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EFFECTS OF IRRIGATION SCHEDULING AT DIFFERENT MANAGED ALLOWABLE DEPLETION IN SALINE SOIL ON THREE RICE VARIETIES

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ABSTRACT

The increasing scarcity of freshwater is threatening the sustainability of irrigated rice. Irrigation scheduling when water is inadequate within the paddy sodic soil can be an alternative to sustain rice crop production. This study focuses on observing the crop growth parameters and yield response of three rice varieties. Three salinity levels were prepared to 1.05 dS/m, 1.55 dS/m and 2.08 dS/m. Four moisture contents were set up to flooded water content, 0.1 to 0.33 bar, 0.45 MAD and 0.60 MAD. Three rice varieties, Pathum Thani 1 (PPT1), PPT1 mutant, and Nerica3 were assigned to the treatments. At flooded water content, both growth and yield were higher, the highest yield recorded was 26.11 g pot^{-1} in PPT1 mutant at 1.05 dS/m with decreases in yield at higher electrical conductivity at saturation extract (ECe) levels in PPT1 variety. All three varieties responded to lower yield in more delayed irrigation scheduling. At 0.1 to 0.33 bar, the yield gap was around 34.5, 35 and 27% lower than that of the flooded water content for PPT1, PPT1 mutant, and Narica3. At 0.45 and 0.60 MAD, yield appeared in Narica3 only. Crop water use was higher in PPT1 mutant at 1.05 dS/m in all the moisture contents, with 5.61 mm/day recorded at flooded water content. The study concludes that the reduction in moisture content from flooded water content to 0.1 to 0.33 bar up to 0.45 MAD and 0.60 MAD has affected both crop growth and yield of rice among all varieties.

Disciplinary: Agricultural and Irrigation Sciences.

1. INTRODUCTION

The increasing scarcity of freshwater due to demand by several bodies is threatening the sustainability of irrigated rice (Bouman & Tuong, 2001). As less water will be available for growing rice, an increase in rice production must keep pace to meet up with the population growth which was estimated to reach 8 billion people by 2025 as projected by the United Nations (Khush, 2005). Producing more rice with less water is, therefore, a challenging task for the food, economic, social and water security of rice production regions globally (Facon, 2000). Reduction in rice yield can be termed as a threat to food security and can also affect the livelihood and economy of more than 3 billion people which rely solely on rice as their primary food source (Van Nguyen & Ferrero, 2006). Rice may not necessarily require much flood as the existing conventional practice as most of the water applied is lost due to seepage, deep percolation and high evapotranspiration due to the high flooding level. Excessive flooding in the paddy field increases percolation which contributes reasonably to water loss than providing the required water need by the rice plant for optimum productivity (Tuong & Bhuiyan, 1999).

Effective water management practice within the salinity threshold of rice can serve as an alternative means to sustain rice crop production in the growing challenges of water scarcity (Maas & Hoffman, 1977). Reported that, rice can withstand a salinity level of up to 3.0 dS/m but will suffer a decrease in yield loss of about 12% for every increase in a unit of dS/m. This study, therefore, aimed at producing rice, by using four different moisture contents within the salinity tolerant limit of rice and focused on observing the crop growth parameters and yield response of three different varieties of rice.

2. METHODOLOGY

The study was conducted in a greenhouse at Kasetsart University, Bangkok of Thailand. The average temperature and the average relative humidity at the greenhouse were 32^0C and 65% respectively. Enclosed pot with a top opening measuring 40 cm × 40 cm to prevent losses due to seepage and percolation were filled with a sandy loam soil volume of 48,000 cm^3 with a plant density of four plants per pot. Three salinity levels were adjusted using sodium chloride (NaCl) according to the salinity adjustment method provided by (Rhoades & Chanduvi, 1999). However, little adjustments were made: 20 g and 30 g of sodium chloride (NaCl) were diluted in separate containers with an equal volume of water, and another container was filled with water without sodium chloride (NaCl) at all, the solution was then poured into the experimental soil. The samples were further collected and the electrical conductivity at saturation extract (ECe) was determined in the laboratory. The corresponding electrical conductivity at saturated extract were 1.05 dS/m, for the experimental soil which no sodium chloride was added (actual ECe of the experimental soil), 1.55 dS/m for the sample which 20 g of sodium chloride (NaCl) was added and 2.08 dS/m for the sample which 30 g of sodium chloride (NaCl) was added. Fertilizer was applied based on the nutrient requirements of the soil at a recommended rate.

Four different moisture content were prepared based on the soil moisture tension relationship of the experimental soil. The experimental soil has the following moisture content, tension relationship: At 15.47% moisture content, the soil tension is 0.1 bar, at 10.13% moisture content (field capacity), the soil tension is 0.33 bar, at 9% moisture content, the soil tension is 0.5 bar, at 7.72%, the soil tension is 1 bar and at 4.4% moisture content (permanent wilting point), the soil tension is 15 bar. Hence, the four (4) different levels of water content were prepared as follows: The control is maintained at flooded level which was named moisture content 1 (MC1), MC2 was managed between soil moisture tensions of 0.1 bar to 0.33 bar (above field capacity which is 0.33 bar), MC3 was managed at 0.45 manageable allowable depletion (MAD), thus, the volumetric water content has to deplete to 0.45 MAD before irrigation water is applied up to field capacity. Similarly, MC4 was managed at 0.60 MAD. Thus, the volumetric water was allowed to deplete up to 0.60 MAD before irrigation water is applied up to field capacity (Figure 1).

