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Field Screening of Rice Genotypes in Drought-prone Rainfed Environment

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Abstract

Rice yield significantly reduced due to drought stress in northwest Bangladesh. Drought-tolerant rice genotypes could play a vital role in increasing rice productivity and sustainability, and improving the livelihood of farmers in drought-prone rainfed ecosystems. Therefore, the study was undertaken to investigate the responses of rice genotypes under drought drought-prone rainfed environment and to select rice genotypes tolerant to drought stress. A total of 30 rice genotypes were evaluated in the drought-prone rainfed high Barind tract at Godagari, Rajshahi, Bangladesh (24.27 N latitude, 88.21 E longitude, 40 masl) over two wet seasons (WS), July to December. Twenty-five-day-old seedlings were transplanted in 25 x 15 cm spacing @ 3 seedlings hill-1 following a randomized complete block design with 3 replications on 16 August of both the WS. Rainfall, temperature, drought severity, groundwater depth, soil moisture content, soil water potential, phenology, leaf rolling and drying, spikelet sterility, dendogram clustering, rooting behaviors, yield, and yield component data were measured to understand drought stress and to evaluate the performance of the genotype. Yield, yield components, leaf rolling, spikelet sterility, and root characteristics varied significantly (p=0.001) among rice cultivars. Grain yield and harvest index of the tested rice genotypes ranged from 1.28 to 4.51 t ha-1 and 0.25 to 0.47, respectively, based on drought severity. Across genotypes, 61% of root biomass was located in the upper 0-10 cm soil layer, and decreased sharply in the layers below (27%, 9%, and 3% in the 10-20, 20-30, and 30-40 cm layers, respectively). Based on overall performance under drought stress, four rice genotypes (IR74371-70-1-1, IR83377-B-B-93-3, IRRI123, and IR83381-B-B-6-1) were selected as drought tolerant, and BR7873-5*(NIL)-51-HR6 was selected as drought escaping. The genotypes IR74371-70-1-1 and BR7873-5*(NIL)-51-HR6 were released as drought-tolerant variety BRRI dhan56 and drought-escaping BRRI dhan57, respectively. Consequently, the genotypic variation in our germplasm selection indicated considerable scope to develop drought-tolerant varieties through breeding to improve rainfed lowland rice.

Keywords: *Drought-tolerance, Leaf Rolling, Spikelet Sterility, Dendogram Clustering, Harvest Index.*

1. Introduction

Drought stress is a serious threat to sustainable rice production worldwide since water resources are limited and good quality irrigation water resources are scarce. However, drought occurrence and its effects on rice productivity often depend more on the rainfall distribution rather than total seasonal rainfall (Hijmans and Serraj, 2008). Intense drought can cause significant damage to the rice crop, often resulting in profound losses impacting farmers' families and the economy (Pandey et al., 2007). In many regions, drought induced losses in crop yields exceed losses from all other stresses, since both its severity and duration are critical (Farooq et al., 2009). The northwest part (Rajshahi region) of Bangladesh is such a drought prone area with low and erratic rainfalls, and limited irrigation potential (Saleh et al., 2000; Saleh and Bhuiyan, 1995). Erratic rainfall distribution causes drought frequently in this region, and results in yield losses that are generally higher than the damage due to flooding and submergence. The recurrent interval of drought is about 2−3 years, and drought occurs especially during the reproductive phase of wet season rice, which is generally classified as terminal drought (Islam, 2007). Often drought is also occurring at the beginning of the wet season, just prior to transplanting of rice seedlings. But apart from these regular events, any growth stage of rice crop can experience intermittent drought during the season due to uneven rainfall patterns (Kamoshita et al., 2008). These conditions are typical for about 0.16 M ha land of northwest Bangladesh which are rainfed and mainly drought prone (Saleh et al., 2000). The major portion of this region is part of the Barind tract which is a distinctive physiographic unit comprising a series of uplifted blocks of undulating terraces. The Barind has a higher elevation than the adjoining floodplain, with two terrace levels, one at 40 masl and another at 20−23 masl (Riches, 2008). Bangladesh as a whole has an average rainfall of about 2300 mm, ranging from 1000 to 5000 mm, but mean annual rainfall is lowest (1000-1200 mm) in the northwestern region (Karmakar et al., 2012; Saleh et al., 2000). Due to the effect of climate change, the weather of this region is getting extremer over the years. Karmakar et al. (2010) reported that only 800 mm rain occurred in Rajshahi during 2009. Annual average rainfall of the Rajshahi region showed a decreasing trend, declining by 3.1 mm per year since the last 50 years (Ferdous and Baten, 2011). Considering these changes occurring, comprehensive research on field screening of rice genotypes were undertaken in the drought prone rainfed environment of northwest Bangladesh.

