Original Research Article

Response of Rice Genotypes to Boron Fertilization and Screening of Efficient Rice varieties under Boron Stress in Inceptisol

Abstract

A pot culture experiment was conducted on Karaikal soil series (*Vertic Ustropept*) to study the response of rice genotypes to boron addition and screening efficient genotypes using stress indices. Ten rice genotypes were tested at two (0, 2 mg kg^{-1}) level of boron. The result revealed that the highest grain yield (88.40 g pot^{-1}) and straw yield (114.7 g pot^{-1}), and the maximum grain boron uptake (2192.3 µg pot^{-1}) and straw boron uptake (3291.9 µg pot^{-1}) were recorded with application 2.0 mg boron kg^{-1}. Amongst rice genotypes, ADT 50 recorded significantly the highest grain and straw yield, boron uptake and boron use efficiency compared to other genotypes on application of boron @ 2 mg kg^{-1}. From the study results, we observed that there are significant differences among rice genotypes on yield, boron uptake and use efficiency with boron fertilization compared to no boron application. Further, based on stress tolerance index (STI), yield under stress (Ys) and adequate condition (Yp) rice genotypes were categorized into Group A – uniform superiority under stress and non – stress condition – ADT 50, ADT43 and ADT 53 with high STI > 1.0; Group B - perform favorably only under non – stress condition - ADT 46, ADT 52,ADT 51, ADT 40 and ADT 37 – STI - 0.7 to 1.0; Group C – genotype yield relatively higher only under stress environment – no genotypes ; Group D – genotype perform poorly in both stress and non-stress environment – ADT 38 and ADT 39 with low STI < 0.70.

Keywords: Boron, Boron uptake, Boron use efficiency, Inceptisol, Rice genotypes, Stress indices,Yield.

1. Introduction

Rice (*Oryza sativa* L.) is an essential grain [1] ~~(Hori and Sun,2022)~~, with almost half of the world's population relying on it for ~~as a~~ staple diet [2] ~~(Rathinapriya et al.,2019)~~, particularly in fast-growing and densely populated parts of the world [3] ~~(Sen et al.,2020)~~. Rice meets 21% of the energy and 15% of the protein needs of the world's population and main sources of calories for millions people [4,5] (Depar et al., 2011; Senthilvalavan and

Ravichandran, 2019). While higher wages, labor scarcity, water constraints, and nutrient mining are ~~all~~ the key issues that must be addressed for sustainable rice cultivation [6] (Kumar et al.,2021). The production declined due to decrease in area cultivated, dry weather, shortage of water, delayed sowing, low plant population, imbalance fertilizer uses and disease attack [7] ~~(Chaudhary et al., 2009)~~. As half of the global population depend on rice for their daily energy requirements; therefore, rice productivity cannot be ignored by reasons [8] ~~(Mohammad Fakhrul Islam and Kareim,2020)~~, especially micronutrient deficiencies [9] ~~(Rehman et al.,2018)~~. Intensification of agricultural land use with high yielding crop varieties and unbalanced fertilizer application led to mining out the native soil nutrients [10] ~~(Sarker et al.,2019~~). Soils with micronutrient deficiencies produce crops with low concentration of micronutrients and their consumption lead to malnutrition. Application of micronutrient through soil and or foliar application in various soil and crop situations help to alleviating micronutrient deficiency both in soil and crop plants [11] ~~(Shukla et al., 2014)~~.

Now a day's micronutrients deficiency such as zinc and boron is become wide-spread in rice growing areas ~~of country~~ that leads to substantial loss in yield and quality of grains [12] ~~(Shukla et al., 2021)~~. Among the micronutrient deficiencies, boron deficiency is a growing concern to all crops [13] ~~(Fatima et al.,2018)~~. Boron is required for optimal plant growth and development ~~crops~~ and its deficiency and excess application pose a problem for crops ~~globally~~ [14] ~~(Sharma et al., 2022)~~. Boron deficiency has a negative impact on the productivity of 132 crops [15] ~~(Camacho- Cristobal et al., 2018)~~ and most of the rice based cropping systems facing boron deficiency [16] ~~(Hanifuzzaman et al.,2022)~~. B deficiency prevailed in different states of India and it was higher in eastern states [12] ~~(Shukla et al., 2021) . Boron is a~~ and became a limiting factor ~~in~~ of crop productivity especially in rice-based systems [9,17] ~~(Rehmanet al., 2018, Das and Purkait,2020)~~. ~~Deficiency of boron has emerged as an important problem in Indian soils and crops, next to zinc.~~ An inadequate amount of accessible B in soils diminishes agricultural productivity, degrade grain quality, and make crops more susceptible to disease [18,19] ~~(Gupta and Solanki,2013, Jokanovic,2020)~~. However, B needs differ amongst plant species and its availability affected by soil type, soil moisture, pH, B concentration, soil organic matter, and plant variety [20] ~~(Khurshid et al.,2021)~~. Severe crop loss due to the reduction in pollen sterility of rice and proper grain filling may occur due to boron deficiency [21] ~~(Rerkasem et al.,2020)~~ and it my caused by either low content or low availability depends on the soil type. Especially in rice B deficiency cause chlorosis thus the plant size is reduced, leaf tips become white and rolled [22] ~~(De Olivera et al.,2006);~~ in severe case leads to necrosis and death of growing point.