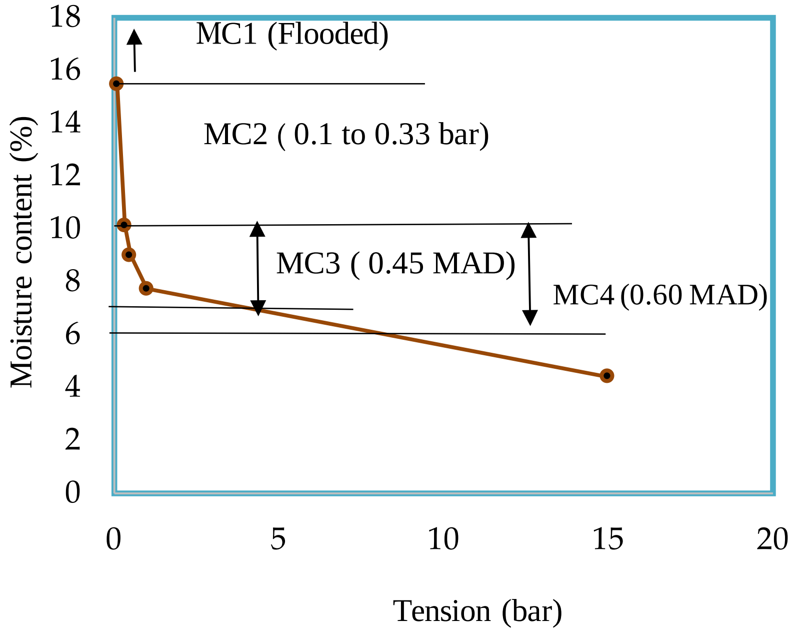


Figure 1: Preparation of different irrigation frequency schemes

MC1 (flooded) represent irrigation scheme at flooded water content, MC2 (0.1 to 0.33 bar) represent irrigation scheme for moisture content managed between 0.1 bar to 0.33 bar soil tension, MC3 (0.45 MAD) represent irrigation scheme managed at 0.45 MAD and MC4 (0.60 MAD) represent irrigation scheme managed at 0.60 MAD.

Three different rice varieties namely, Pathum Thani 1, Pathum Thani 1 mutant and new rice for Africa (Nerica3) were assigned to the treatments in randomized complete block design. The treatment combination of moisture content (MC), soil ECe and rice variety is 4x3x3 factorial with a total of 36 treatments, replicated three times.

2.1 IRRIGATION APPLICATION AT VARIOUS SOIL MOISTURE CONTENTS (MC)

Irrigation water was maintained at 2.5 cm above the soil surface after planting for one (1) week at all pots. Adjustment begins after one week at all the MC's. Volumetric water content was monitored regularly at all treatments on a daily basis using ProCheck 5TE (water content, EC and temperature sensor, Decagon Device). The depleted percentage of moisture content is then calculated and recorded.

$$PV = \frac{d}{D} \times 100 \quad (1),$$

where PV is the percentage of volumetric water content d refers to the depth of the total available water and D depth of soil.

Hence, the equivalent volume of water depleted is been calculated and applied in volume (liters).

$$V = A \times d \quad (2),$$

where V the volume of water applied is, A refers to area irrigated and d refers to the depth of total available water depleted.

Crop water use was determined by dividing the volume of irrigation water applied by the irrigated area (mm^3/mm^2). Rice growth and yield parameters data were collected in line with the standard evaluation system for rice provided by the International Research Institute of Rice (IRRI 2002). Rice root was removed using an electric pressure pump and measured. The plant dry weight (above-ground biomass) was oven dried for 72 hours at 70^0 C and weighed using an electronic digital weighing scale.

2.2 EXPERIMENTAL VARIETIES

Pathum Thani 1 (PPT1): PPT1, is a semi-dwarf photoperiod insensitive low land rice variety, which can be grown all year round. It is widely grown in the dry season in Thailand's irrigated areas with plenty of water during the dry season (Sreethong et al., 2018). Pathum Thani 1 mutant (PPT1 mutant) is an induced mutant of PPT1using gamma-ray (Mekaroon et al., 2013). New Rice for Africa (Nerica3) is a variety developed from crosses between *Oryza glaberirima* and *Oryza sativa* species which is specifically targeted at upland and dry areas of sub-Saharan Africa (Jones et al., 1997). Harvesting duration among varieties differs as the varieties reach maturation differently. Nerica3 was harvested at 90 days after planting while PPT1 and PPT1 mutant were harvested at 115 days after planting.

3. RESULTS AND DISCUSSION

3.1 CROP WATER USE OR CONSUMPTION RATE

The irrigation frequency among the MC's generated more and more drought starting from MC1 MC2, MC3, and MC4 (Figure 1). Crop water use among the varieties was high in PPT1 mutant followed by PPT1 and Nerica3 at all MC. Consequently, the consumption rate was high among all the varieties at the lowest ECe level (1.05 dS/m) and the water use decrease with an increase in ECe. The highest crop water use recorded was 5.61 mm/day in MC1 at 1.05 dS/m ECe in the PPT1 mutant (Figure 2a). There was no significant difference statistically at $P \geq 0.05$ among three (3) ECe levels in crop water use at MC1 in same variety The higher crop water use, as well as yield recorded in PPT1 mutant, can be attributed to it higher above-ground biomass which is link to high crop water use as reported by (San-Oh et al., 2008). Which reported that high yielding rice varieties are characterized by higher above-ground biomass as well as high water uptake. Similarly, crop water use recorded at 1.55 dS/m and 2.08 dS/m are lower than that of 1.05 dS/m which could be the influence of salinity stress over the plant water uptake as reported by (Castillo et al., 2015).

3.2 PLANT HEIGHT

Plant height decreases with a decrease in MC among all the varieties and with no significant difference at ECe level within MC at $P \geq 0.05$. However, there is a highly significant difference in plant height among the varieties at $P < 0.01$, as PPT1, and PPT1 mutant with more height compared to that of Nerica3 (Figure 3). The decrease in plant height with a decrease in MC could be due to the stress response of rice to avoid both drought and salinity stress as reported by (Vani et al., 2017).

Plant height recorded at MC3 is similar to that of MC4 in this experiment despite the higher drought before irrigation in MC4 over that of MC3. Lower plant height difference both in MC3 and MC4 compared to that of MC1 in Narica3 revealed the better tolerant in drought and ECe.

3.3 ROOT LENGTH

Root length among varieties was higher in Nerica3 at all the MC levels and the highest root length was recorded in MC2 at 1.05 dS/m in Nerica3 (61 cm) (Figure 4b). The root length among all varieties increased at MC2 compared to MC1 this could be due to drought response of the rice crop as reported by (Anupama et al., 2019). However, at MC3 and MC4 the root decreased compared to that of MC2 and the root length decreases with an increase in ECe among all the varieties, this could be due to combining the stresses of drought and salinity which were said to hinder both growth and development (Hussain et al., 2017). They reported that salinity decreases both growth and development of root thereby affected rice water uptake, growth, and yield. Under severe drought, rice roots seize to grow (Pandey & Shukla, 2015).