The wet season (Aman) rice production in Bangladesh is dependent on monsoon rainfall. Farmers largely rely on rainfall and experience late transplanting of Aman rice when the monsoon is delayed, or yield reduction when drought occurs during the booting stage of rice in October. Delayed onset of the monsoon can create water stress for transplanted rice seedlings resulting to lower yields. Water stress due to extended delay of rainfall may even destroy rice seedlings (Mahmood et al., 2003) which is a recurrent phenomenon and an important constraint to rainfed rice production in Asia. However, rice yield is more affected by drought from panicle initiation to the grain filling stage. These stages occur late in the season when the probability of drought is higher than early in the season. Thus, late-season drought has a larger aggregated production impact than early-season drought (Pandey and Bhandari, 2008). Genotypes with increased drought tolerance are considered to be the first necessary step to improve the productivity of drought-prone rice-based systems. Consequently, research efforts were directed for many years towards the development of early-maturing and drought-tolerant rice varieties.

Another important element in drought tolerance are root systems. Rice root systems vary significantly among genotypes and soil conditions in drought prone rainfed environments (ref???). Root characteristics are strongly associated with drought resistance under rainfed conditions (Sharma et al., 1994). The root system of rice cultivars is strongly determined by genetics, however, it also affected by the soil moisture situation and crop management practices (Mambani et al., 1990; Sharma et al., 1987; Cruz et al., 1986). Reports showed that root length density (RLD) in lowland rice is affected by environmental conditions, genotype, management practices and soil depth (Tuong et al., 2002; Samson et al., 2002).

Recent research at the International Rice Research Institute (IRRI) has shown that direct selection for grain yield under drought stress is effective (Bernier et al., 2007; Venuprasad et al., 2007). IRRI and its National Agricultural Research and Extension System (NARES) partners identified several promising breeding lines that can produce 1.0−1.5 t ha^{-1} higher yield than current mega varieties in drought prone environments (Mackill et al., 1996). However, many of these promising genotypes have not yet been tested in drought prone rainfed environments of Bangladesh. But in order to identify the most promising and adaptable genotypes, screening and fine-tuning are required in the target environment. Therefore, a drought screening trial needed to be pursued in the drought-prone rainfed northwest Bangladesh. The main purposes of this study were to evaluate the performance of rice genotypes in drought-prone rainfed environment, and to select rice genotypes for drought tolerance based on root index and overall performance.

2. Materials and methods

2.1 Experimental site

The experiments were conducted in a farmer's field at Edulpur, Godagari, Rajshahi, Bangladesh (24°27′ N latitude, 88°21′ E longitude, 43 masl) during the 2009 and 2010 wet season (WS). A drought prone rainfed topmost field in the *Barind tract* was selected for the experiment. The experimental site belongs to the Agro-ecological Zone (AEZ) 26, having silt loam to silty clay soils with a grey color (BARC, 2018). The topsoil at the experimental site had a soil pH of 5.8, a texture of 17% clay - 68% silt - 15% sand, soil organic carbon of 0.70%, total soil N of 0.078%, a C/N ratio of 9.0, available P_{Olsen} of 10.0 mg kg^{-1}, exchangeable $K_{exch.}$ of 0.21 me/100 g and a cation exchange capacity (CEC) of 6.8 cmol kg^{-1}.

2.2 Background of the tested rice genotypes

Thirty rice genotypes including 4 check varieties were tested for drought tolerance in the drought-prone rainfed conditions (Table 1). The rice genotypes were collected from the International Rice Research Institute (IRRI), the Bangladesh Rice Research Institute (BRRI), the Bangladesh Institute of Nuclear Agriculture (BINA) and farmers. IRRI and NARES partners identified several promising breeding lines that can produce 1.0–1.5 t ha^{-1} higher yield than current mega varieties under drought stress (Mackill et al., 1996). Some of the breeding lines were developed following crosses between two drought-tolerant breeding lines with the aim to accumulate positive alleles for drought tolerance from the two parents. Another set of breeding lines were developed by crossing drought-tolerant breeding lines with high-yielding popular drought-susceptible lines, with the aim to develop drought-tolerant breeding lines with high yield potential and good grain quality. All crosses were advanced through cyclic selection under reproductive stage drought stress from F_2 to F_6 generations based on drought tolerance, high yield, insect and disease tolerance, and good grain quality traits (amylose content, chalkiness etc.). The F_6 generation was transplanted under reproductive stage drought and selection was carried out in the nurseries. High-yielding lines under drought stress were bulked and forwarded to the observational yield trial (OYT). In the OYT, selection for high yield was repeated under reproductive stage drought stress and the best lines were forwarded to the advanced yield trials (AYT). In the AYT, selected lines were again tested with drought imposition at the reproductive stage. Selected drought tolerant genotypes from IRRI Philippines were then brought to Bangladesh for field screening in drought prone rainfed environments. Since there was no existing drought tolerant rice variety, 4 promising rice varieties were used as checks in the screening experiments.

