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Evaluation of elite rice genotypes under normal and moisture restricted environments based on stress tolerance and adaptability

Mukti Ram Poudel[1*], Sushil Raj Subedi[2], Bimal Roka Magar[1], Sashi Bhusan Kumar Yadav[1], Naresh Upadhaya[1]

[1]Tribhuvan University, Institute of Agriculture and Animal Science (IAAS), Paklihawa Campus, Bhairahawa, Rupandehi, Nepal.
[2]Nepal agriculture research council, Nepal.

[*]**Correspondence**
Mukti Ram Poudel
muktipoudel8@gmail.com

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Background: Rice is one of the most significant cereal crops in Nepal in terms of area of cultivation, production, and productivity. One major limiting factor for the production of rice is scarcity of moisture at critical stages. The study aims to understand the relationship of yield and yield-attributing traits, adaptability, and stability of elite rice genotypes under irrigated and moisture restricted environments.

Methods: A randomized complete block design was used for the experiment at IAAS Paklihawa Nepal consisting of nine rice genotypes taken from Hardinath, NRRP.

Results: The percent reduction in effective panicles per m², plant height, and grain yield under moisture-restricted conditions compared to irrigated conditions was 22%, 8%, and 24%, respectively. Stress tolerance indices showed that IR17L1387, IR16L1713, and IR16L1801 had the highest STI, indicating their potential for cultivation under moisture-restricted conditions. GGE biplot analyses (Which-Won-Where and Mean vs. Stability) demonstrated that Sukhadhan 3 was the most stable genotype across both environments. Additionally, IR16L1713 and IR17L1387 were identified as the winning genotypes under moisture-restricted and irrigated environments, respectively.

Conclusion: The current study concluded that the most valuable option for increasing yield would be to choose one trait effective panicle per meter square and Sukhadhan 3 was the most stable genotype under both environments.

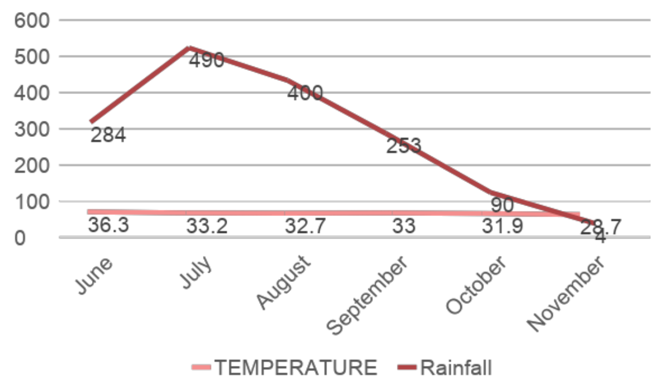
Keywords: *biplot, stability, stress tolerance, irrigated, rice*

Introduction

Rice is one of the most important cereal crops in the world, feeding more than 3.5 billion people and contributing 20% of calories to individuals around the world (Shrestha et al., 2018). The major rice producing countries in the world are China (214MT) and India (172 MT) and listed as the first and second rice producing countries based on global output (Pokhrel et al., 2021). In Nepal, Rice occupied first as a major cereal crop in the case of growing area, production, and consumption. Rice is believed to be the backbone of Nepal's GDP due to its contribution to the national economy. It ranks first in terms of production and productivity and has a significant impact on the living standard of the majority of people (Tiwari et al., 2019). The production of rice has become increasingly problematic worldwide due to numerous biotic and abiotic challenges. Moisture stress is the most significant because it can endure for a very long time and has a wide impact range. Moisture stress in rice causes a variety of modifications to the morphology, physiology, and biochemistry of the plant which eventually lowers crop output (Nahar et al., 2016). The two most crucial phases of rice growth are panicle initiation and flowering. During these phases, moisture stress may result in larger yield losses than other phases. Water deficit, or moisture restriction, is a key abiotic stress that can significantly impact the growth and productivity of rice crops. Among the abiotic stress, water stress is a global problem that is expected to affect more than half of the world's cultivable land by 2050 (Poudel et al., 2019). According to a study by Leng & Hall, (2019), it was concluded that by the end of 21st century, the loss of rice production in Asia due to drought is expected to increase over 19% if adaptation measures are not taken in time. Water stress is a major concern for rice production in Nepal, as a significant portion of the country's rice-growing areas lack irrigation facilities. Among the total cultivable land of Nepal, only 29% land has irrigation facilities (World Bank, 2020) and even in the country's irrigated areas timely and sufficient supply of irrigation can be in doubt (Poudel et al., 2021). As rice alone contributes to 11.3% of the agriculture GDP and the target of fifteen five-year plan is to increase the yield of rice production from 3.73 to 4.5 ton/ha, so it has been significant to know the factors affecting rice production in Nepal ensuring food security and global food demand (NPC, 2019; Vaiknoras et al., 2021). This study aims to determine the stress tolerance indices and yield adaptability under irrigated and moisture-restricted environments in the western region of Nepal.