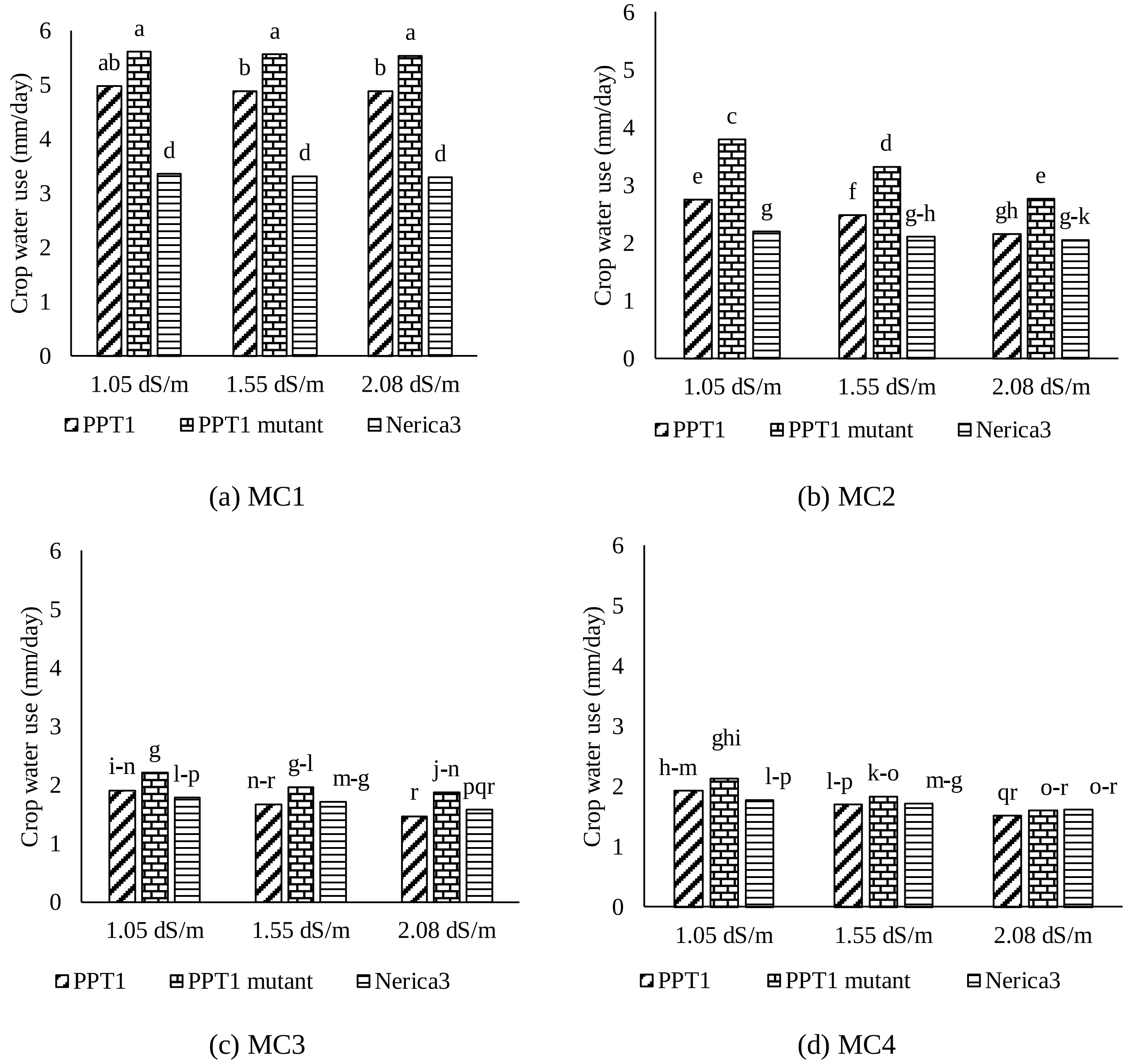


Figure 2: Crop water use among PPT1, PPT1 mutant and Nerica3 at different MC level under different ECe levels

Crop water use determined in this experiment does not include losses due to percolation, and seepage. MC1, MC2, MC3, and MC4 represent soil moisture content at flooded level, at tension from 0.1 to 0.33 bar, at 0.45 MAD and 0.60 MAD. PPT1, PPT1 mutant, and Nerica3 represent rice varieties: Pathum thani 1, Pathum thani 1 mutant and new rice for Africa.

