method of AWD (Alternate Wet and Dry) and lowland rice cultivation is a traditional fully flooded with first 3 cm than 5-10 cm irrigation water kept continuously. Soil water content, growth parameters, nitrogen absorption at different growth stages and yield and yield components were investigated after harvest. Seed rate was applied as 30-40 kg/ha. Seeds were sown on 08th May, 2014 through direct (spot) seeding as four (4) seeds per hill. Fertilizer was applied as 80:100:100 (N:P:K, respectively). Soil samples were collected from center of each plot, a total of 18 samples were collected with soil sampling tool then mixed immediately and dried at room temperature. When soil was completely dried, it was re-mixed, grinded to powder and filtered with 0.2mm sieve. Few samples from 300-500mg were chosen for analysis. The results of soil analysis are as total nitrogen (1110 kg/ha), available phosphorus (112.6 kg/ha), exchangeable potassium (123 kg/ha), exchangeable calcium (2386.7 kg/ha) and exchangeable magnesium (235.4 kg/ha).

Irrigation water was calculated by fresh water application through velocity and rain by millimeter fall/unit area. Under lowland conditions, 21 million liters ha^{-1} irrigation was applied, while under aerobic conditions, 9 million liters ha^{-1} irrigation water was utilized. Soil water content was calculated on fresh and dry weight basis on each data point (Fig. 1). Each data point consisted of six replicates. Irrigation water was introduced about one month after seeding at early tillering stage when plant age in leaf number was 3 to 3.5 (Fig. 2). Soil water content was kept significantly (p<0.05) higher under lowland conditions throughout the cropping season as compared to aerobic conditions (Fig. 1). Graph suggested that the method of irrigation application was effective, resulting desired soil water under both the conditions.

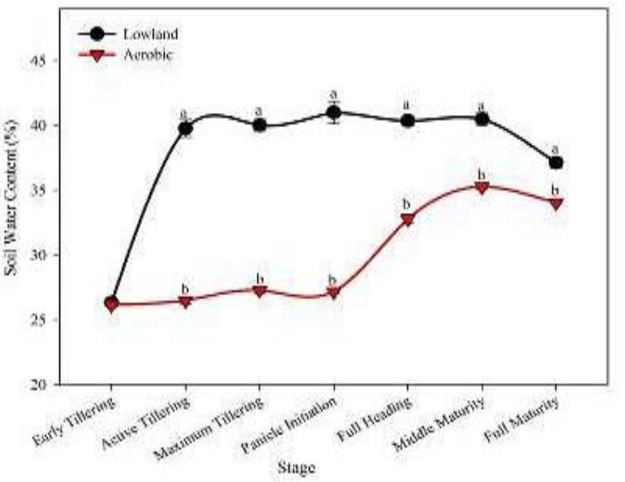

Fig. 1. Soil water content (%) under lowland and aerobic conditions, alphabetical letters show significant (p<0.05) difference among both the water conditions on each selected stage.

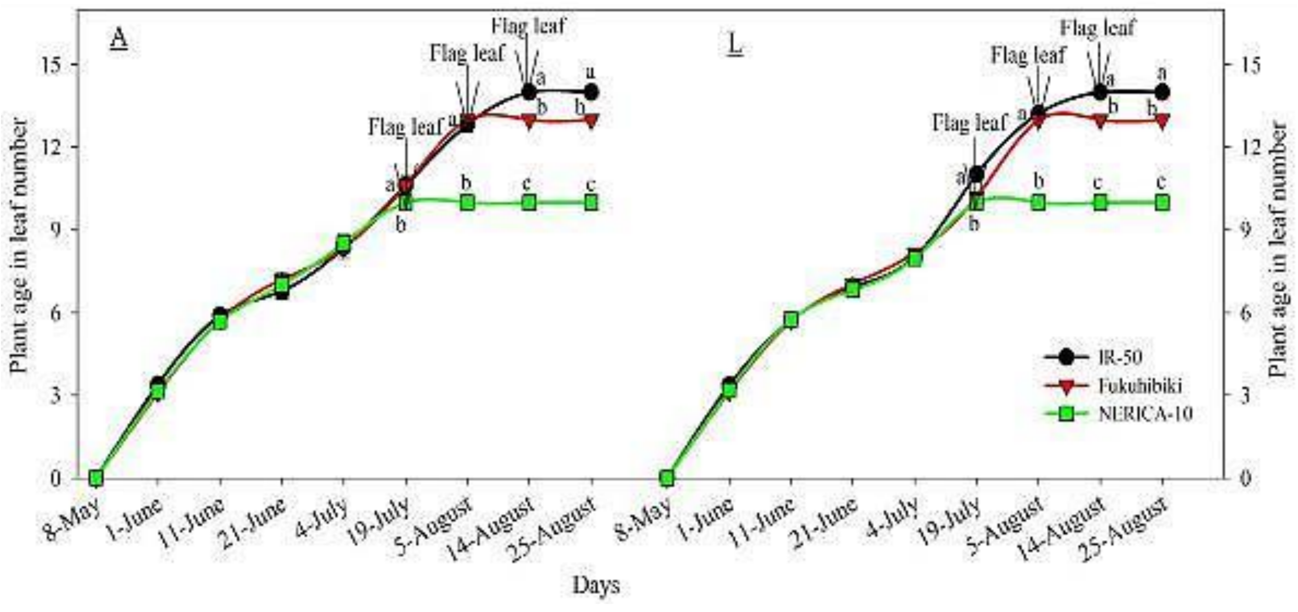

Fig. 2. Plant age in leaf number under aerobic conditions (A) and lowland conditions (L) arrows show flag leaves appearance.

All statistical analyses were undertaken by Minitab 17.1.0.0 version (Minitab Inc., USA) including general linear model analysis (statistically differences between all the growth stages, differences among cultivars and water conditions) and ANOVA (statistical significant differences between genotypes and water conditions on selected data point by $p<0.05$ Tukey 95% confidence) were also done separately. Relationship analysis, curve fitting and all the figures were drawn in SigmaPlot 11.0.0.77 version (Systat Software Inc., Germany).

Results

Grain yield was calculated by partial harvesting of 35 hills (1.58 m^2) from each plot. Higher ($p<0.05$) grain yield was recorded in IR-50 than Fukuhibiki and NERICA-10 cultivars under aerobic conditions. Under lowland conditions, IR-50 and Fukuhibiki showed significantly ($p<0.05$) higher grain yield than NERICA-10 (Fig. 3A). Similarly, total straw weight was also calculated by partial harvesting of 35 hills (1.58 m^2) from each plot which was significantly ($p<0.05$) higher in IR-50 and Fukuhibiki compared to NERICA-10 under aerobic and lowland water conditions (Fig. 3B). Our results indicated that IR-50 produced more grain yield under water shortage conditions, while under fully flooded conditions, IR-50 and Fukuhibiki performed better. However, Fukuhibiki and IR-50 produced more straw as compared to NERICA-10 under both the water conditions. With respect to number of spikelets per panicle, Fukuhibiki and NERICA-10 showed significantly ($p<0.05$) higher number of spikelets per panicle as compared to IR-50 under aerobic conditions. Under lowland conditions, Fukuhibiki and IR-50 formed significantly ($p<0.05$) higher number of spikelets per panicle as compared to NERICA-10 (Fig. 4A). Considering the ripening ratio, it was significantly ($p<0.05$) higher in IR-50 and Fukuhibiki as compared to NERICA-10 under both the aerobic and lowland conditions (Fig. 4B). Results indicated that Fukuhibiki and NERICA-10 formed higher number of spikelets per panicle under water frighten conditions, while under lowland Fukuhibiki followed by IR-50 produced more spikelets per panicle. IR-50 and Fukuhibiki acquired more ripening ratio as compared to NERICA-10 under both the water conditions.