Further, if rice is affected by B deficiency during panicle formation, the plants may fail to produce panicles. As the problem of micronutrient deficiency especially boron in rice in Inceptisols has not taken necessary attention. To obtain B tolerant rice lines, the selections under the condition of low B several selection parameters have been used by researchers based on stress selection indices under optimum and stress conditions to identify the tolerant rice genotypes. A number of research outputs showed that boron fertilizers increased the rice yield and its requirements differ significantly according to soil type, climate, management practice, timing of application and cultivars used [23] ~~(Lestari et al., 2019)~~. Further, there were several yield-based stress indices have been developed those may be more applicable for nutrient deficiency stress environment [24] ~~(Hussain et al., 2021)~~. Keeping all these issues in boron application to rice in various soil types, this present study was carried out with the aim that ~~how different levels of~~ boron application affects the yield, boron uptake and boron use efficiency among rice genotypes and screening efficient rice genotypes using various stress tolerance indices in *Vertic Ustropept* of Karaikal region of Puducherry Union Territory, India and to take this study findings to field scale application for recommendation to rice under boron deficient soils.

2. Materials and Methods

As a part of doctoral research on boron fertilization to rice and fixing critical limits of boron to rice in Karaikal region soils under three soil orders *viz*., Entisol, Inceptisol and Vertisol and part of work published related to this study by [25];further identifying the efficient rice genotypes under boron stress and non-stress condition in Inceptisol (as it covers major area compared to other soil orders in the study area) this pot experiment was carefully planned and conducted in net house of experimental farm of ICAR –KVK, Karaikal ($10^0$99' N latitude and $79^0$75' E longitude) during June - October 2021 to study the response of rice genotypes to boron fertilization and screening the efficient rice genotypes under B stress and non-stress conditions. The experimental soil belonged to Karaikal soil series (Fine Montmorillonite isohyperthermic *VerticUstropept*). The physico chemical characterization of the soil was pH– 8.73, EC – 0.47dSm^{-1}, organic carbon – 8.12 g kg^{-1}, $KMnO_4$-N – 327 kg ha^{-1}, Olsen – P – 26 kg ha^{-1}, NH_4OAC – 218 kg ha^{-1} and hot water B – 0.49 mg kg^{-1}. The experimental soil was deficient in B (critical limit < 0.59 mg kg^{-1}). The treatments consisted of ten rice genotypes (ADT37, ADT38, ADT39, ADT40, ADT43, ADT46, ADT50, ADT51, ADT52, and ADT53) and two B levels (0 and 2.0 mg kg^{-1}) applied through sodium tetra borate. Each pot was filled with 10 kg of processed soil sample. All the pots received uniform dose of 150:50:50 kg N, P_2O_5 and K_2O applied through urea, super phosphate and muriate of potash respectively. The experiment was conducted in factorial completely randomized design (FCRD) with two replications. To determine grain, straw yield and boron uptake, crops were harvested at maturity from the respective treatments and processed for further analysis and data observation. Dried grain and straw samples were ground and digested in triple acid mixture and boron concentration was determined by azomethine method in spectrophotometer. Boron uptake was calculated by multiplying the grain and straw yield with respective boron concentration. Based on grain yield and grain B uptake following boron use efficiency parameters were worked out as suggested by [26, 27] ~~Fageriaet al. (2010)~~.

$$\text{Agronomic efficiency (mgmg}^{-1}\text{)} = \frac{\text{Grain yield with B – grain yield without B}}{\text{Quantity of B applied (mgkg}^{-1}\text{)}} \text{.............(1)}$$

$$\text{Physiological efficiency (µgµg}^{-1}\text{)} = \frac{\text{Grain + straw yield with B – Grain + straw yield without B}}{\text{Grain + straw B uptake with B – Grain + straw yield without B}} \text{............(2)}$$

$$\text{Agro physiological efficiency (µgµg}^{-1}\text{)} = \frac{\text{grain yield with B – grain yield without B}}{\text{Grain + straw B uptake with B – Grain + straw yield without B}} \text{.............(3)}$$

$$\text{Apparent B recovery} = \frac{\text{Grain + straw B uptake with B – Grain + straw yield without B} \times 100}{\text{Quantity of B applied (mgkg}^{-1}\text{)}} \text{............(4)}$$

$$\text{Boron utilization efficiency (µgµg}^{-1}\text{)} = \text{Physiological efficiency} \times \text{Apparent B recovery} \text{....(5)}$$

The ultimate objective of this investigation was to compare grain yield response of 10 rice genotypes to boron fertilization to select high grain yield boron efficient genotypes both under boron stress and non - stress conditions. To assess the high yielding efficient rice genotypes under B deficient condition, ~~following~~ using various stress indices proposed by different authors were employed as follows,