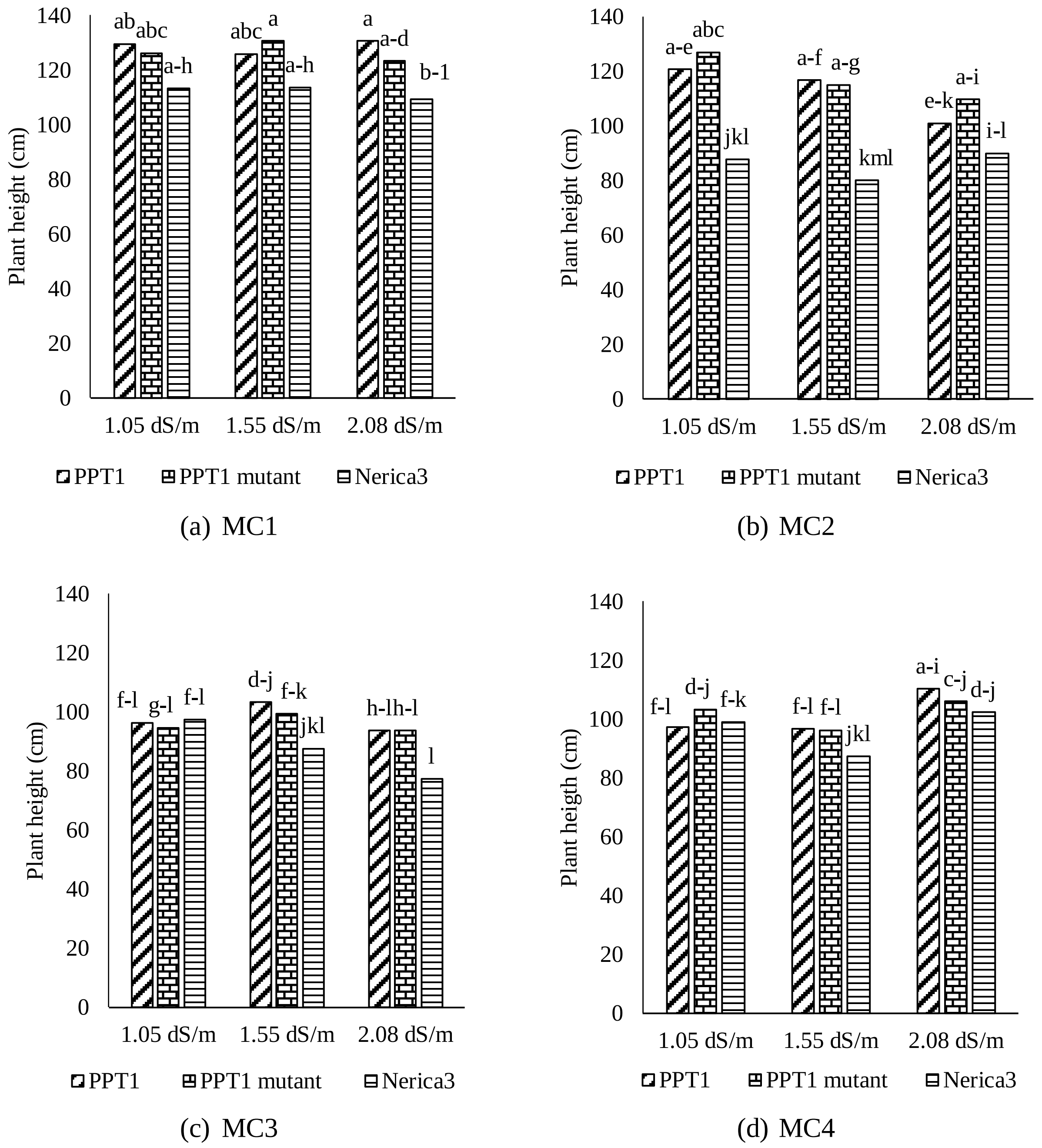


Figure 3: Interactions between MC, ECe, and varieties on plant height

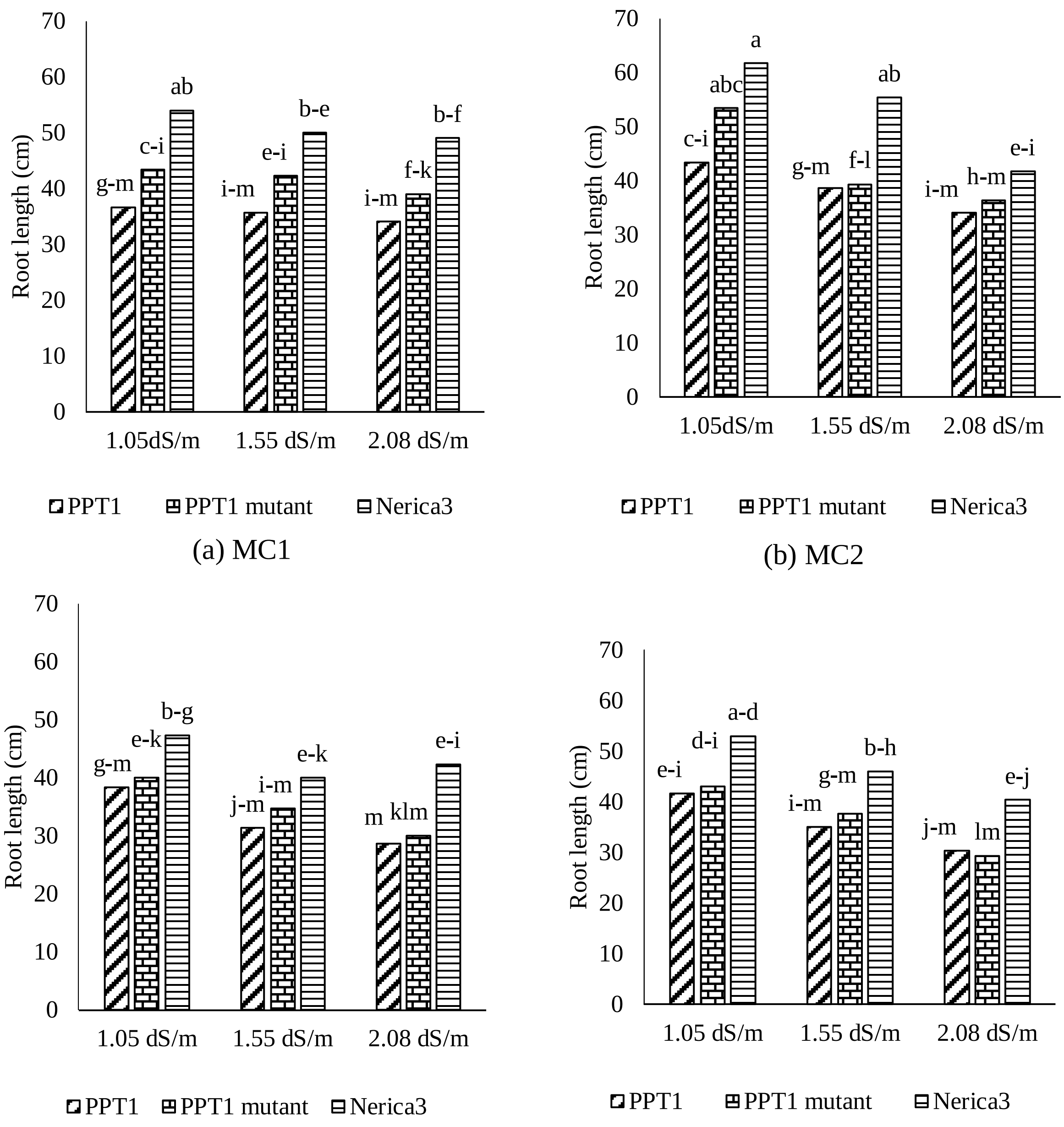
MC1, MC2, MC3, and MC4 represent soil moisture content at flooded level, at tension from 0.1 to 0.33 bar, at 0.45 MAD and 0.60 MAD. 1.05 dS/m, 1.55 dS/m and 2.08 dS/m, represent values of electrical conductivity at saturation extract (ECe). PPT1, PPT1 mutant and Nerica3 represent rice varieties: Pathum thani 1, Pathum thani 1 mutant and new rice for Africa.