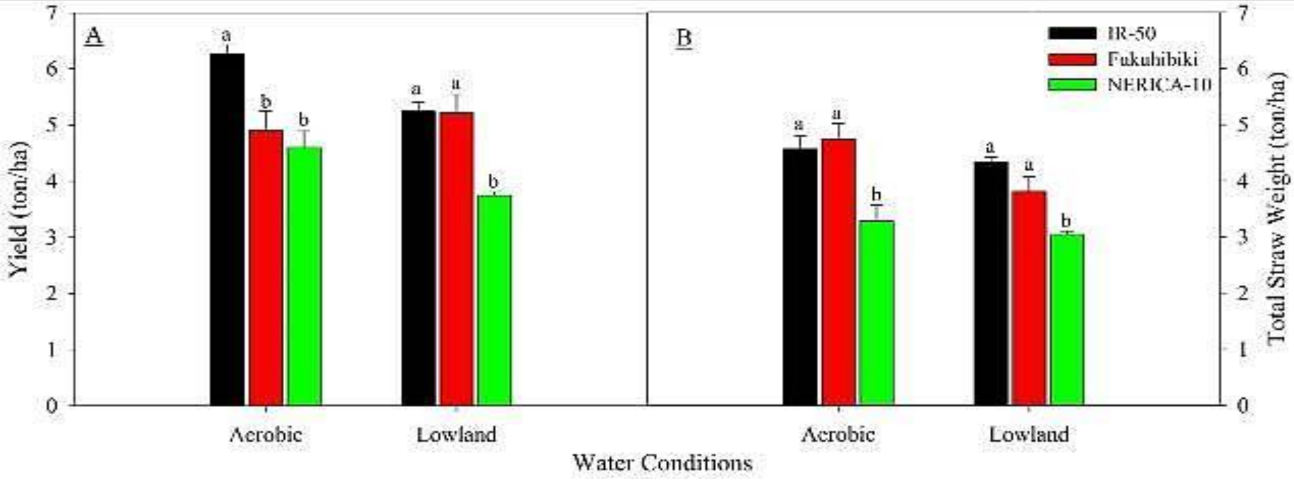

Fig. 3. Grain yield (ton/ha) (A) and Total straw weight (ton/ha) (B), alphabetical letters show significant ($p<0.05$) differences among varieties on selected water conditions.

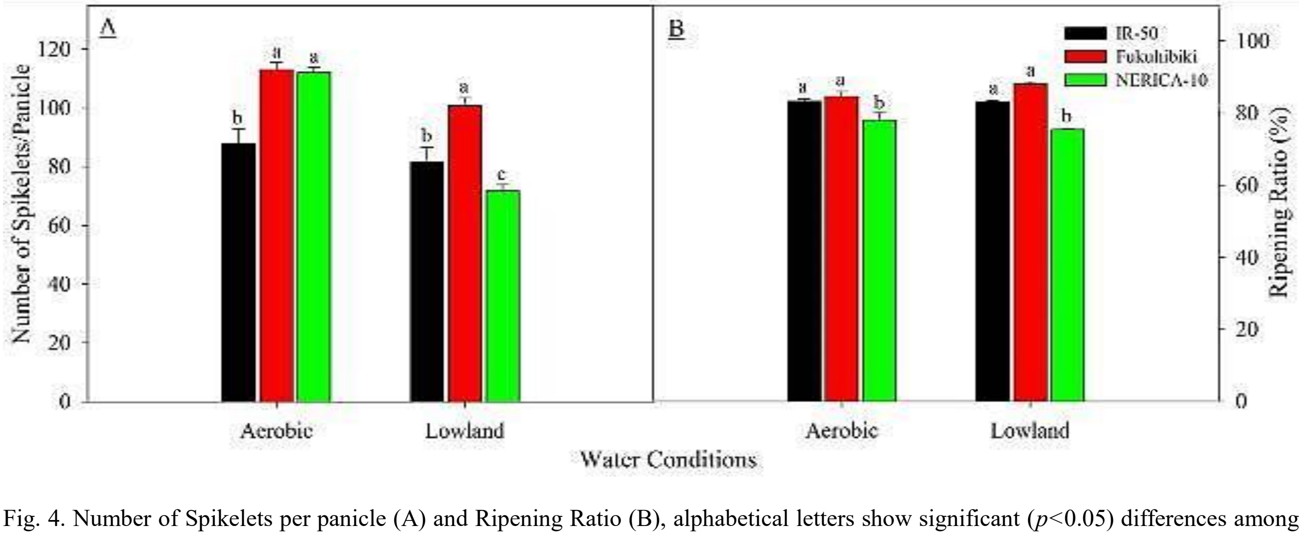

Fig. 4. Number of Spikelets per panicle (A) and Ripening Ratio (B), alphabetical letters show significant ($p<0.05$) differences among varieties on selected water conditions.

In respect to number of panicle/m^2, IR-50 showed significantly ($p<0.05$) higher in number of panicles per square meter compared to Fukuhibiki and NERICA-10 under both the aerobic and lowland conditions (Fig. 5A).Whereas, cultivars IR-50 and Fukuhibiki showed significantly($p<0.05$) higher sink size compared to NERICA-10 under lowland conditions. While, no significant differences were observed under aerobic conditions but a massive sink size was noticed in IR-50 (Fig. 5B). Findings revealed that IR-50 had potential to produce higher yields under water terrifying situation and fully flooded conditions with positive support of number of panicle per meter square. More sink size expressed positive effect towards grain yields, so IR-50 and Fukuhibiki maintained higher sink size under both the water conditions. Moreover, significantly higher 1,000 grains weight was observed in Fukuhibiki and NERICA-10 compared to IR-50 under both the lowland and aerobic conditions. While under lowland conditions, NERICA-10 also found significantly higher 1,000 grain weight as compared to Fukuhibiki (Fig. 6A). IR-50 had significantly higher number of spikelets per meter square as compared to NERICA-10 under both the water conditions. While, IR-50 showed different trend with Fukuhibiki as it had significantly higher spikelets number under aerobic conditions, whereas under lowland conditions no differences were observed (Fig. 6B). Results showed healthy grains also contribute toward yields, hence higher 1,000 grain weight was exhibited by Fukuhibiki and NERICA-10 under both the water conditions. Number of spikelets per meter square largely sustained yields and IR-50 retains higher number of spikelets compare to Fukuhibiki and NERICA-10 under both the conditions.