Table 1. Rice genotypes tested in the experiments

SN	Rice genotype	Parentage (Male parent/Female parent)
1	IR83376-B-B-71-1	IR71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
2	IR83381-B-B-137-1	IR72022-46-2-3-3-2 (DT)/IR77080-B-34-1-1 (DT)
3	IR83373-B-B-25-3	IR71700-247-1-1-2 (DT)/IR72875-94-3-3-2 (DT)
4	IR83376-B-B-130-2	IR71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
5	IR83381-B-B-6-1	IR 72022-46-2-3-3-2 (DT)/IR 77080-B-34-1-1 (DT)
6	IR83372-B-B-33-2	IR 71700-247-1-1-2 (DT)/IR 57514-PMI 5-B-1-2 (DT)
7	IR83381-B-B-55-4	IR72022-46-2-3-3-2 (DT)/IR77080-B-34-1-1 (DT)
8	IR83373-B-B-81-2	IR71700-247-1-1-2 (DT)/IR 72875-94-3-3-2 (DT)
9	IR83383-B-B-141-2	IR72022-46-2-3-3-2 (DT)/IR57514-PMI 5-B-1-2 (DT)
10	IR83376-B-B-150-1	IR 71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
11	IR83376-B-B-110-2	IR 71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
12	IR83376-B-B-24-2	IR 71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
13	IR83383-B-B-129-4	IR 72022-46-2-3-3-2 (DT)/IR 57514-PMI 5-B-1-2 (DT)
14	IR74371-70-1-1	IR 55419-4*2 (DT)/WAY RAREM (DS)
15	IR83387-B-B-27-4	IR 72022-46-2-3-3-2 (DT)/SAMBHA MAHSURI (DS)
16	IR83614-427-B	IR 78875-131-B-1-2 (DT)/IR 64 (DS)
17	IR83388-B-B-108-3	IR 72022-46-2-3-3-2 (DT)/SWARNA (DS)
18	IR83377-B-B-93-3	IR 71700-247-1-1-2 (DT)/SAMBHA MAHSURI (DS)
19	IR83388-B-B-8-3	IR 72022-46-2-3-3-2 (DT)/SWARNA (DS)
20	IR83387-B-B-134-2	IR 72022-46-2-3-3-2 (DT)/SAMBHA MAHSURI (DS)
21	IRRI123	IR 47761-27-1-3-6 (DT)/IRRI 108 (DS)
22	IR83377-B-B-48-3	IR 71700-247-1-1-2 (DT)/SAMBHA MAHSURI (DS)
23	IR78937-B-3-B-B-1	IR 47701-6-B-1 (DS)/IR 55435-05 (DT)
24	BR7870-5*(Nils)-8-HR4	BR10 (DS)/5*CR146-7027-224 (DT)
25	BR7873-5*(NIL)-51-HR6	BR11 (DS)/5*CR146-7027-224 (DT)
26	NERICA4	WAB 56-104 (DT)/CG 14 (DS)
27	IR64 (Check)	IR 5657-33-2-1 (DT)/IR 2061-465-1-5-5 (DS)
28	Binadhan-7 (Check)	TNDB100/ Kienguyen
29	BRRI dhan49 (Check)	BR4962-12-4-1/IR33380-7-2-1-3
30	Guti Swarna (Local check)	Popular variety of northwest Bangladesh