3.4 TILLER NUMBER

The tiller number among the varieties was recorded higher at MC2 in PPT1 and PPT1 mutant with no significant difference among ECe within MC, and PPT1 mutant recorded the highest tiller number among the varieties (Figure 5b). Nerica3 has the least tiller number at all MC and at all ECe levels and the tiller number decreases with a decrease in moisture content in the case of Nerica3. High tiller number were recorded in both MC3 and MC4 at all ECe levels for PPT1 and PPT1 mutant, even though the tillers were not productive. Both PPT1 and PPT1 mutants have productive tillers at only MC1 and MC2, while Nerica3 produces productive tiller at all MC levels.

3.5 PLANT DRY WEIGHT

The Plant dry weight of the above-ground biomass was recorded high in PPT1 mutant followed PPT1 with Nerica3 yielding the least among the varieties. The highest plant dry weight was recorded in the PPT1 mutant at MC1 under 1.05 dS/m (Figure 6a). Statistically, there is no significant difference at $P \geq 0.05$ in the plant dry weight at all the ECe levels. Moreover, there is a highly significant difference at $P < 0.01$ in plant dry weight among varieties as well as among MC levels. The weight decreases with a decrease in moisture content among all the varieties.



(c) MC3 (d) (MC4)

Figure 4: Integrations between MC, ECe, and varieties on root length

MC1, MC2, MC3, and MC4 represent soil moisture content at flooded level, at tension from 0.1

to 0.33 bar, at 0.45 MAD and 0.60 MAD. 1.05 dS/m, 1.55 dS/m and 2.08 dS/m, represent values of electrical conductivity at saturation extract (ECe). PPT1, PPT1 mutant, and Nerica3 represent rice varieties: Pathum thani 1, Pathum thani 1 mutant and new rice for Africa.

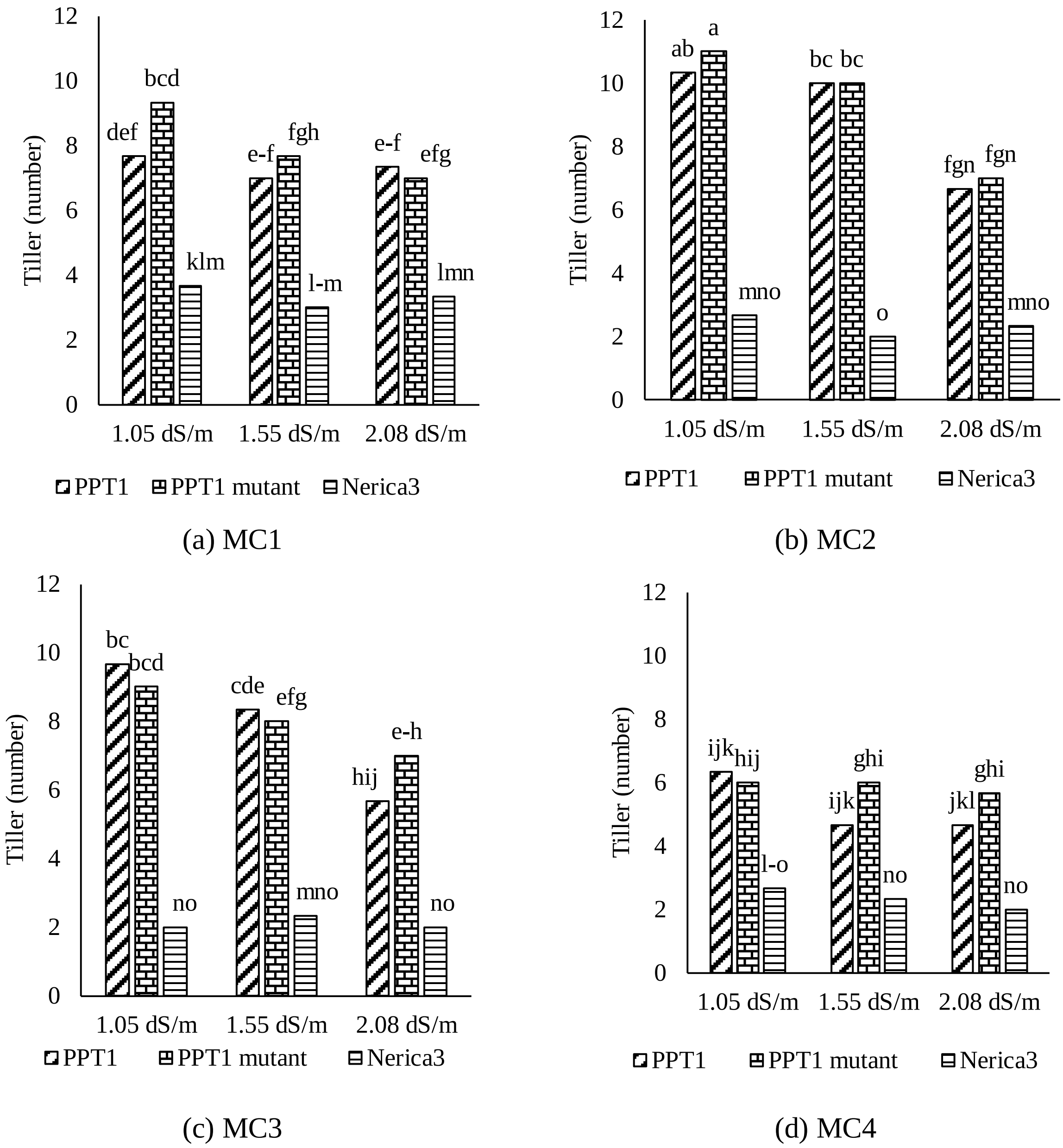
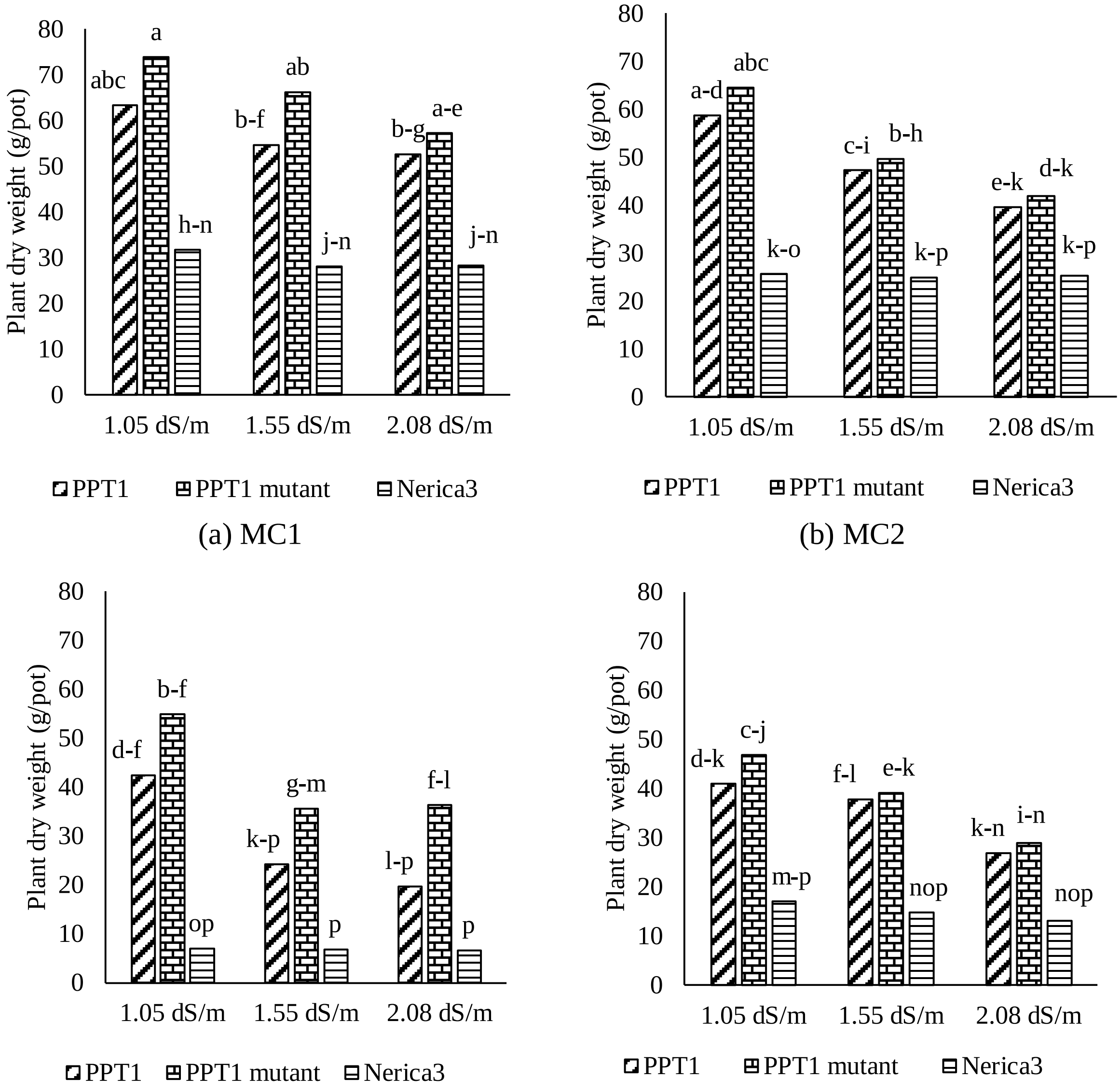