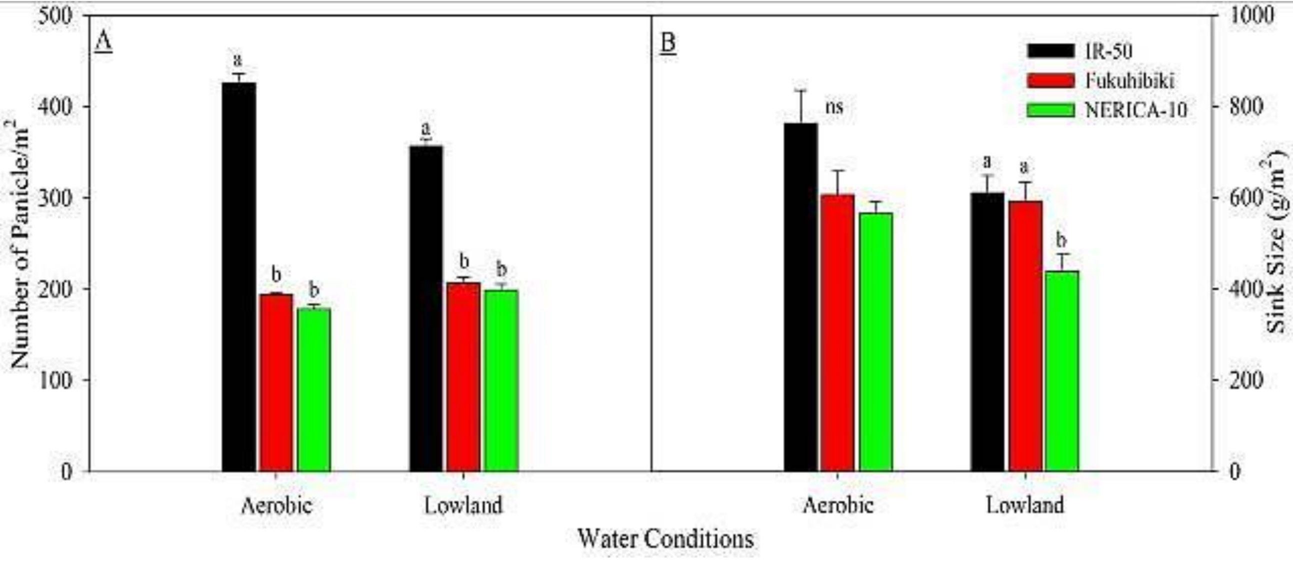

Fig. 5. Number of panicle/m^2 (A) and Sink size (g/m^2) (B), alphabetical letters show significant ($p<0.05$) differences among varieties on selected water condition.

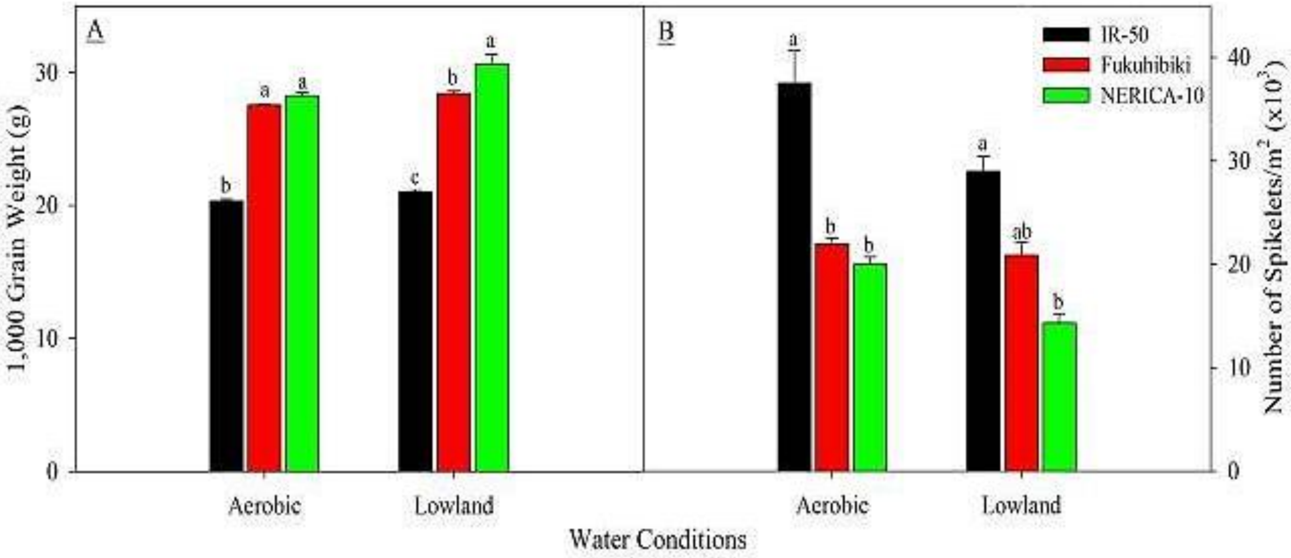

Fig. 6. 1,000 grain weight (A) and number of spikelets m^2 (x10^3) (B), alphabetical letters show significant differences among varieties under selected water condition.

For grain straw ratio, *Indica* cultivars; IR-50 and NERICA-10 produced significantly higher grain-straw ratio compared to *Japonica* cultivar Fukuhibiki under aerobic conditions. In contrast, a *Japonica* cultivar Fukuhibiki exhibited significantly higher grain-straw ratio compared to both *Indica* cultivars IR-50 and NERICA-10 under lowland conditions (Fig. 7A). Harvest index was significantly higher in IR-50 and NERICA-10 against Fukuhibiki under aerobic conditions. Fukuhibiki indicated significantly higher harvest index under lowland conditions compared to both IR-50 and NERICA-10 cultivars (Fig. 7B). It was observed that higher the grain-straw and harvest index resulting grain yield will be higher. Results suggested that IR-50 and NERICA-10 showed higher grain-straw ratio and harvest index under water scare conditions, while Fukuhibiki gave higher grain-straw ratio and harvest index under fully flooded conditions.Taking panicle length under consideration under aerobic conditions, NERICA-10 showed significantly higher panicle length compared to Fukuhibiki under lowland conditions in both *Indica* cultivars; IR-50 and NERICA-10 showed significantly higher panicle length compared to a *Japonica* cultivar Fukuhibiki (Fig. 8A). The cultivar IR-50 showed significantly smaller culm length compared to Fukuhibiki and NERICA-10 cultivars under aerobic conditions. However, no significant differences were observed among cultivars under lowland conditions (Fig. 8B). Findings revealed that higher panicle length possessed by NERICA-10 under aerobic conditions and IR-50 and NERICA-10 under lowland conditions. Bigger culm length is believed important for good yields under water frighten situation, NERICA-10 and Fukuhibiki retain higher culm length.