Boron efficiency (BE)

This was calculated using the formula suggested by [28] ~~Blum (1988)~~

$$BE = \frac{\text{Yield S}}{\text{Yield P}} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots.(6)$$

Where,

S = Grain yield produced under B deficiency

P = Grain yield produced under B fertilization

Stress tolerance (TOL)

This was calculated using the formula suggested by [29] ~~Rosielle and Hamblin (1981)~~

$$TOL = (Y_p - Y_s) \quad \ldots\ldots.(7)$$

Where,

Y_p = The yield in stress conditions

Y_s = The yield in non – stress conditions

Mean productivity (MP)

This was calculated using the formula suggested by [29] ~~Rosielle and Hamblin (1981)~~

$$MP = \frac{(Y_s + Y_p)}{2} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots.(8)$$

Where,

MP = The average yield of Y_s and Y_p

Geometric mean productivity (GMP)

This was calculated by the formula suggested by [30] ~~Ramirez and Kelley (1988)~~

$$GMP = \sqrt{Ys.Yp} \ldots\ldots\ldots\ldots\ldots.(9)$$

Y_s = The yield in non – stress conditions

Y_p = The yield in stress conditions

Stress Susceptibility Index (SSI)

This was calculated using the formula by [31] ~~Fischer and Maurer (1978)~~

$$SSI = [1-\frac{Ys}{Yp}]SI \qquad \text{……….(10)}$$

Where,

SI = (stress intensity) and it is estimated as $[1-[\bar{y}s/\ \bar{y}_p]]$

Where,

$\bar{y}s$ – mean yield over all genotypes evaluated under stress conditions

$\bar{y}p$- mean yield over all genotypes evaluated under non stress conditions

Stress Tolerance Index (STI)

This was calculated using the formula suggested by [32] ~~Fernandez (1992)~~

$$STI = [\frac{Yp.Ys}{Yp2}]\text{……………. (11)}$$

In identify the best stress indices, simple correlation was worked out between grain yield under B stress and B non-stress condition with various stress indices. The stress indices with high correlation value at both condition was selected as the best one.

The data were subjected to analysis of variance (ANOVA). All the statistical tests were performed using SPSS software. The significant differences between the means were tested against the critical difference at 5 % probability level.

~~Boron use efficiency~~

~~Based on grain yield and nutrient uptake, various boron use efficiency parameters were worked out based on formula suggested by [27] Fageria, (2009)……. (12)~~

3. Results and Discussion

3.1. Rice yield

Grain and straw yield of rice genotypes responded significantly to boron application (Table 1). The highest grain (61.2 g pot^{-1}) and straw yield (77.42 g pot^{-1}) was noticed with addition of 2.0 B mg kg^{-1}.The percent increase over control was 7.46%.The grain yield ranged from 47.30 to 88.40 g pot^{-1} and straw yield ranged from 65.30 to 114.7 g pot^{-1}due to boron application. The highest grain yield (88.40 g pot^{-1}) and straw yield (114.7 g pot^{-1}) was noticed with ADT 50 and minimum grain yield (47.30 g pot^{-1}) and straw yield (65.30 g pot^{-1}) was observed with ADT 39. The percent increase in grain yield ranged from (5.5 to 10.2) and straw yield (5.3 to 12.9) among rice genotypes due to boron. Boron is an important micronutrient greatly influences the yield of rice due to its nutritional value in metabolism [33] ~~(Berger and Truog, 1940)~~. This experiment clearly demonstrated that genotypes differ in grain and straw yield observed under boron deficient and their response to added boron in controlling it. ~~Rerkasem and Jamjod (1997) defined~~ B efficiency as an ability of a genotype/cultivar to function properly in a soil too low in boron for other cultivars [34]. ~~Rashid et al. (2002) reported~~ Variation in positive responses to B application to a calcareous soil (pH 8) containing 0.08 mg hot water soluble (HWS) B kg^{-1}among rice varieties that ranged from10 % to 46 % in grain yield and 2 % to 77 % in straw yield reported by[35]. Application of 2 mg kg^{-1} B helped the rice plants to improve numerous physiological, bio-chemicals, metabolic and enzymatic activities. Boron fertilization in deficient soils not only enhances crop yield but also improves rice grain quality [36] ~~(Rehman et al., 2014)~~.

Generally, application of boron has long been known to be an effective means of increasing boron concentration of the reproductive organs resulting in higher crop yield. Increase in grain yield among rice genotypes due to boron is also associated with higher availability of boron in soil leading to higher absorption of boron by rice plants. This was confirmed by significant positive linear relationship between boron uptake and rice yield ($y=28.411x-614.4$, $R^2= 0.9345^{**}$) (fig.1).The application of boron highly influenced the rice crop, providing greater grain yield, which can be explained by the numerical increase in various boron use efficiency parameters. This was confirmed by significant positive linear relationship between grain yield and B recovery efficiency (Fig. 2). It showed that 69.39% variation in grain yield is accounted by nutrient recovery of boron. The highest grain yield noticed in ADT 50 is because, the highest agronomic, physiological, agro-physiological, boron utilization efficiencies, besides apparent B recovery were noticed in ADT 50. The beneficial effect of B on enhancement of crop yield has been reported by [37,38]. ~~Raoet al. (2013) and Laiket al. (2021).~~