Figure 5: Interactions between tiller MC ECe and varieties on tiller number

MC1, MC2, MC3, and MC4 represent soil moisture content at flooded level, at tension from 0.1 to 0.33 bar, at 0.45 MAD and 0.60 MAD. 1.05 dS/m, 1.55 dS/m and 2.08 dS/m, represent values of electrical conductivity at saturation extract (ECe). PPT1, PPT1 mutant, and Nerica3 represent rice varieties: Pathum thani 1, Pathum thani 1 mutant and new rice for Africa.



(a) MC1 (b) MC2

(c) MC3 (d) MC4

Figure 6: Interactions between MC, ECe, and varieties on plant dry weight

MC1, MC2, MC3, and MC4 represent soil moisture content at flooded level, at tension from 0.1 to 0.33 bar, at 0.45 MAD and 0.60 MAD. 1.05 dS/m, 1.55 dS/m and 2.08 dS/m, represent values of ECe. PPT1, PPT1 mutant and Nerica3 represent rice varieties: Pathum thani 1, Pathum thani 1 mutant and new rice for Africa.

3.6 FILLED GRAIN PERCENTAGE

Filled grain percentage was high among all the varieties at MC1 with Nerica3 and PPT1 mutant having the highest percentage, followed by PPT1. However, the percentage of filled grain among varieties has decreased at MC2, MC3, and MC4 compared to that of MC1 but decreased severely in PPT1 and PPT1 mutant at MC3 and MC4 compared to that of Nerica3. Both PPT1 and PPT1 mutants suffer more than 90% grain abortion at MC3 and MC4 (Figures 7a and 7b). Nerica3, on the other hand, produces the highest filled grain percentages from 37% to 55% at both MC3 and MC4.