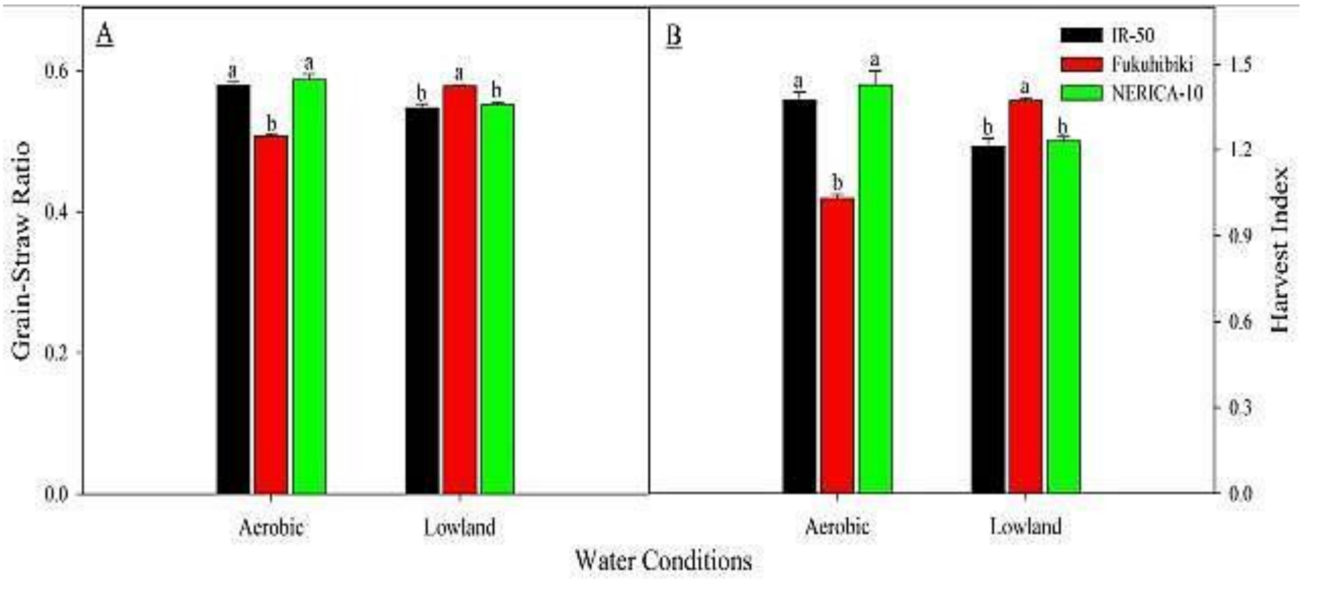

Fig. 7. Grain-straw ratio (A) and harvest index (B), alphabetical letters show significant ($p<0.05$) differences among varieties on selected water condition.

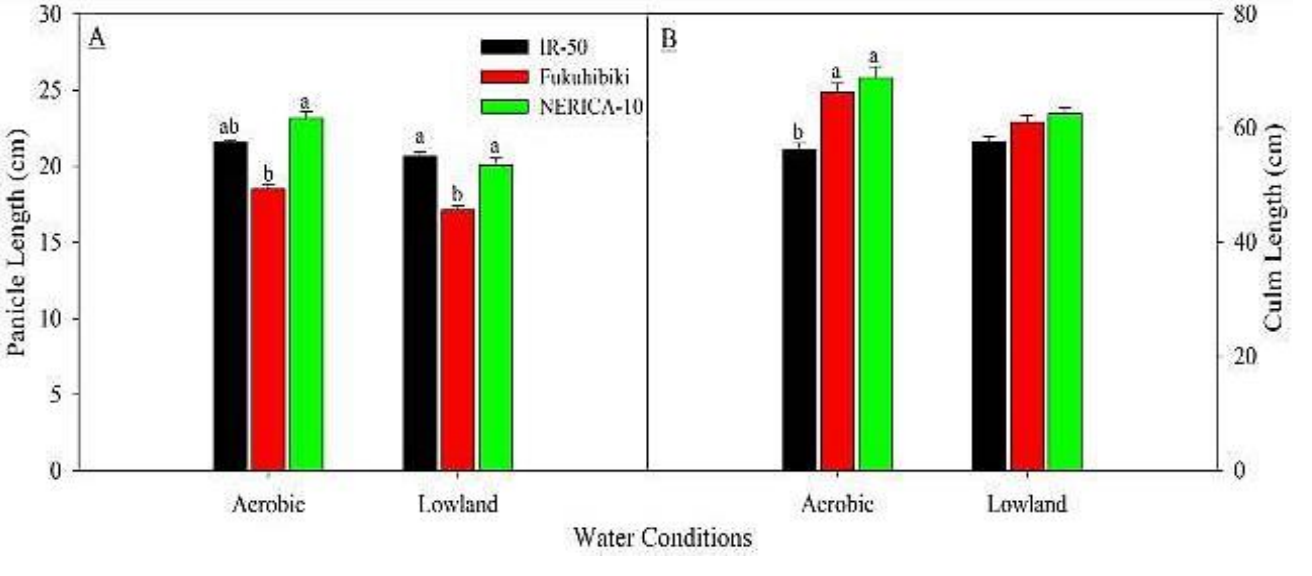

Fig. 8. Panicle length (cm) (A) and Culm length (cm) (B), alphabetical letters show significant ($p<0.05$) differences among varieties on selected water condition.

Total dry matter weight (Fig. 9) was significantly (p<0.05) higher in IR-50 compared to Fukuhibiki and NERICA-10 at maximum tillering and panicle initiation. While, IR-50 and Fukuhibiki showed significantly higher (p<0.05) total dry matter weight at full heading compared to NERICA-10. Similarly, IR-50 displayed significantly (p<0.05) higher total dry mass at full maturity compared to NERICA-10 under aerobic conditions. Under lowland condition, a similar kind of trend was observed where IR-50 showed significantly (p<0.05) higher total dry matter weight at maximum tillering and panicle initiation compared to NERICA-10 and Fukuhibiki. While same cultivar had significantly higher (p<0.05) total dry matter weight at full heading and full maturity stages compared to NERICA-10 only. Total dry matter weight was significantly (p<0.05) higher in IR-50 and Fukuhibiki at middle maturity compared to NERICA-10. Higher dry mass production means higher starch accumulation, resulting higher yields. IR-50 produced higher dry mass under both the conditions, this might result higher grain yields. With regard to total nitrogen absorption (Fig. 10), the *Indica* cultivars IR-50 and NERICA-10 showed higher nitrogen absorption compared to a *Japonica* cultiva; Fukuhibiki under aerobic conditions. Nitrogen absorption was higher in IR-50 followed by Fukuhibiki compared to NERICA-10 at almost all the growth stages under lowland conditions. Findings indicated IR-50 absorbed more nitrogen under both the water conditions compared to NERICA-10 and Fukuhibiki.