3.2. Boron Uptake

The boron uptake by grain and straw of rice due to boron fertilization revealed that there were significant differences among rice genotypes due to born fertilization over control (Table 2). The grain boron uptake ranged from 586.5 to 2192.3 µg pot^{-1} and straw boron uptake ranged from 1169 to 3292 µg pot^{-1}. Addition of 2.0 mg kg^{-1} B recorded the maximum grain B uptake (1440.2 µg pot^{-1}) and straw B uptake (2238 µg pot^{-1}) and this treatment caused 45% and 30.8% increase over no boron addition in grain and straw, respectively. With respect to rice genotypes, grain B uptake ranged from 755.5 to 1853 µg pot^{-1} and straw B uptake ranged from 1347 to 2902 µg pot^{-1}. The genotype ADT39 and ADT 50 registered the lowest and highest boron uptake in grain and straw. The maximum grain boron uptake (2192.3 µg pot^{-1}) and straw boron uptake (3291.9 µg pot^{-1}) was recorded with application 2.0 mg B kg^{-1} to ADT 50. It was significantly superior to rest of the treatments. The percent increases in grain boron uptake among rice genotypes due to boron fertilization ranged from 33.6 to 57.6 and percent increases in straw boron uptake among rice genotypes due to boron fertilization ranged from 26.9 to 33.6. Application of B increased the B uptake might be due to more vegetative and root growth, which releases root exudates resulting in increased boron availability in soil and finally, the uptake in plants [39]. ~~(Debnathet al., 2015).~~ ~~Abbas Bhutto et al.(2013), Rana et al. (2017),Abinayaet al.(2021) and Laiket al. (2021)~~ Similar results were reported by [40,41,42,38] i.e. a higher B uptake by rice plants with soil-applied B.

3.3.Boron use efficiency

Boron fertilization caused significant impact on boron use efficiency among rice genotypes over control (Table 3). There was significant positive relationship between B uptake and apparent B recovery (Fig.3) indicating that increases in B efficiency caused enhanced B uptake. Among rice genotypes agronomic efficiency (Eqn-1) ranged from 0.175 to 0.305 g mg^{-1}, physiological efficiency (Eqn-2) ranged from 9.1 to 14.8 mg µg^{-1}, agro physiological efficiency((Eqn-3) ranged from 3.4 to 6.6 mg µg^{-1} , apparent recovery (Eqn-4) of boron ranged from 1.55 to 3.39%, and boron utilization efficiency (Eqn-5) ranged from 17.9 to 39.3 mg µg^{-1}. The highest agronomic efficiency (0.305 g mg^{-1}), apparent boron recovery (3.39%) and boron utilization efficiency (39.3 mg µg^{-1}) was noticed with ADT 50. While the highest physiological efficiency (14.8 mg µg^{-1}) and agro physiological efficiency (6.6 mg µg^{-1}) was noticed with ADT 38. ~~Jena and Nayak(2016),Galindo et al. (2018) and Sara Eliana et al.(2021) reported~~ An increase in various boron use efficiency parameters over control due to boron fertilization was reported by [43,44,45]. Better and efficient uptake of boron by rice crop as noticed in the present study justifies the higher boron use efficiency observed in various rice genotypes. This was aptly supported by the establishment of significant linear relationship between grain B uptake and boron recovery efficiency ($y= 495.02x + 107.98$, $R^2 = 0.8288$**) (Fig 3.)

3.4. Identification of high yielding rice genotypes using stress indices

The various stress indices that are used for identification of rice genotypes with higher yield under boron stress and boron adequate are furnished in Table 4. Rice genotypes with small response to boron fertilization are considered as the boron efficient genotypes and boron inefficient genotypes have larger yield response. Boron efficiency (Eqn-6) was worked and it ranged from 90.77 to 94.74 per cent among rice genotypes and average mean value recorded 93.05 per cent. The stress tolerance (TOL) (Eqn-7) ranged from 3.50 to 6.10 and an average genotype recorded a TOL value of 4.64. The average yield (MP) (Eqn-8) ranged from 49.05 to 85.35 g pot^{-1} among genotypes and on an average genotype recorded a MP value of 64.44 g pot^{-1}. Similarly, geometric mean yield (GMP) (Eqn-9) ranged from 49.02 to 85.30 g pot^{-1} among genotypes. The average GMP among genotypes was 64.40 g pot^{-1}. The stress susceptible index (SSI) (Eqn-10) ranged from 0.75 to 1.32 per cent. Similar value of SSI, greater the resistance to boron stress among genotypes. Accordingly, genotypes ADT 39, ADT 43, ADT 46, ADT 50, ADT 51 and ADT 52 have lower SSI indicating that they perform well under B stress while recording low yield under non-boron stress condition. Stress tolerance index (STI) (Eqn -11) was employed to find out the best stress tolerance with good yield potential. Stress tolerance index ranged from 0.54 to 1.63 per cent. Accordingly, genotypes were grouped into three categories *viz.,* STI greater than 1.0 per cent – ADT 50, ADT 43 and ADT 53, STI – 0.7 to 1.0 per cent – ADT 46, ADT 52, ADT 51, ADT 40 and ADT 37, and STI < 0.7 per cent – ADT 38 and ADT 39.