NB: SN-Serial number, DT-Drought tolerant and DS-Drought susceptible

2.3 Experimental protocol and management practices

Seedlings were raised in a seedbed according to the traditional farm practice. Seeds were soaked in water for 24 h and incubated until the radicle emerged. Sprouted seeds were broadcasted at 80 g m^{-2} on 22 July of the two successive wet seasons 2009 and 2010. Fertilizers containing N, P, K and S at 46, 20, 30 and 18 kg ha^{-1}, respectively, were applied in the seedbed during final land preparation (BRRI, 2019). Urea (N at 46 kg ha^{-1}) was top dressed at 10 days after seeding (DAS). Wet land soil preparation with puddling was done according to the common practice. Initially, the land was ploughed once with a country plow, followed by two power tiller passes and laddering. After 7 days, the land was finally prepared by one pass with a power tiller, followed by laddering to level the land. The levee around the plot was newly made. Fertilizers used were urea, TSP, MOP, gypsum and zinc sulfate, applied at a rate of N, P, K, S and Zn of 82, 15, 38, 10.6 and 2.7 kg ha^{-1}, respectively. The full amount of TSP, MOP, gypsum, zinc sulfate and one-third of the urea were applied basally during the final land preparation. The remaining urea was top-dressed in two equal splits at 20 days after transplanting (DAT) and 40 DAT synchronized with rainfall or wet soil conditions as the experiment was conducted under rainfed conditions. The experiment was laid out following a randomized complete block design with 3 replications. Twenty five-day-old seedlings were transplanted with a 25 x 15 cm spacing (BRRI, 2019) at 3 seedlings $hill^{-1}$ on 16th August in both years. Transplanting of rice seedlings purposely delayed from optimum planting (July) to address terminal drought at reproductive stage. Unit plot size was 2.5 m x 4 m. Based on the drought characteristics of the experimental site, transplanting was purposively delayed compared with the normal transplanting time (July) of Aman rice (wet season) to increase the potential exposure to drought stress (Torres et al., 2012). The levee around the experimental plots was opened at 28 DAT to ensure severe drought stress at reproductive stage of the crop. Uniform and standard management practices were followed to control weed and pest in the plots.

2.4 Sampling and data collection

Recommended procedures were followed to collect data for yield and yield components, agronomic parameters, and drought stress measurements (Gomez, 1972; Gomez and Gomez, 1984; IRRI, 2002; IRRI, 1994). At maturity, tillers and panicles $hill^{-1}$, empty and full spikelets $hill^{-1}$, and 1000-grain weight were counted from 2 x 2 hill sampling units from three places (12 hills $plot^{-1}$) sampled on a diagonal in each plot (Gomez, 1972). From the center of each plot, 6-m^2 areas were harvested for determination of grain and straw yields at maturity. After harvest and threshing, grains were sun-dried, and weight and moisture content were measured. Grain yield was adjusted to 14% moisture content, and expressed in t ha^{-1}.

2.5 Climate monitoring and drought stress characterization

Meteorological data (daily rainfall, air temperature, evaporation and sun shine hour) were collected from the mini-weather station at Edulpur, Godagari, Rajshahi, Bangladesh set up by BRRI Rajshahi and very close (25 m) to the experimental plots.

2.6 Rainfall status

The experimental site at Edulpur, Godagari, Rajshahi received the lowest seasonal rainfall (744 mm) since a decade in the year 2009. Of the total, 210 mm occurred in August, which also had 17 rainless days (Fig.1). In September, rainfall was 181 mm but 80% of that occurred in the 1st half of the month and 21 days were rainless. There were 27 rainless days in October and only 15.8 mm rainfall was observed (Fig. 1). Consequently, the crop of 2009WS experienced severe drought stress during the reproductive phase. In contrast, 897 mm rain occurred at the experimental site in the WS 2010 of which 115, 160, 192, 133 and 2.4 mm rain occurred in July, August, September, October and November, respectively (Fig. 2). Rainfall from July to October 2010 was well distributed (Fig. 2). Therefore, especially the short and medium duration genotypes did not face drought stress in the 2010WS. However, the long duration genotypes flowering after the 3rd week of October experienced medium drought stress.

2.7 2Temperature status

Monthly mean temperatures from July to November of 2009 were comparatively higher than in 2010. Temperature fluctuation of both years followed similar trends, but the day-night temperature difference in October to November 2009 was higher than in 2010. Monthly mean maximum and minimum temperatures at the site from July to November were 32.1 and 20.5 °C in 2009, and 29.4 and 25.2 °C in 2010. The mean daily sunshine duration was 6.14 h in the 2009WS and 5.65 h in the 2010WS.

2.8 Drought measuring protocol

Drought stress was assessed indirectly by measuring soil moisture content, soil water potential, drought amount quantification, leaf rolling and drying score, spikelet sterility percentage, phenotypic acceptability and root characteristics. The methods are outlined below.

2.9 Ground water depth measurement

Ground/perched water table was monitored daily with Polyvinyl chloride (PVC) pipe/ piezometers of 1 m length and 0.05 m diameter. The lower 0.8 m end of the pipe, which was below ground, was perforated with 4 mm holes. Three PVC pipes were installed in the experimental plots and the water level was regularly monitored in relation to the upper end of the pipe. Water table depth in the experimental field fell sharply from 13th September onward in the 2009 WS (Fig. 3). It reached 0.8 m below ground on the 25th September and stayed there until the end of the 2009 season. In the 2010 WS, the perched water table started to fall from the 27th September but fell slowly. This confirmed that the 2009 WS experienced a severe drought while the 2010-WS was only a moderately drought for the crop.