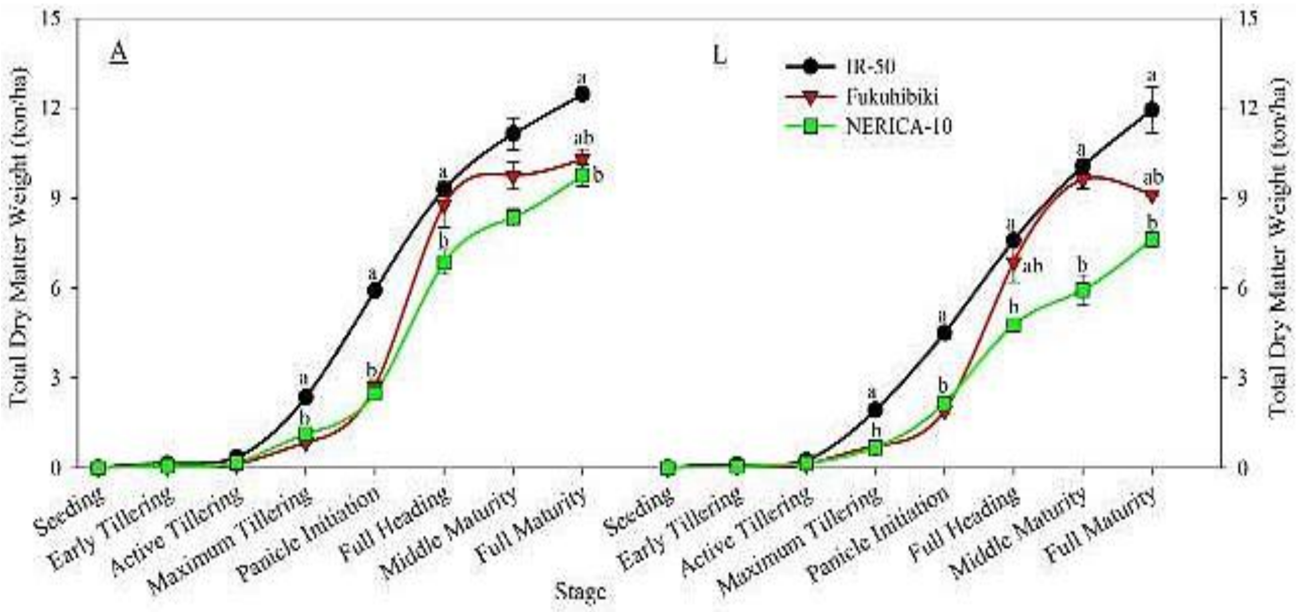

Fig. 9. Total dry matter weight (ton/ha) from seeding to full maturity stage under aerobic conditions (A) and lowland conditions (L), alphabetical letters show significant (p<0.05) differences among varieties on each selected growth stage.

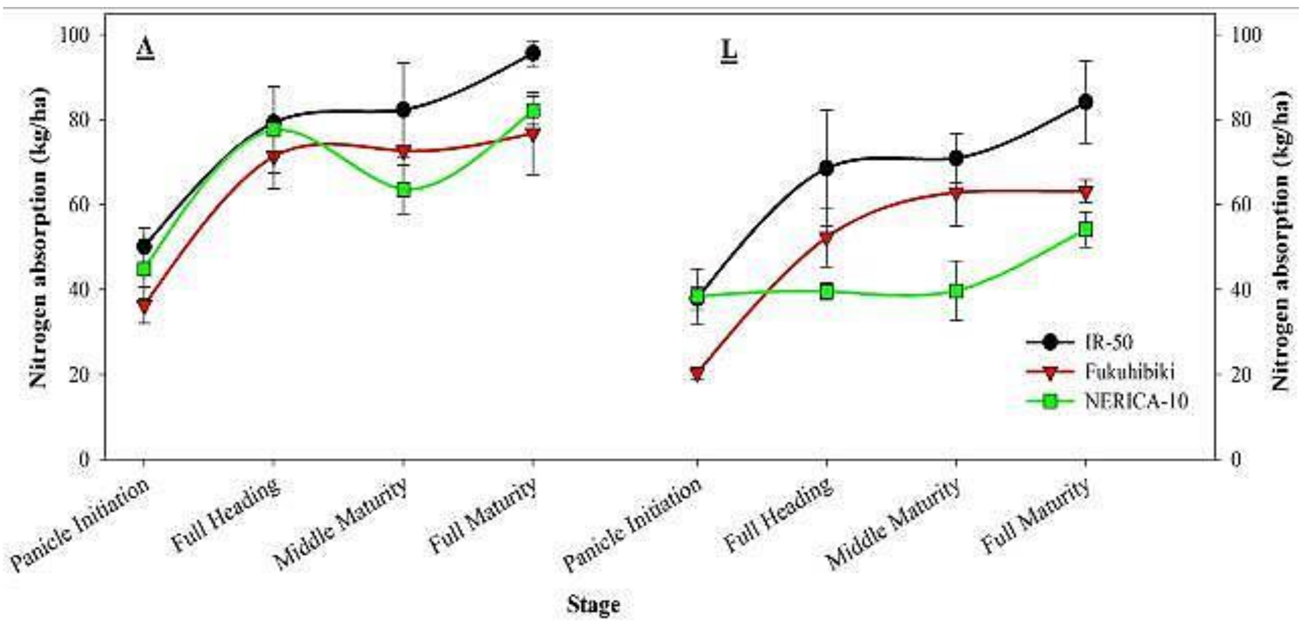

Fig. 10. Nitrogen absorption (kg/ha) from panicle initiation to full maturity under aerobic conditions (A) and lowland conditions (L).