The genotypes tested under boron stress and non-stress environment differed significantly among them. The grain yield under stress ranged from 47.30 g pot^{-1} (ADT 39) to 82.30 g pot^{-1} (ADT 50) with a mean value of 62.12 g pot^{-1}. While under boron adequate condition, grain yield ranged from 50.80 g pot^{-1} (ADT 39) to 88.40 g pot^{-1} (ADT 50) with a mean value of 66.76 g pot^{-1}. Genotypic variation in response to boron deficiency in number of crops have been reported earlier by [46] ~~(Jamjod and Rerkasem, 1999~~ in Barley~~)~~, ~~Lordkaew*et al*., 2013~~ [47] in rice, and [48] ~~Mehboob*et al*., 2022~~ in chick pea. Rice genotypes with small response to boron application are considered as B efficient genotypes and larger response to B application is considered B inefficient genotypes. Accordingly, in the present study, ADT 37,ADT 38, ADT 40, ADT 53, ADT 50 were considered as B inefficient genotypes and ADT43, ADT 46, ADT 51 and ADT 52 were considered B efficient.

Boron efficiency was worked out and it ranged from 90 to 94 per cent among rice genotypes (Table 4). There are several mechanisms that could be involved in nutrient efficiency that include root process that increase the bioavailability of soil nutrients to root uptake, enhanced root uptake and translocation of nutrients from root to shoot [49] ~~(Fageria and Baligar, 2003)~~. There was limitation in using boron efficiency as parameter to identify boron efficient genotype with high yield potential. This is because a genotype which is considered as B efficient produced yield which is lower than B inefficient genotypes for e.g., ADT 37, ADT 38, ADT 40, ADT 53, ADT 50 recorded higher grain yield than B efficient genotypes ADT43, ADT 46, ADT 51 and ADT 52. This was supported by weak relationship between B efficiency and grain yield under B stress ($y= 3.8235x-293.1$, $R^2=0.2235^*$ Fig.4) and between B efficiency and grain yield under B adequate ($y= 3.403x -249.39$, $R^2= 0.1652^*$ Fig.5). ~~Sadrarhami*et al.*, (2010) and Muthukumararaja (2014)~~ Reports of [50,51] also observed similar relationship in selecting high grain yield iron deficient tolerant wheat genotypes in calcareous soil and zinc deficient tolerant rice genotypes in zinc stress soil, respectively.

Thus, to identify rice genotype which will provide high yield both under boron deficient and adequate condition and high stress tolerance, various stress tolerance indicators were studied (Table 4). In the present study, lowest value of TOL was recorded in ADT 39, ADT 46 and ADT 51. The index only pointed out that above genotypes that performed poorly under non-stress condition. Greater the TOL value, the larger the yield reduction under boron stress condition and higher sensitivity to boron deficiency. Mean productivity is the average yield of Ys and Yp. The average yield (MP) ranged from 49.05 to 85.35 g pot^{-1} among genotypes and on an average genotype recorded a MP value of 64.44 g pot^{-1}. Mean productivity had strong and positive correlation with Ys and Yp (Table 5). Similarly, geometric mean productivity (GMP) was recorded highest by the above genotypes and also had significant and positive correlation with Ys and Yp. Further MP and GMP strongly correlated between each other ($r=0.99^{**}$). While MP and GMP were less strongly correlated with TOL Stress susceptible index (SSI) is another indicator used for screening genotypes. Greater value of SSI indicates relatively more sensitive to stress and thus a smaller value of tolerance is favored. Accordingly, genotypes ADT 39, ADT 43, ADT 46, ADT 50, ADT 51and ADT 52 have lower SSI indicating that they perform well under B stress while recording low yield under non-boron stress condition. In the present study, SSI was negatively correlated with yield under Ys and Yp and had positive correlation with TOL. Selection for this parameter would also tend to favor low yield genotypes. It was confirmed by poor linear relationship between SSI and yield under B stress ($y= -25.139x + 87.383$, $R^2 = 0.1529$- Fig.4) and between SSI and yield under B adequate ($y= -22.196x + 89.066$, $R^2= 0.1529$- Fig.4) SSI has been ordinarily used by researcher for identifying sensitive and tolerant genotypes [52, 53] ~~(Mardeh*et al*., 2006, Golabadi*et al*., 2006)~~. ~~Fernandez (1992)~~ [32] claimed that selection based on stress tolerance index (STI) would result in genotype with high stress tolerance and good yield potential. Larger the value of STI for a genotype in stress environment, the higher was its tolerance and yield potential.