2.10 Soil moisture content measurement

The levee surrounding the plots was cut at 28 DAT, so that the soil dried faster during rainless days. Cracks developed in the soil of the plots quickly and became deeper during the season. Three soil samples from 0-0.2 m depth of each replication were taken by auger twice weekly from 30 DAT until the ripening stage. After recording the initial weight, the soil samples were wrapped in aluminum foil and oven dry weight was determined after drying at 70 ˚C temperature for 72 h. Initial and oven dry weight of the soil samples were used to calculate soil moisture content as a measure of soil water status in the field. Soil moisture content was calculated using the following formula:

$$\text{Soil moisture content (\%)} = \frac{\text{W1-W2}}{\text{W1}} \times 1 - W \quad (1)$$

where W1 is the initial weight of the sample and W2 is the oven dried weight of the sample.

Soil moisture status of the experimental plots during the seasons is shown in Fig.4. In general, soil moisture during the 2009 WS was much lower than in the 2010 WS. It decreased to 8% at the last week of October during 2009 WS while it was still 20% at the end of the 2010 WS.

2.11 Soil water potential measurement using Tensiometer

Soil water potential measured with tensiometers (give specs of the equipment used???) after draining the plots at 28 DAT in both seasons is shown in Fig. 5. The soil water potential declined generally but fluctuated up and down in both early seasons due to alternating periods of drought and rainfall (Fig. 5). Fluctuating soil water potentials continued longer in the 2010 WS. A steady decline started from 7th October 2009 but only the 17th October 2010.

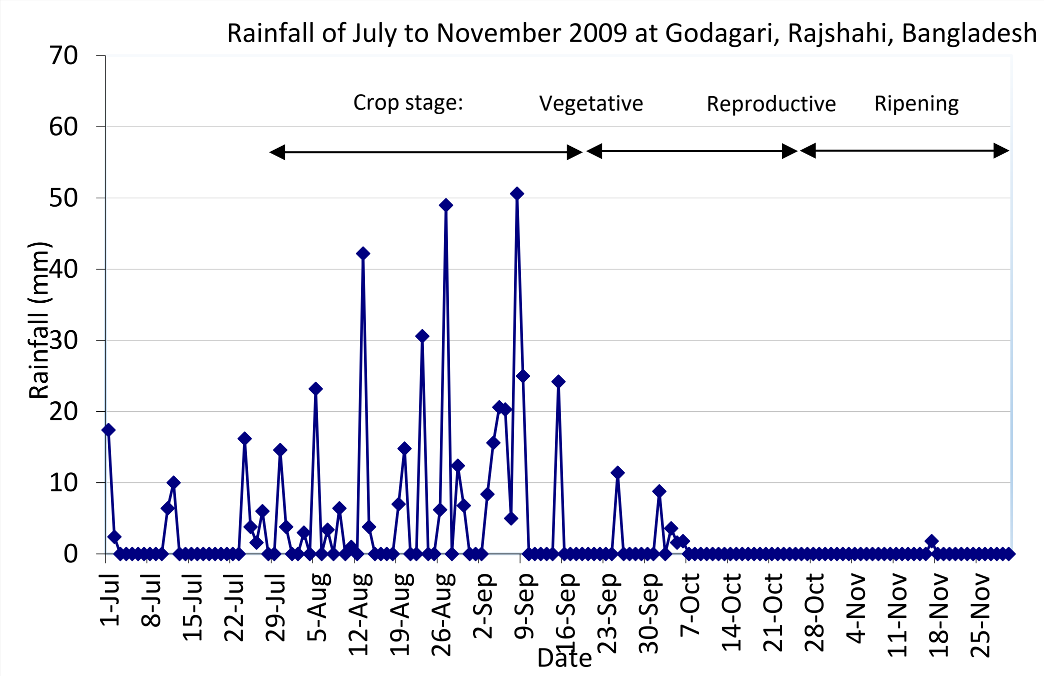


Figure 1. Crop stage and rainfall distribution at the experimental site during July-November 2009 (Source: Mini weather station of BRRI Rajshahi at Godagari, Rajshahi, Bangladesh).