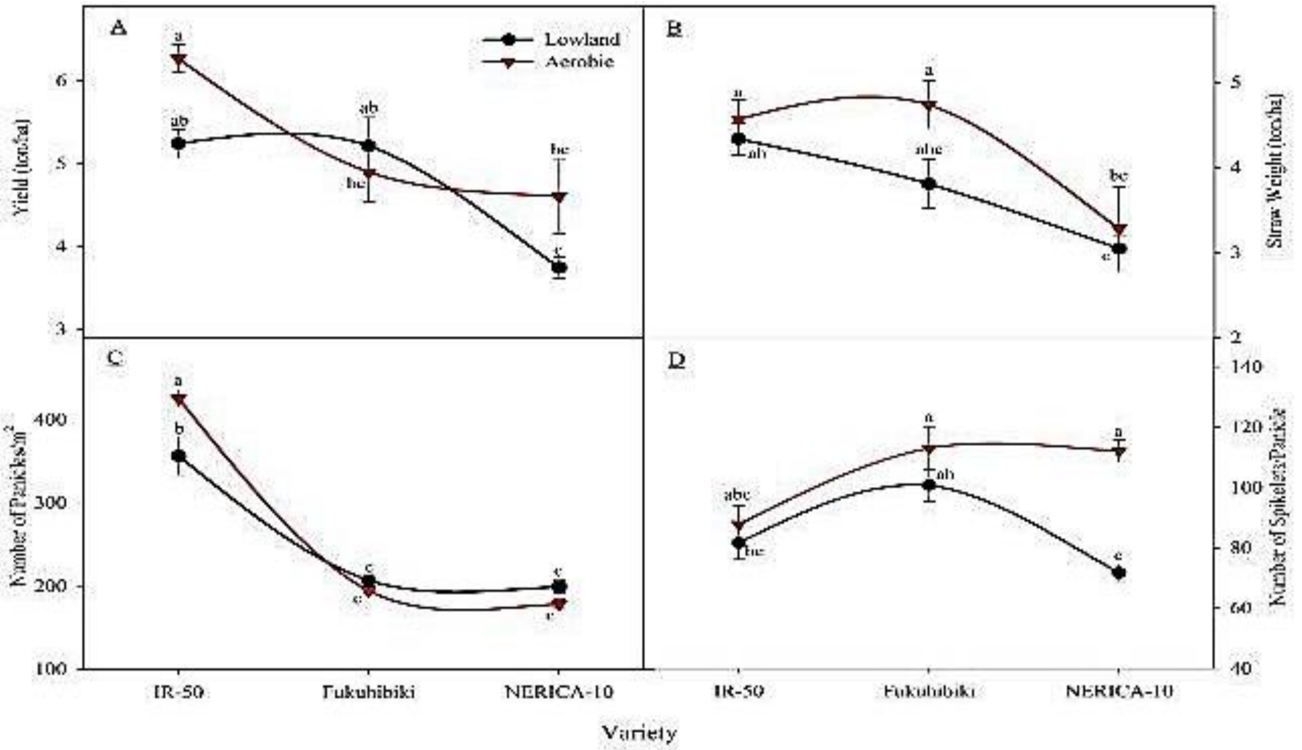

Fig. 11. Interaction between varieties and water conditions for yield ton/ha (A), straw weight ton/ha (B), number of panicles per square meter (C) and number of spikelets per panicle (D), alphabetical letters show significant ($p<0.05$) interactions between cultivars and water conditions.

Interactions were significantly ($p<0.05$) higher for varietal response over lowland and aerobic water conditions. Cultivar IR-50 performed better and gave significantly higher grain yield under aerobic conditions, while NERICA-10 had significantly worst grain yield under lowland conditions (Fig. 11A). Higher straw was produced by IR-50 and Fukuhibiki compared to NERICA-10 under aerobic conditions. Interactions were also significant ($p<0.05$) between aerobic and lowland conditions and more straw was recorded under aerobic conditions compared to lowland conditions (Fig. 11B). IR-50 showed significantly higher number of panicles under aerobic conditions, followed by same cultivar under lowland conditions compared to other cultivars (Fig. 11C). NERICA-10 and Fukuhibiki showed significant higher number of spikelets per panicle under aerobic conditions compared to all the other interactions among cultivars and water conditions. NERICA-10 also showed significant lower number of spikelets under lowland conditions (Fig. 11D). Interactions for ripening ratio were significantly different among the cultivars and water conditions. Ripening ratio was significantly higher in Fukuhibiki and lower in NERICA-10 under aerobic conditions and other interactions were intermediate (Fig. 12A). Interactions of varieties and irrigation conditions were significantly different for grain-straw ratio. NERICA-10 showed significantly higher grain-straw ratio under aerobic conditions, followed by IR-50 under aerobic and Fukuhibiki under lowland conditions. Grain-straw ratio was significant lower in Fukuhibiki under aerobic conditions (Fig. 12B). Interactions between cultivars and water conditions were significantly ($p<0.05$) higher as NERICA-10 showed significantly ($p<0.05$) higher 1,000 grain weight under lowland conditions, followed by NERICA-10 also under aerobic and Fukuhibiki under lowland conditions. 1,000 grain weight was significantly ($p<0.05$) lower in IR-50 under both the water conditions (Fig. 12C). Number of spikelets per square meter had shown significantly ($p<0.05$) different interactions among all the cultivars and both the water conditions. The cultivar IR-50 had retained significant ($p<0.05$) higher number of spikelets per square meter under aerobic conditions, followed by IR-50 and Fukuhibiki under lowland conditions and Fukuhibiki and NERICA-10 under aerobic conditions. While, the significant ($p<0.05$) lower number of spikelets per square meter was observed in NERICA-10 under lowland conditions (Fig. 12D). Interactions for the panicle length among water conditions and varieties were also significant ($p<0.05$). NERICA-10 showed significantly ($p<0.05$) longer panicle length under aerobic conditions, followed by IR-50 under aerobic and lowland and NERICA-10 under lowland conditions. The lowest ($p<0.05$) panicle length was recorded in Fukuhibiki under lowland conditions (Fig. 12E). Both the water conditions and all the three rice cultivars had significantly ($p<0.05$) higher interactions for culm length. NERICA-10 showed significantly ($p<0.05$) higher culm length under aerobic conditions followed by Fukuhibiki under aerobic, NERICA-10 and Fukuhibiki, IR-50 under lowland conditions. The culm length was significantly ($p<0.05$) smaller in IR-50 under aerobic conditions, this might result no lodging in this cultivar (Fig. 12F). Findings clearly indicated that all the cultivars responded differently to water conditions for yield and yield components. The cultivars IR-50 and Fukuhibiki positively interact with both the water conditions. While cultivar NERICA-10 exhibited positive interactions under aerobic conditions and negative under lowland conditions. Interactions for nitrogen absorption at different growth stages, *Indica and Japonica* rice cultivars were significantly (p<0.05) different under both the water conditions (Fig. 13). IR-50 absorbed significantly (p<0.05) higher nitrogen at panicle initiation stage under aerobic conditions followed by IR-50 and NERICA-10 under lowland and Fukuhibiki and NERICA-10 under aerobic conditions. While, the lowest (p<0.05) nitrogen absorption was recorded in Fukuhibiki under lowland conditions. IR-50 and NERICA-10 had significantly (p<0.05) higher nitrogen absorption at full heading stage under aerobic conditions followed by Fukuhibiki under aerobic and IR-50 and Fukuhibiki under lowland conditions. Nitrogen absorption was significantly (p<0.05) lower in NERICA-10 at full heading stage under lowland conditions. Interactions were also significantly (p<0.05) higher among cultivars and water conditions at middle maturity stage. IR-50 showed significantly (p<0.05) higher nitrogen absorption under aerobic conditions followed by Fukuhibiki and NERICA-10 under lowland, and IR-50 and Fukuhibiki under lowland conditions. NERICA-10 showed significantly (p<0.05) lower nitrogen absorption under lowland conditions at middle maturity stage. Interactions for nitrogen absorption at full maturity were similar as at middle maturity stage among all the cultivars and both the aerobic and lowland water conditions. Our findings clearly suggested that higher nitrogen absorption by all the cultivars under aerobic conditions was because of strong root network this resulted outcome higher grain yields under aerobic conditions.

Discussion

Growing paddy under lowland conditions has been engaged continuously since many centuries, but the “threatening water crisis” may change the approach of rice production in future. Under traditional lowland method, paddy cultivation requires 400 to 5000 liters of fresh water to produce each kilogram of paddy grains (Thakur *et al*., 2014 and Tabbal *et al*., 1992). Hence the objectives of this research are to save irrigation water and obtain good grain yields under water scaring scenario compared to traditional lowland paddy cultivation method.