Materials and methods

The present investigation was conducted at Rupandehi, western Terai region of Nepal. The experimental location is situated at an elevation of 79 meters above sea level and falls under the humid subtropical climate and is geographically located at 27° 30' N latitude and 83° 27' E longitude.
The agro-climatic data was presented in Figure 1.



Source: Agrometeorological station, Bhairahawa

Figure 1. Agro meteorological feature of Experimental site during crop growing period

The plant materials used for the present research along with the source of information were given in Table 1.

Table 1. List of rice genotypes

S.N	Genotypes	Source
1	IR17L1408	NRRP, Hardinath
2	IR16L1831	NRRP, Hardinath
3	IR16L1704	NRRP, Hardinath
4	IR16L1713	NRRP, Hardinath
5	IR17L1323	NRRP, Hardinath
6	Vandana	NRRP, Hardinath
7	Sukhdhan 3	NRRP, Hardinath
8	IR16L1801	NRRP, Hardinath
9	IR17L1387	NRRP, Hardinath

At first, the land was ploughed deep with a cultivator and then a rotavator was used to break lumps of soil and to provide good soil tilth. The recommended dose of fertilizer was given under irrigated and moisture-restricted conditions as recommended by the Nepal rice research programme, Nepal. Under irrigated conditions, the recommendation dose of 130:40:50 kg NPK/ha and on moisture-restricted conditions, the recommendation dose of 60:40:40 kg NPK/ha was provided. Sowing was carried out for making a nursery bed on June 7, 2023, while transplanting was carried out on July 8, 2023. Irrigation was given based on two environments. Under irrigated conditions, irrigation was given at the seedling stage, transplanting stage, tillering, vegetative phase and reproductive (critical) stage.

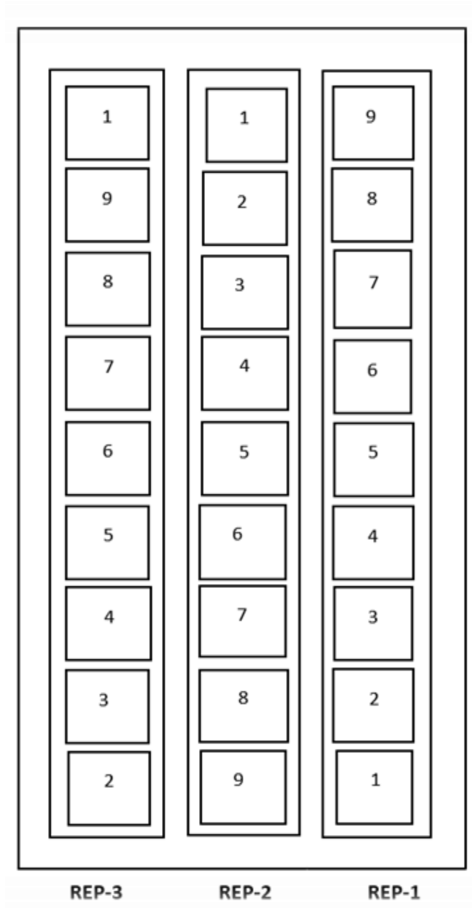


Figure 2. Layout of Experimental Field (RCBD Design)