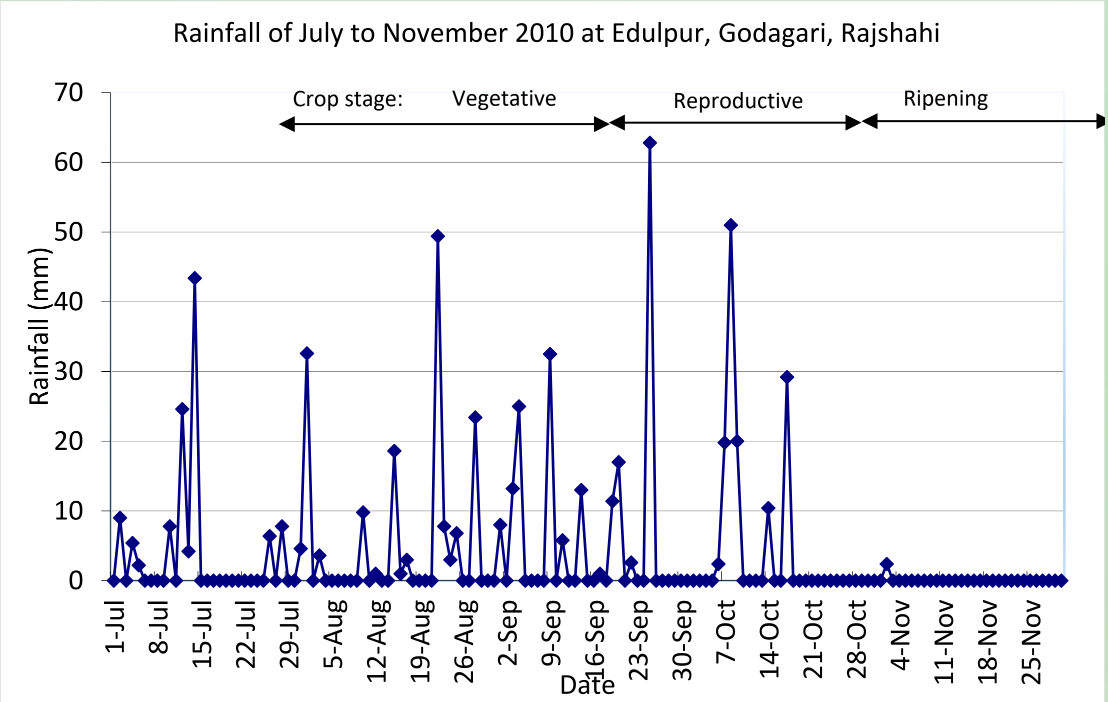


Figure 2. Crop stage and rainfall distribution at the experimental site during July-November 2010 (Source: Mini weather station of BRRI Rajshahi at Godagari, Rajshahi, Bangladesh).

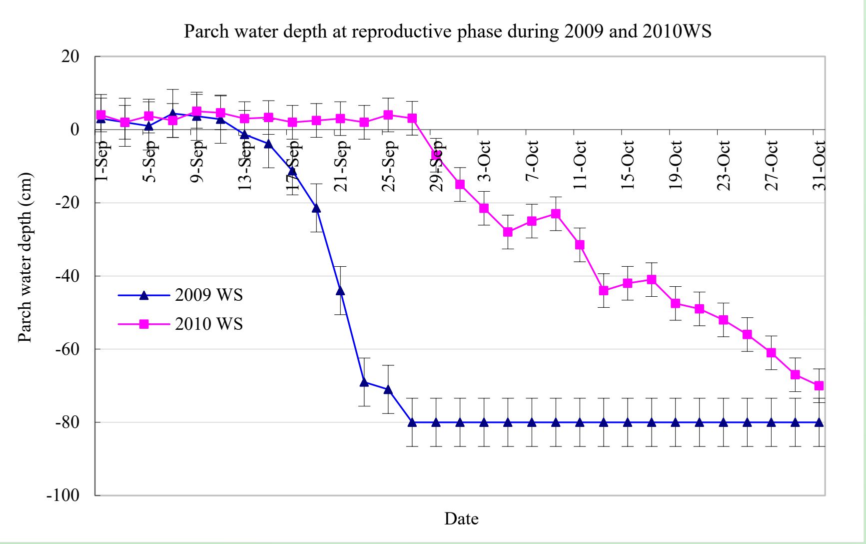


Figure 3. Parch water depth at the experimental field during 2009WS and 2010WS at Godagari, Rajshahi, Bangladesh.