This was supported in the present study by significant and positive correlation between STI and grain yield under B stress ($y= 32.345x + 31.165$, $R^2 = 0.9915^{**}$ - Fig.5) and between STI and grain yield under B adequate ($y = 33.509 x+ 34.691$, $R^2= 0.9932^{**}$ - Fig.5). Further, STI had significant positive correlation with Y_s, Y_p, MP and GMP, poor relationship with TOL and negative relationship with SSI (Table 5). Thus, MP, GMP and STI were good predictor of Y_s and Y_p than TOL and SSI. The observed relationship were consistent with those reported by [32] ~~Fernandez(1992)~~ in mungbean, [54] ~~Farshadfar and Sutka (2002)~~ in maize, [53] ~~Golabadi*et al.* (2006)~~ and [55] ~~Talebi*et al.*(2009)~~ in wheat and ~~Muthukumararaja (2014)~~ [51] in rice. In the present study, the STI value ranged from 0.54 to 1.63. Based on STI, yield under stress (Ys) and adequate condition (Yp) ten rice genotypes were categorized into 4 groups.

Group A – uniform superiority under stress and non – stress condition – ADT 50, ADT43 and ADT 53 with high STI > 1.0

Group B- perform favorably only under non – stress condition - ADT 46, ADT 52,ADT 51, ADT 40 and ADT 37 – STI - 0.7 to 1.0.

Group C – genotype yield relatively higher only under stress environment – no genotypes

Group D – genotype perform poorly in both stress and non-stress environment – ADT 38 and ADT 39 with low STI < 0.70.

Comparatively, B-efficient genotypes utilize B more efficiently from B deficient medium, thus can be successfully grown in B deficient soil without any additional B application. Inversely, B-responsive genotypes require additional B application to produce the maximum yield [58] ~~(Rengel and Damon, 2008)~~. Hence, growing of B-efficient and in-efficient rice genotypes accordingly not only overcomes B deficiency problem but also reduce the input cost of fertilizer [57]. ~~(Baligar*et al*., 2001).~~

4. CONCLUSION AND FUTURE PROSPECTS

The study proved that all rice genotypes tested were responded well to application of boron and improved the rice productivity compared to no boron application. Therefore, it can be recommended that 2 mg kg^{-1} of boron application to rice in Inceptisols. Further, screening of rice genotypes based on the stress indices studied, it was evident that ADT 50 rice genotype could be the best choice for the farmers of Karaikal region of Puducherry, Union Territory, India. The results of present work can provide base strategy for managing boron deficient and or sufficient soils and helps to select the right rice variety that can be grown in Inceptisols. Thus avoid the consequence low crop productivity or crop loss due to boron mismanagement or choosing unsuitable rice variety by farmers.

DATA AVAILABILITY STATEMENT

All relevant data are within the paper and its supporting files.

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COMPETING INTERESTS

Authors have declared that no competing interests exist

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Table 1. Effect of boron fertilization on grain yield and straw yield (g pot^{-1}) in rice genotypes

Rice genotypes	Grain		Mean	Straw		Mean
	Boron levels (mg kg^{-1})			Boron levels (mg kg^{-1})		
	B_0	$B_{2.0}$		B_0	$B_{2.0}$	
ADT37	54.29	58.79	56.54	69.31	75.01	72.16
ADT38	52.01	57.30	54.65	67.90	74.30	71.10
ADT39	47.30	50.80	49.05	65.30	69.60	67.45
ADT40	54.83	60.40	57.61	69.60	76.30	72.95
ADT43	76.44	80.80	78.62	97.80	105.80	101.80
ADT46	64.90	68.50	66.70	85.80	91.67	88.73
ADT50	82.30	88.40	85.35	103.80	114.7	109.2
ADT51	57.42	61.20	59.31	73.50	77.42	90.61
ADT52	63.80	67.90	65.85	77.40	84.65	79.07
ADT53	67.90	73.50	70.70	78.70	88.90	83.15
Mean	62.12	66.76		78.91	85.83	
	B	G	B×G	B	G	B×G
SEd	0.40	0.90	1.27	0.46	1.04	1.48
CD(p=0.05)	0.81	1.82	2.58	0.94	2.12	3.00

Table 2. Effect of boron fertilization on grain and straw boron uptake among rice genotypes

Rice genotypes	Grain		Mean	Straw		Mean
	Boron levels (mg kg^{-1})			Boron levels (mg kg^{-1})		
	B$_0$	B$_{2.0}$		B$_0$	B$_{2.0}$	
ADT37	830.6	1193	1012	1483	1898	1691
ADT38	744	1128	936	1311	1716	1513
ADT39	586	925	756	1169	1524	1347
ADT40	927	1359	1143	1559	2014	1787
ADT43	1361	1899	1630	2298	3004	2651
ADT46	961	1411	1186	1768	2356	2062
ADT50	1514	2192	1853	2512	3292	2902
ADT51	941	1316	1128	1610	2043	1826
ADT52	921	1230	1075	1571	2099	1835
ADT53	1141	1749	1445	1825	2436	2131
Mean	992.5	1440.2		1711	2238	
	B	G	B×G	B	G	B×G
SEd	8.11	18.1	25.6	12.6	28.2	39.9
CD(p=0.05)	16.4	36.7	51.9	25.5	57.1	80.7