While in moisture-restricted conditions, irrigation was not given at all. At maturity, the crop was harvested by cutting the plant with the help of sickle at ground level. Harvested crop per plot was tied in bundle and sun-dried. The crop was then threshed and grain was collected. Crop from one meter square area of each plot was harvested and grain obtained from $1m^2$ is weighted and finally converted into kg ha^{-1}.

Results

The correlation among drought tolerance indices and yield under stress and normal environment was calculated and presented in Table 2.

Table 2. Correlation coefficient between grain yield (Yp and Ys) genotypes and stress tolerance indices of different rice genotypes

	Yp	Ys	TOL	YSI	STI	MP	SSI	GMP
Yp	1							
Ys	0.441	1						
TOL	0.326	-.705*	1					
YSI	-0.086	.851**	-.965**	1				
STI	.747*	.920**	-0.379	0.580	1			
MP	.812**	.879**	-0.284	0.507	.988**	1		
SSI	0.155	-.683*	.842**	-.877**	-0.417	-0.390	1	
GMP	.749*	.925**	-0.383	0.591	.996**	.993**	-0.443	1

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).

Where, Yp = Grain yield of genotypes under irrigated environment, Ys = Grain yield of genotypes under moisture-restricted environment, TOL = Tolerance index, YSI = Yield Stability Index, SSI = Stress Susceptibility Index, MP = Mean Productivity, GMP = Geometric Mean Productivity, STI = Stress Tolerance Index

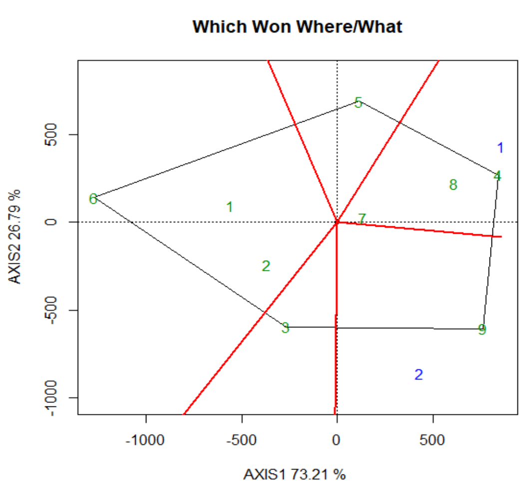
The correlation between Ys and GMP (0.925**), STI (0.920**) and MP (0.879*) was highly positively significant. Stress tolerance indices of nine rice genotypes were determined on the basis of their grain yield under the irrigated and moisture-restricted environment (Table 3). Stress tolerance index (STI) was applied to find the genotypes that have effective yields in both irrigated and moisture-restricted environments. The greater value STI indicates higher tolerance to stress. IR 17L1387, IR 16L1713 and IR 16L1801 showed high STI among the nine genotypes. The high stress tolerance potential of a given cultivar is denoted by the lower TOL (stress tolerance) value. Here, IR 17L1323 and IR16L1713 showed lower TOL value. IR 16L1704 shows higher TOL values, indicating non-suitability for drought conditions. IR 17L1387 showed the highest values of MP and GMP.