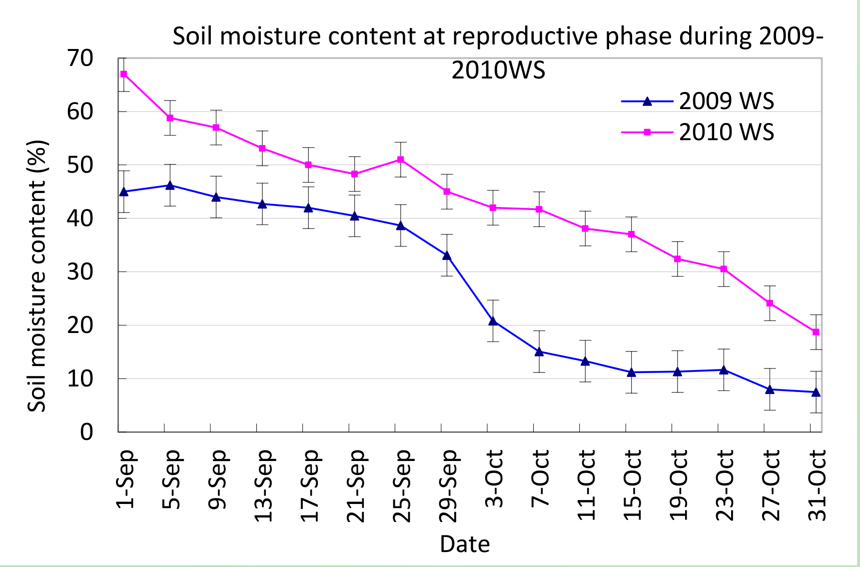


Figure 4. Soil moisture content at the experimental fields during 2009WS and 2010WS at Godagari, Rajshahi.

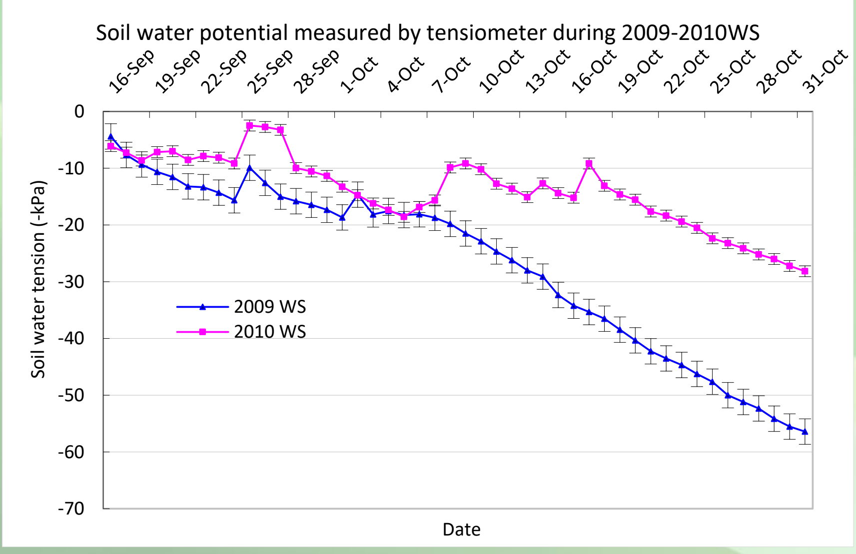


Figure 5. Soil water potential at the experimental fields during 2009WS and 2010WS at Godagari, Rajshahi, Bangladesh.

2.12 Drought Severity quantification

Drought Severity was determined using Drought Simulation Model (Islam et al., 2007) and expressed in water deficit compared to a simulated normal watered crop. Drought severity was considered as the water deficit in the soil being equal to the unfulfilled demand of a simulated normal crop and drought duration was the period of time during which the crop suffered from drought. Drought severity was the cumulative amount of drought for that duration. Based on the seeding and transplanting date of the crop in 2009 and 2010WS, drought amount and duration were quantified in three crop stages like vegetative (08 August to 15 September), reproductive (16 September to 15 October) and ripening stage (16 October to 15 November). The model assumes two storages of water; the first one is called surface water storage (SWS) and the second one is soil moisture storage (SMS). SWS contain standing water in the field above the soil surface and SMS contains soil moisture in the root zone soil. The ET demand of crop is met from the first storage (SWS) if there is water in it on the dry days. When first storage is exhausted then ET demand is met from the second storage (SMS). If the SMS is unable to satisfy ET demand in the continued dry period, and the crop experiences drought stress. The amount of drought is considered to be equal to ET demand that remains unfulfilled due to inadequate moisture in the soil.

2.13 Leaf-rolling and Leaf-drying

Drought sensitivity of the germplasm tested was measured through scoring of leaf rolling and drying during the vegetative and reproductive stage of the crop following the protocol developed by IRRI, using a score between 0 (leaves healthy; no rolling) and 9 (leaves tightly rolled) (IRRI, 2002).