In present study, about 59% total irrigation water (12.2 million litres/ha) was saved under aerobic conditions compared to traditional lowland paddy cultivation method (Fig. 1). This was because of efficient water use and application timetable of irrigation water under aerobic conditions (Fig. 2). In this connection, 1627 litres water were utilized to produce one kilogram of paddy grains under aerobic conditions and 4375 litres under lowland (Bouman *et al*., 2002) have indicated that 50% irrigation water can be saved under aerobic cultivation as compared to lowland cultivation. Lowland paddy utilizes 2-3 times more irrigation water as compared to aerobic crops like wheat and maize (Grassi *et al*., 2009). The potential irrigation water will be saved when rice is grown as an aerobic crop (Bouman, 2001). Better adaptation was observed in IR-50 cultivar, which exhibited higher nitrogen absorption under aerobic conditions (Fig. 10), this also had resulted higher grain yields 6.3 ton/ha under aerobic conditions compared to lowland conditions 5.2 ton/ha (Fig. 3). Grain yields in aerobic conditions were identified to be maintained or even surpass than lowland conditions in China (Li, 2001). These results were also in substantial agreement with (Chan *et al*., 2012), who harvested 4.7 to 6.6 ton grain yield per hectare under aerobic conditions. The same cultivar showed smaller culm size (Fig. 8B), this might expressed tolerance to lodging under aerobic conditions, which was the main factor of adaptation under the water threatening conditions. Higher nitrogen absorption (Fig. 10) retained a greater number of panicles and spikelets, higher tiller number, total dry matter weight, higher panicle number, ripening ratio, grain-straw ratio and finally grain yields. Hence, this cultivar performed better in water scaring conditions compared to lowland conditions. (Jing *et al*., 2006). It was found that the cultivars showed high grain yield retained higher number of panicle and spikelets number, while increasing nitrogen absorption had reflected with increase in number of spikelets and grain yield (Jing *et al*., 2006). The cultivars accumulated higher dry mass have maintained higher photosynthetic activity and acquired superior yields (KeZhang & Zhang, 2014).

An upland cultivar, NERICA-10 maintained higher grain yields of 4.6 ton/ha also under aerobic conditions compared to lowland conditions (3.74 ton/ha). NERICA-10 retained higher 1,000 grain weight, grain-straw ratio and culm length under aerobic and lowland conditions. NERICA-10 also showed higher nitrogen absorption at full heading and suddenly dropped at middle maturity to full maturity stages under aerobic conditions, this may be the reason of decreasing the grain yields compared to IR-50 cultivar. Similarly, NERICA-10 showed lower nitrogen absorption under lowland conditions resulting lower grain yields under lowland conditions. Culm length under aerobic conditions is an important trait to be considered hence NERICA-10 retained higher culm length that may be somehow lodging susceptible under water threatening situation. These results were in line with Sandhu *et al.*, (2019), where five different rice cultivars were tagged as potential breeding materials for aerobic rice breeding. Moreover, a set of new rice varieties had also been released for commercial cultivation after assessing their genetic potential by aerobic cultivation in India (Gandhi *et al*., 2012; Sandhu and Kumar, 2017). Joshi *et al.*, (2018) also reported that DRRH-2 produced improved number of panicles, spikelets number and maximum filled grain number under aerobic conditions, ensuing in the higher grain yield. In contrast, several reports (Kreye *et al*., 2009; Patel *et al*., 2010; Shah *et al*., 2011; Jana *et al.*, 2013) reported a severe loss in grain yield due to aerobic mode of cultivation. NERICA-10 cultivars panicle can stand with only few grains because they belong to wild type parent (*Oryza glaberrima*) and the most cultivars having higher culm are sensitive to lodging (Ishii, 2003; Heuer *et al*., 2003).On the other hand, Fukuhibiki a *Japonica* cultivar had higher grain yields of 5.12 ton/ha under lowland conditions compared to aerobic conditions 4.9 ton/ha. Fukuhibiki had resulted good ripening ratio, sink size, 1,000 grain weight and straws production. While, grain yields were higher under lowland conditions compared to aerobic conditions, this might be due to higher nitrogen absorption under lowland conditions. This cultivar also holds higher culm length identical to NERICA-10, this may even lodge under different water and environmental conditions.

Interactions for grain yields and yield components were significant among all the varieties and both the water conditions. Bouman *et al*., (2002) and Akter *et al.*, (2016) found higher interactions among varieties and water conditions. Under aerobic conditions, average grain yields were higher (5.3 ton/ha) than those of lowland conditions (4.7 ton/ha). Hence ~11% more grain yields were obtained under aerobic conditions compared to lowland conditions with 59% less irrigation. Many researchers indicated that the aerobic cultivation is a water saving technology (Bouman, 2001, Bouman & Tuong 2001, Bouman *et al*., 2002; Grassi *et al*., 2009 & Nei *et al*., 2012). In present study, 11% more grain yields were produced and these were paired with the saving of 60% fresh irrigation water under aerobic cultivations. Hence this paddy cultivation technology is recommended to apply in Asia to tackle water scarcity, which is being predicted by 2025. Higher dry mass production in relation with higher nitrogen absorption under aerobic conditions suggests that selected cultivars have developed strong and deeper roots network to absorb required nutrients under water frightening scenario. Interactions were also higher among all the varieties and both the water conditions, while better performance of lowland (IR-50) and upland (NERICA-10) cultivars was observed under aerobic system. On the other hand, cultivar Japonica (Fukuhibiki) showed better performance under lowland conditions. Considering above varietal performance significantly higher interactions between varieties and water conditions were observed.