Table 3. On the basis of grain yield under both conditions of nine rice genotypes, Stress Tolerance indices were calculated

S.N.	Genotypes	Yp	Ys	TOL	YSI	STI	MP	SSI	GMP
1	IR17L1408	3153.33	2202.33	951	0.698	0.567	2677.83	1.240	2635.28
2	IR16L1831	3541	2226	1315	0.628	0.644	2883.5	1.526	2807.54
3	IR16L1704	3900	2154.66	1745.33	0.552	0.687	3027.33	1.840	2898.83
4	IR16L1713	3630	3537	93	0.974	1.049	3483.5	1.105	3583.2
5	IR17L1323	2993.33	2941.66	51.67	0.982	0.719	2967.5	0.071	2967.39
6	Vandana	2790.33	1589.06	1201.26	0.569	0.362	2189.7	1.771	2105.71
7	Sukhdhan3	3526.67	2793.33	733.33	0.792	0.805	3160	0.855	3138.66
8	IR16L1801	3566.67	3306.67	260	0.927	0.964	3436.67	0.299	3434.21
9	IR17L1387	4373.33	3069	1304.33	0.701	1.097	3721.17	1.226	3663.57

Where, Yp = Grain yield of genotypes under irrigated environment, Ys = Grain yield of genotypes under moisture restricted environment, TOL = Tolerance index, YSI = Yield Stability Index, SSI = Stress Susceptibility Index, MP= Mean Productivity, GMP = Geometric Mean Productivity, STI = Stress Tolerance Index

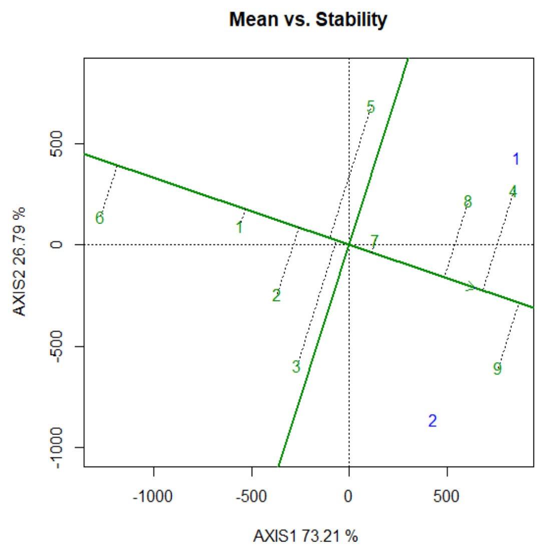
The polygon is drawn by interconnecting the markers located farthest from the origin, the polygon is formed, which includes all other markers. The polygon view of this study revealed that 9 rice genotypes lies under 5 sectors and 2 test environments lies under 2 sectors in the polygon (Figure 3). The region with moisture-restricted conditions consists of rice promising rice genotypes IR16L1713 and IR16L1801 indicating the genotypes are responsive in this environment. The promising rice genotype IR16L1713 vector is characterized by having the longest distance from the origin. The vertex line of this sector indicates that it has specialized adaptation in the moisture-restricted environment but lesser stability in the other environment. Similarly, the sector with irrigated condition having IR17L1387; which is susceptible in this environment**.** Additionally, the IR17L1387 vector is the vertex line of the sector having the longest distance from origin, resulting in the most responsive in an irrigated environment. Therefore, the which-won-where pattern of the experiment showed line IR17L1387 as the winning genotypes i.e. most adaptable in the irrigated environment while IR16L1713 as the winning genotype (most adaptable) in the moisture-restricted condition.



1-9(Green color)- Treatment 1-9, 1(Blue color)- moisture-restricted environment, 2 (Blue color)- irrigated environment

Figure 3. Polygon view of GGE biplot (which-won-where model) illustrating 9 promising rice genotypes in irrigated and moisture-restricted environment

Furthermore, the polygon view demonstrated the promising rice genotype Sukhadhan 3 is close to the biplot's origin, showing that this genotype is the most stable and ranks the same in both conditions. In addition, promising rice genotypes IR17L1323, Vandana, IR17L1408, IR17L1408, IR16L1831 and IR16L1704 are present in the sector without a test environment that indicates the genotypes are not effectively adapted to either environment. As per the which-won-where (WWW) pattern suggestion for winning promising genotype, it is required to analyze the mean performance along with the stability of all the promising rice genotypes for the selection decision. GGE biplot demonstrates the performance along with stability graphically by using Average Environment Coordinates (AEC). The arrowhead in figure 4 represents the average of the test environment's first and second primary component scores (AEC). The AEC abscissa is the line that passes between the origin and arrowhead and the ordinates is the line that is perpendicular to its origin. The length of ordinates indicates the FEI associated with the genotypes that is longer in length which refers to higher variability and lower stability and vice versa. The length of abscissa shows the yield of genotypes which is above average and below yields if right and left of the origin respectively.