3.7 YIELD

The highest yield was recorded in MC1 among all the varieties. PPT1 mutant yielded higher among the varieties in MC1 and MC2 with the highest yield recorded at MC1 under 1.05 dS/m as

26.11 g pot-[1]. The yield decreases with a decrease in MC among all varieties. All the varieties have produced yield at MC2, with a significant difference at $P < 0.05$ among ECe levels within the MC in PPT1 and PPT1 mutant. However, there was no significant difference at $P \geq 0.05$ in yield among ECe levels within the MC2 in Nerica3. At MC3 and MC4 no yield was recorded for PPT1 and PPT1 mutant except Nerica3 which produces yield at both MC3 and MC4 (Figure 8). The ability of Nerica3 to produce at all the MC's is due to its stress-tolerant morphological features such as low above-ground biomass and deeper root as reported (Bernier et al., 2008). That, stress-tolerant varieties are characterized by low above-ground biomass and deeper root. However, the yield is not comparable to MC1 and MC2. The yield recorded in MC4 for Nerica3 is higher than the yield observed in MC3, this could be due to a higher depth of irrigation water at MC4 compared to MC3 which has closer irrigation frequency but lower irrigation depth as reported by (Wang et al., 2010). Higher irrigation depth in sodic soil results in higher yield in rice.

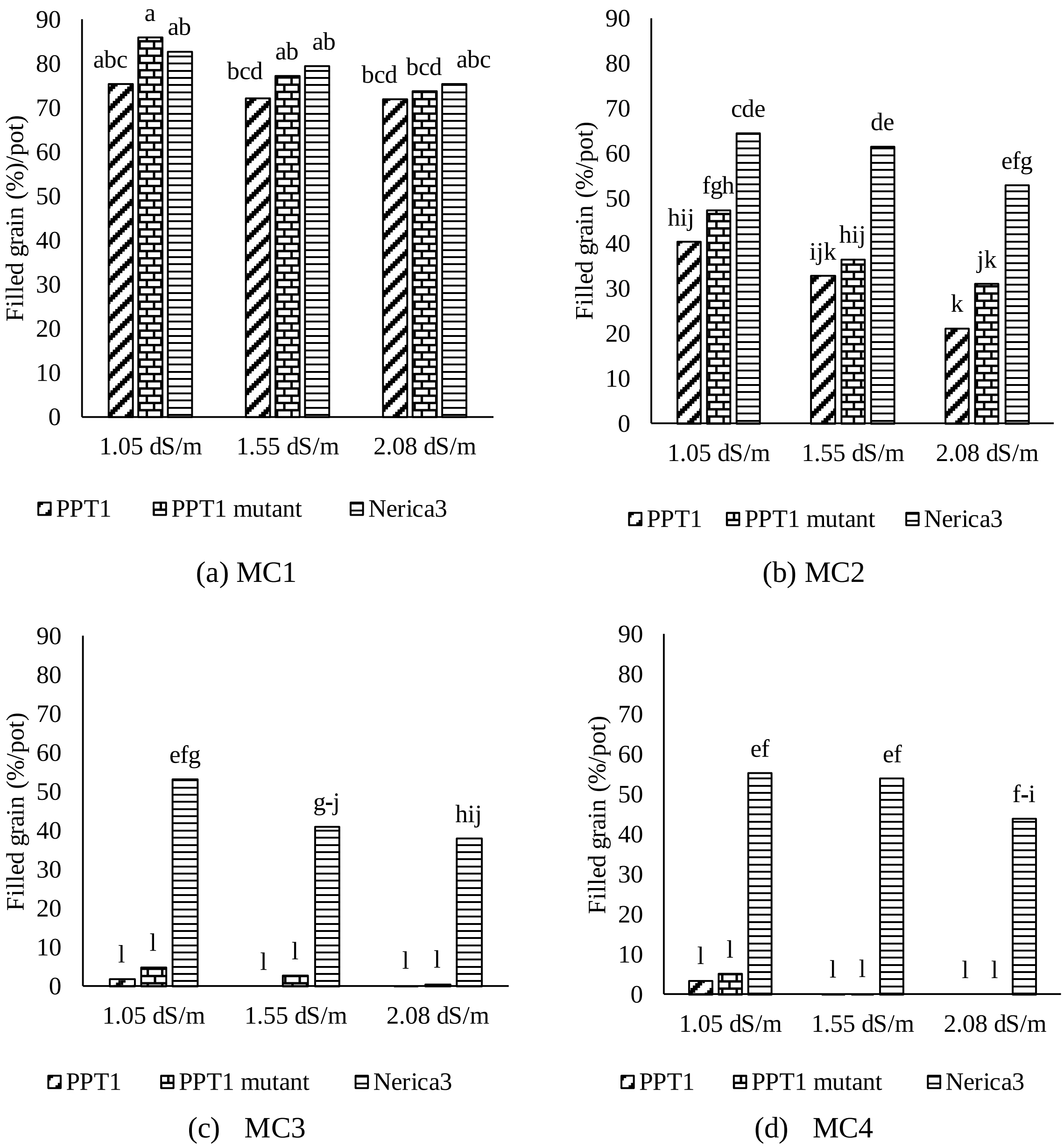


Figure 7: Interactions between MC, ECe and varieties on filled grain percentage

MC1, MC2, MC3, and MC4 represent soil moisture content at flooded level, at tension from 0.1

to 0.33 bar, at 0.45 MAD and 0.60 MAD.   1.05 dS/m, 1.55 dS/m and 2.08 dS/m, represent values of ECe. PPT1, PPT1 mutant, and Nerica3 represents rice varieties: Pathum thani 1, Pathum thani 1 mutant and new rice for Africa