Table 3. Effect of boron fertilization on boron use efficiency among rice genotypes

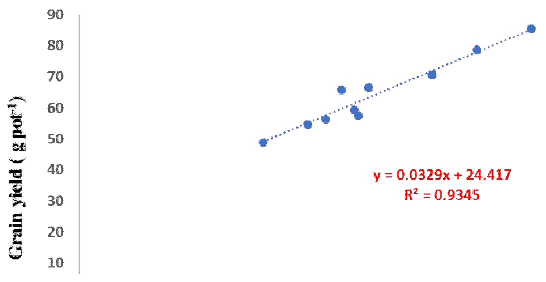
Rice genotypes	Agronomic efficiency (g mg^{-1})	Apparent recovery of boron (%)	Physiological efficiency (mg µg^{-1})	Agro physiological efficiency (mg µg^{-1})	Boron utilization efficiency (mg µg^{-1})
ADT37	0.225	1.81	13.1	5.7	23.6
ADT38	0.265	1.92	14.8	6.6	28.4
ADT39	0.175	1.69	10.6	4.7	17.9
ADT40	0.279	2.16	13.8	6.2	25.8
ADT43	0.218	2.69	9.9	3.5	26.6
ADT46	0.180	2.26	9.1	3.4	20.6
ADT50	0.305	3.39	11.6	4.1	39.3
ADT51	0.189	1.88	9.5	4.6	17.9
ADT52	0.205	1.55	13.6	4.8	21.1
ADT53	0.280	3.04	12.9	4.5	39.2
SEd	0.004	0.04	0.22	0.09	0.54
CD(p=0.05)	0.009	0.09	0.47	0.19	1.13

Table 4.Stress tolerance attributes in rice genotypes estimated from yields under boron stress and boron non-stress and B efficiency

Genotypes	**Ys**	**Yp**	**TOL**	**MP**	**GMP**	**SSI**	**STI**	**B efficiency (%)**
ADT37	54.29	58.79	4.50	56.54	56.50	1.09	0.72	92.35
ADT38	52.01	57.30	5.29	54.66	54.59	1.32	0.67	90.77
ADT39	47.30	50.80	3.50	49.05	49.02	0.98	0.54	93.11
ADT40	54.83	60.40	5.57	57.62	57.55	1.32	0.74	90.78
ADT43	76.44	80.80	4.36	78.59	78.59	0.77	1.39	94.60
ADT46	64.90	68.50	3.60	66.70	66.68	0.75	1.00	94.74
ADT50	82.30	88.40	6.10	85.35	85.30	0.99	1.63	93.10
ADT51	57.42	61.20	3.78	59.31	59.28	0.88	0.79	93.82
ADT52	63.80	67.90	4.10	65.85	65.82	0.86	0.97	93.38
ADT53	67.90	73.50	5.60	70.70	70.64	1.09	1.12	92.38
Mean	62.12	66.76	4.64	64.44	64.40	0.99	0.93	93.05

Table 5. Correlation between several stress tolerance parameters

Genotype	Ys	Yp	TOL	MP	GMP	SSI	STI
Ys	1						
Yp	0.9972**	1					
TOL	0.3836*	0.4517*	1				
MP	0.9993**	0.9993**	0.4189*	1			
GMP	0.9993**	0.9993**	0.4172*	0.9991**	1		
SSI	-0.4584*	-0.3910*	0.6394**	-0.4241*	-0.4257*	1	
STI	0.9958**	0.9966**	0.4271*	0.9969**	0.9969**	-0.4130*	1