1-9(Green color)- Treatment 1-9, 1(Blue color)- Moisture-restricted environment, 2(Blue color)- irrigated environment

Figure 4. GGE biplot illustrating the mean performance and stability of 9 promising rice genotype in irrigated and moisture-restricted environments

Results showed promising rice Sukhadhan 3 is above average yielders and is the most stable genotype under irrigated and moisture-restricted conditions. Whereas IR16L1801, IR16L1713 and IR17L1387 are above-average yielders although have lower stability. Furthermore, IR17L1408, IR16L1831 and Vandana are stable yet are less than average yielders and IR16L1704 and IR17L1323 are both less stable and below-average yielders.

Discussion

Those which have a high correlation with yield in both stress and non-stress environments are considered as the most effective drought indices (Poudel et al., 2019). The correlation coefficient among Ys and Yp was low and insignificant which declares that both irrigated and moisture-restricted conditions affect the genotype separately (Poudel & Poudel, 2016). Bishwash et al (2021), also reported that positive association between the yield of irrigated and water-stressed conditions. There was a significant negative correlation found between Ys and TOL and SSI in our study. El-Hashash et al., (2018) also observed the same result during the study of seventeen rice genotypes in two successive seasons. Therefore, lower values of TOL and SSI indicate that the genotype is more tolerant of moisture moisture-restricted environment. Therefore, choosing a genotype with a high yield potential under both environments would include taking MP, GMP and STI into consideration. According to Poudel et al. (2021), genotypes with lower SSI values (less than 1) are considered to be drought resistant as they show lower yield reduction in comparison to water stress and irrigated environment IR 17L1323 and IR 16L1801 shows the lowest SSI values, While IR 16L1704 shows highest value of SSI followed by Vandana. Therefore, in comparison to other promising genotypes under study above genotypes are considered to be highly stable and productive under both environments. The polygon view of GGE dataset, which shows the Which-Won-Where pattern of a multi-environment dataset can be the most efficient short way of summarizing the genotype and G*E interaction (Poudel et al., 2020).

Conclusion

In the case of Nepal, Rice ranks first regarding production and productivity which influence the majority of people's quality of life. To evaluate the stability and stress tolerance indices under moisture-restricted environments. It is concluded that the genotypes IR17L1387 and IR16L1704 had the highest grain yields under irrigated conditions, while IR16L1713 and IR16L1801 exhibited high grain yield under moisture-restricted conditions. Overall, the genotypes under moisture-restricted conditions showed a 24% reduction in grain yield compared to those under irrigated conditions. In terms of stress tolerance indices, the genotypes IR16L1704, IR16L1801, and Sukhadhan 3 had the maximum mean productivity (MP) and geometric mean productivity (GMP) under both irrigated and moisture-restricted conditions. This suggests that these genotypes may have a higher level of stress tolerance and may be more suitable for growing under moisture-restricted conditions. Sukhadhan 3 was found to be the most stable across both irrigated and moisture-restricted conditions, while IR16L1713 was identified as the most adaptable genotype under moisture-restricted conditions and IR17L1387 was identified as the most adaptable genotype under irrigated conditions. These results suggest that Sukhadhan 3 may be a good choice for growers looking for a stable genotype that performs well under a range of environments, while IR16L1713 and IR17L1387 may be suitable for growers looking for genotypes that are well-adapted to specific environments.

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Author contributions

Mukti Ram Poudel conceptualized the research. The manuscript was proofread by all the authors and submitted to the journal.

Conflict of interest

The authors declare no conflict of interest.

Ethics approval

Not applicable.

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