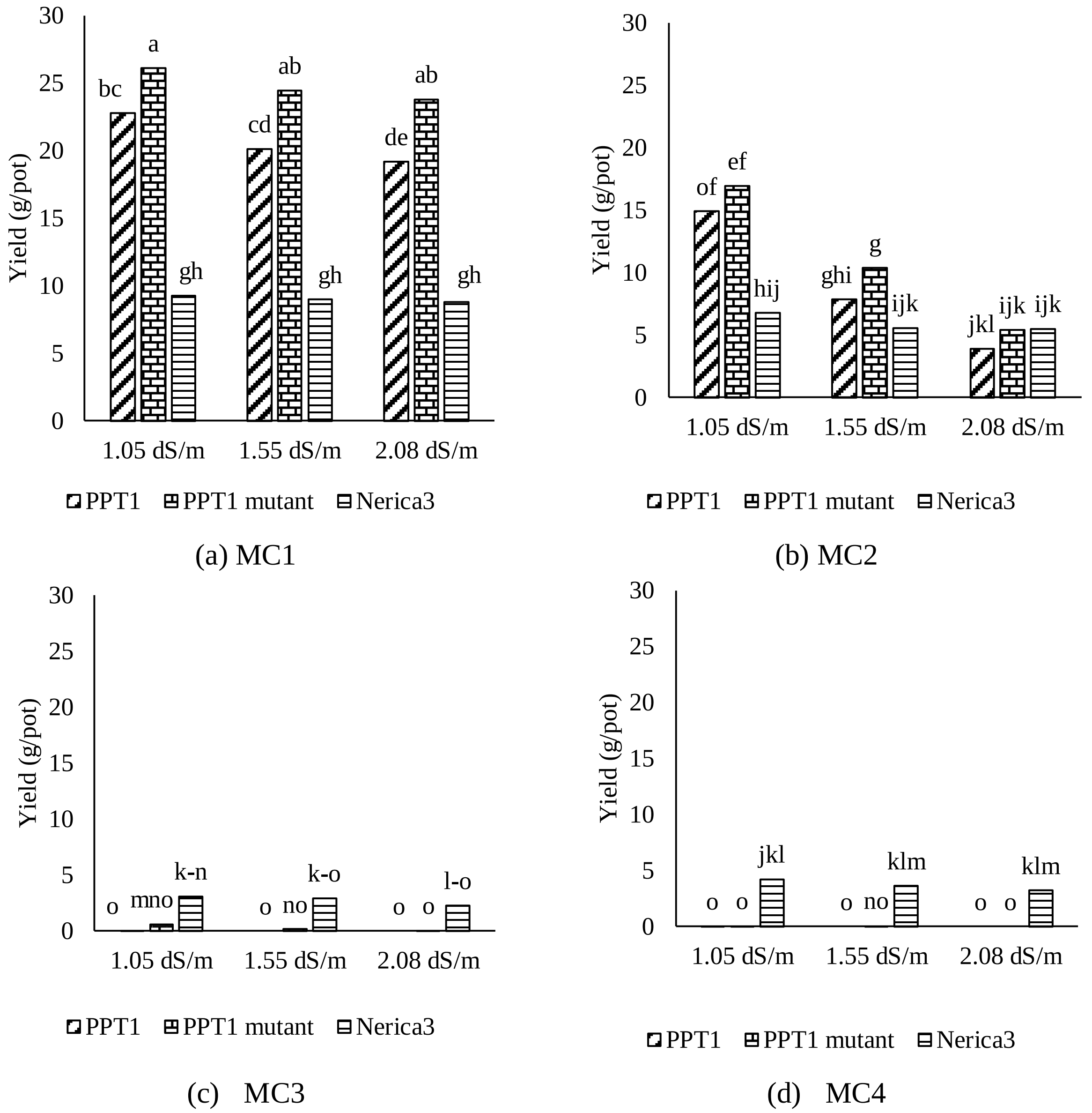


Figure 8: Interactions between MC, ECe, and varieties on yield

MC1, MC2, MC3, and MC4 represent soil moisture content at flooded level, at tension from 0.1 to 0.33 bar, at 0.45 MAD and 0.60 MAD.   1.05 dS/m, 1.55 dS/m and 2.08 dS/m, represent values of ECe. PPT1, PPT1 mutant, and Nerica3 represent rice varieties: Pathum thani 1, Pathum thani 1 mutant and new rice for Africa.

This study is in accordance with the finding of (Tao et al., 2007). Which reported that reduction in soil water content reduces both above-ground biomass and yield in a compared study between flooded paddy, a non-flooded, and plastic-film-covered system of rice production. However, there are other growth parameters such as tiller number which were recorded higher under a non-flooded moisture content compared to the flooded water content in this experiment.

4. CONCLUSION

Based on the findings of this study, at flooded water content (MC1), plant height among all the varieties at all ECe has not been affected by the ECe, but root lengths are higher at 1.05 dS/m and lower at 2.08 dS/m. At 0.1 to 0.33 bar (MC2) plant height decreased compared to that of flooded water content and tiller number increased higher than that of flooded water content with PPT1 mutant having highest tiller number followed by PPT1, for Nerica3 however, tiller number were recorded higher at flooded water content than the moisture content managed at 0.1 to 0.33 bar, 0.45 MAD and 0.60 MAD. The root length is higher at the moisture content managed from 0.1 to 0.33 bar (MC2) among all varieties and is it higher at 1.05 dS/m compared to 1.55 dS/m and 2.08 dS/m. At 0.45 MAD and 0.60 MAD, the plant height, tiller number, and root length were higher at 1.05 dS/m. The plant height among the varieties is higher in PPT1 and PPTT1 mutant, while Nerica3 has the least plant height among the varieties. Tiller number was recorded higher in PPT1 mutant, followed by PPT1 and Nerica3 has the least tiller number among the varieties. Crop water use is higher in PPT1 mutant, followed by PPT1 and Nerica3, at all MC levels. The crop water use is high at 1.05 dS/m in water flooded control and it decreases with an increase in ECe level among all the varieties. When more drought applied in the experiment, all varieties could give the growth parameters, but lesser in yield competition. Narica3 behaved the best variety for drought in sodic sandy loam soil. Grain yield has been affected by the decrease in water content from flooded to 0.1 to 0.33 bar moisture content. Moreover, the grain yield recorded at 0.1 to 0.33 bar moisture content was higher than that of 0.45 MAD and 0.60 MAD among all varieties. Grain yield among the varieties was recorded higher in PPT1 mutant at flooded water content and 0.1 to 0.33 bar followed by PPT1 and Nerica3. Percentage of filled grain was higher at flooded water content among all the varieties with PPT1 mutant having the highest followed by Nerica3 and PPT1. Filled grain percentage decreased at 0.1 to 0.33 bar, 0.45 MAD and 0.60 MAD among all varieties with Nerica3 having the highest at 0.1 to 0.33 bar, 0.45 MAD and 0.60 MAD. At 0.45 MAD and 0.60 MAD Nerica3 has the highest yield while no grain yield was recorded for PPT1 and PPT1 mutant. Plant dry weight among the varieties was recorded higher in PPT1 mutant at all MC levels followed by PPT1 and Nerica3

5. DATA AVAILABILITY

Relevant information is available by contacting the corresponding author.

6. ACKNOWLEDGEMENTS

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