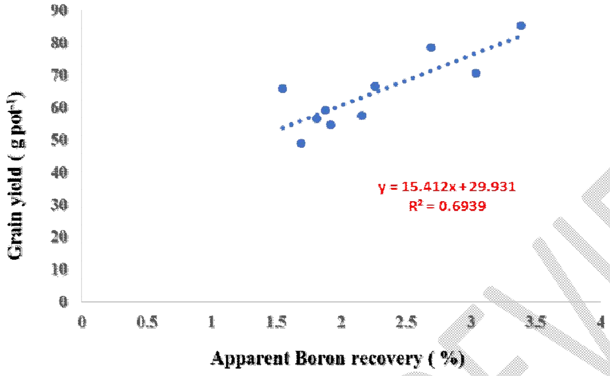


Fig.2. Linear relationship between grain yield and apparent B recovery

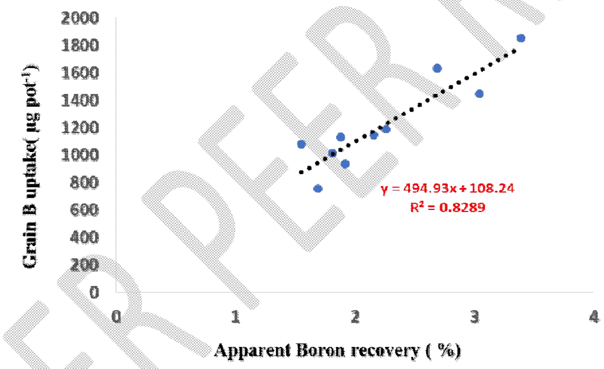
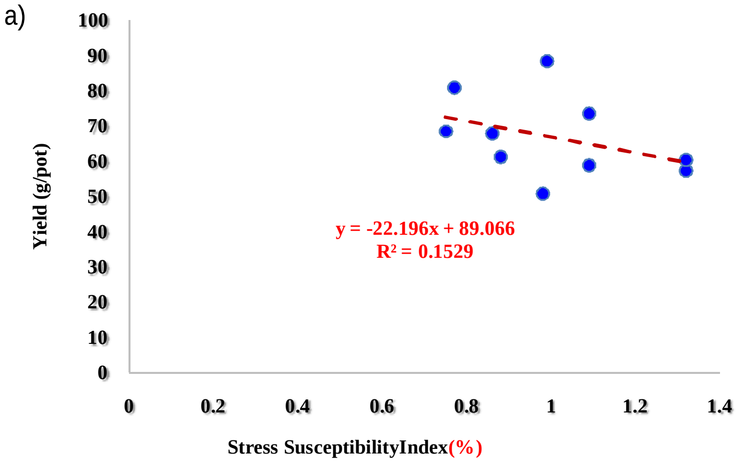


Fig. 3. Linear relationship between grain B uptake and apparent B recovery



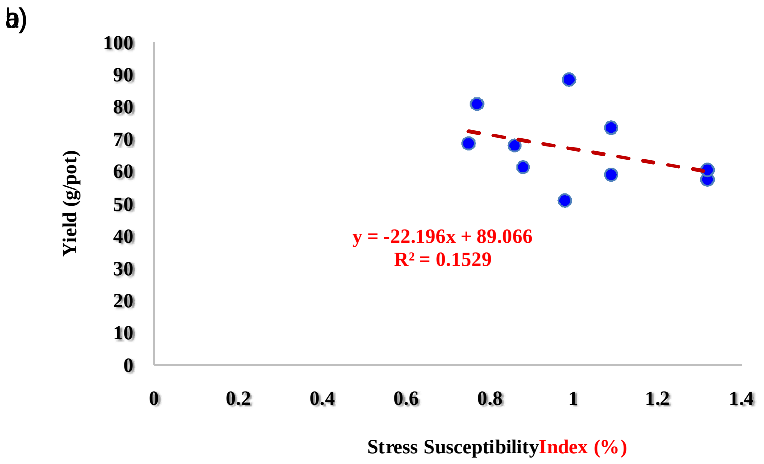
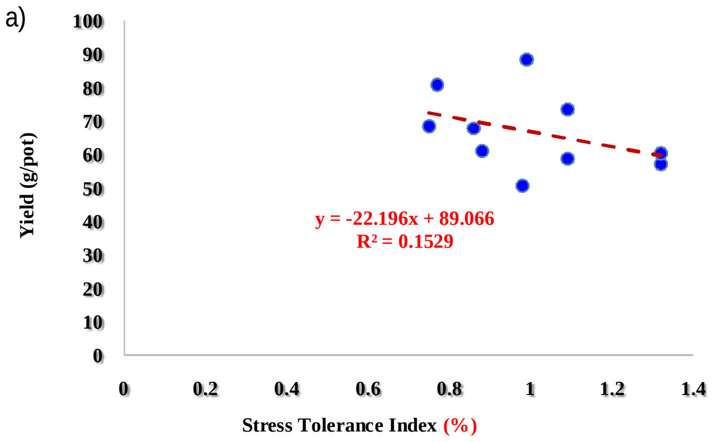


Fig. 4. Linear relationship between SSI with grain yield a) B stress b) B adequate



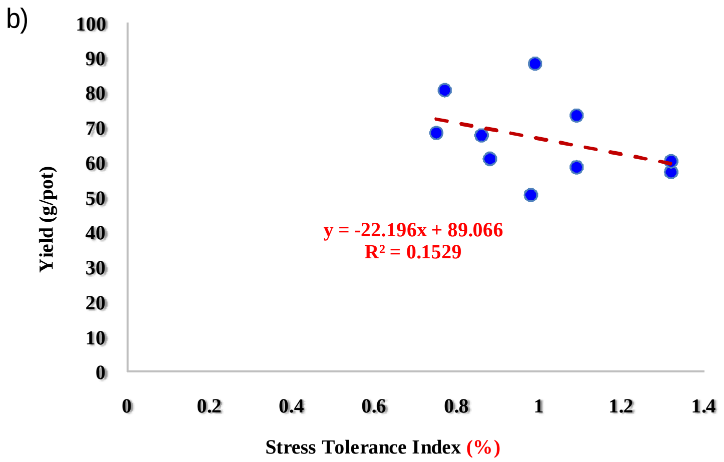


Fig.5. Linear relationship between STI with grain yield a) B stress b) B adequate