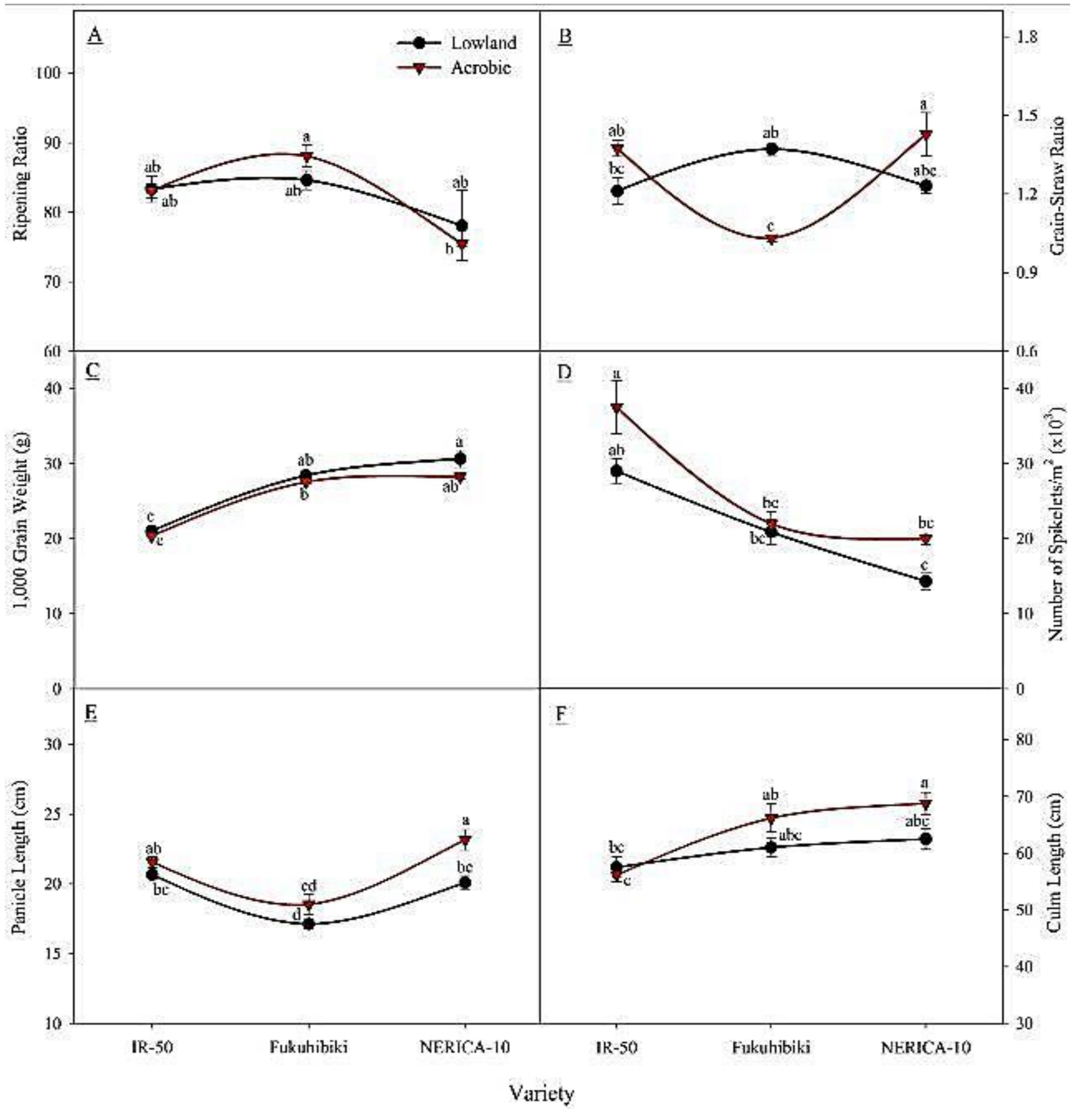

Fig. 12. Interaction between varieties and water conditions for ripening ratio (A), grain-straw ratio (B), 1,000 grain weight (C), number of spikelets/m^2 (D), panicle length (E) and culm length (F), alphabetical letters show significant (P<0.05) interactions beween cultivars and water conditions.

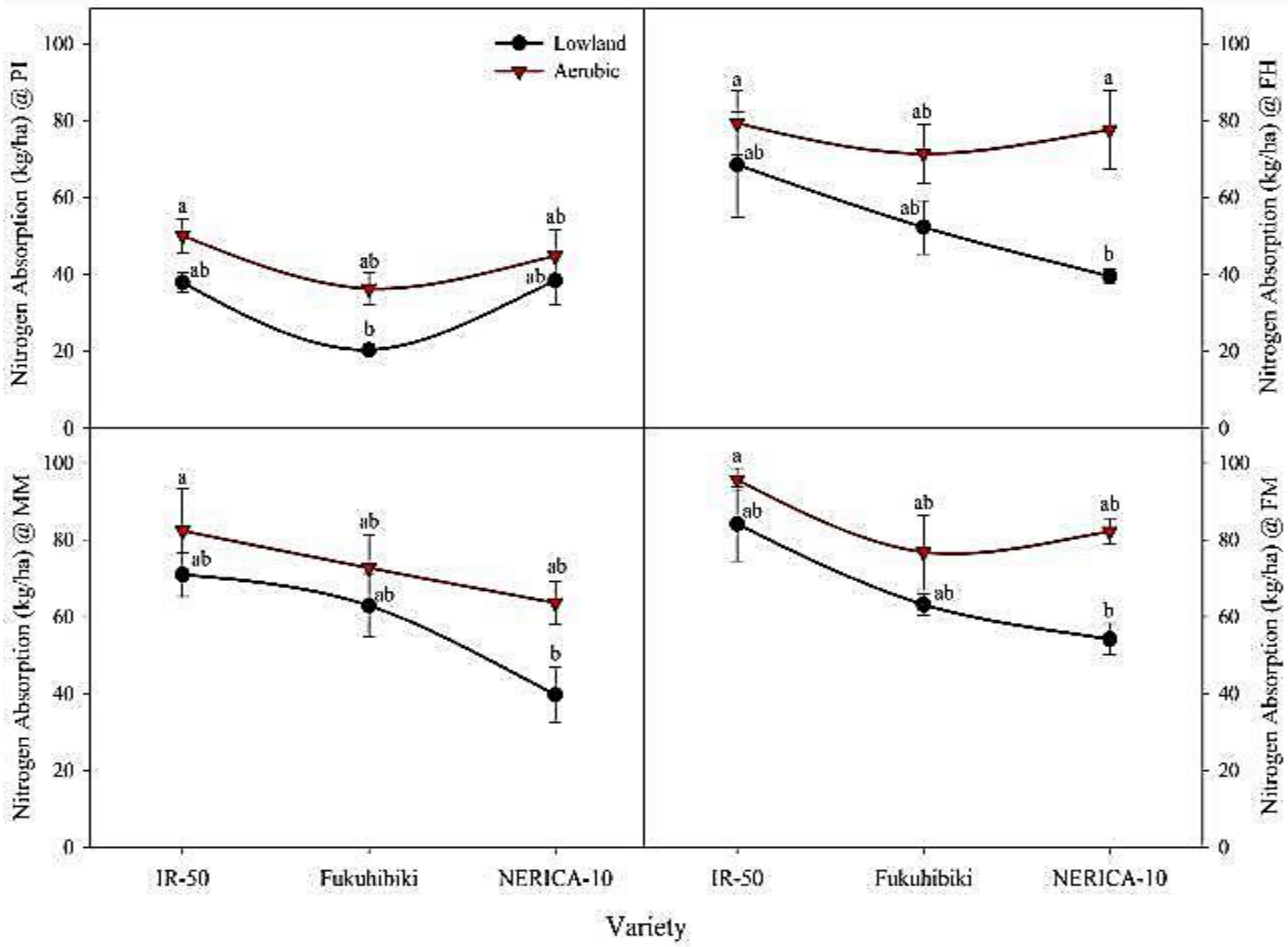

Fig. 13. Interaction between varieties and water conditions for nitrogen absorption (kg/ha) at different growth and maturity stages, PI= Panicle Initiation (A), FH= Full Heading (B), MM= Middle Maturity (C) and FM= Full Maturity (D), alphabetical letters show significant ($p<0.05$) interactions between cultivars and water conditions.

Conclusions

It is therefore concluded that upland and lowland cultivars are adaptive under aerobic conditions, ~59% of the total irrigation water and ~72% of the freshwater was saved under aerobic conditions respectively, except rainfall as compared to lowland conditions. While, the cultivar *Indica* IR-50 showed higher grain yields under aerobic conditions as compared to lowland. Finally, aerobic cultivation reduces GHGs (CH_4 and N_2O) emission, which is an eco-friendly practice compared to traditional fully flooded lowland cultivation, however emission of GHGs (CH_4 and N_2O) increases under traditional rice farming (Imran *et al*., 2017).

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