2.14 Spikelet fertility and sterility

Drought stress was also measured indirectly through the level of spikelet sterility, using a score between 1 (less than 20% sterility) and 9 (more than 90%) (IRRI, 2002).

2.15 Root Biomass

Roots from the depth of 0-10, 10-20, 20-30 and 30-40 cm were collected during harvest, by soil core sampler (10 cm diameter auger) from the center of a hill and 5 cm apart from the center of hills with average tiller number (Karmakar et al., 2004). The soil core sampler was placed on the soil surface and hammered in to 40 cm depth (Uddin et al., 2009). Five samples were taken from each plot. After sampling, soil cores were divided into 0-10, 10-20, 20-30 and 30-40 cm layers with a knife. Each layer was kept on an iron net (2 mm mesh) and the roots were separated from soil by applying water. After washing each sample was spread out and root length was measured with a Comair Root Length Scanner (Hawker De Havill and Victoria Ltd., Australia). After root length scanning, root samples were dried in an oven at 70 ˚C for 48 hours (Henry et al., 2012; Uddin et al., 2009; Karmakar et al., 2004). A high precision balance (milligram) was used to measure the dry weight of root biomass.

2.16 Statistical analysis

Data recorded in the experiments were statistically analyzed following procedures described by Gomez and Gomez (1984). Analysis of variance (ANOVA) was conducted using statistical software CropStat 7.2, cluster constructed by JMP 7.0.2 based on phenotypic characteristics and diversity analyses were done by GenStat 5.3. Means were compared with the least significant difference (LSD) test.

3. Results and Discussion

3.1 Drought severity and drought duration quantification

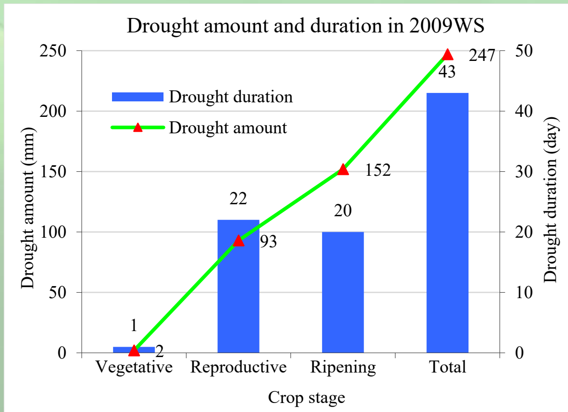
The genotype screening experiment was conducted under rainfed conditions and the bund was cut at 28 days after transplanting (DAT). Consequently, the crop was fully depended on rainfall. The crop of the wet season 2009 received rains up to the vegetative stage while the crop of 2010 received rainwater up to reproductive stage. Therefore, drought severity and drought duration were higher in 2009 WS than in the 2010 WS. Drought severity at vegetative, reproductive and ripening stage in 2009 was 2, 93 and 152 mm water deficit, respectively while it was 9, 22 and 76 mm water deficit in 2010 WS (Fig. 6). Accordingly, the total water deficit (247 mm) was remarkably higher during in 2009 WS than 2010 WS (107 mm). For drought duration, the data followed the trend of drought amount. Drought duration at vegetative, reproductive and ripening stage was 1, 22 and 20 days in 2009 but it was 3, 8 and 14 days in 2010 WS. Therefore, the crop of the 2009 WS faced 43 days drought stress whereas the stress duration was only 25 days in 2010 WS. Consequently, the crop of the 2009 WS experienced a severe drought stress while it faced moderate drought stress in the 2010 WS.

3.2 Genotype clustering through dendogram regarding leaf rolling and drying, spikelet sterility; and phenotypic acceptability

A dendogram was constructed using a distance matrix which was calculated from phenotypic acceptability, leaf-rolling, leaf-drying and spikelet fertility values. This dendogram determined the relationship among the tested 30 rice genotypes and grouped them into 3 clusters (Fig. 7). The distribution pattern indicated that cluster I comprised the highest number of tested entries (22), followed by cluster II (2), and cluster III (6) (Table 2). Among the clusters, genotypes in cluster III had the highest score having lowest values of phenotypic acceptability, leaf rolling, leaf drying and spikelet sterility scores, indicating that these genotypes possess more drought tolerance compared to other clusters. In contrast, the mega varieties BRRI dhan49 and Guti Swarna were placed in cluster II which showed more susceptibility to drought stress. Cluster I showed intermediate drought tolerance, having values of the parameters phenotypic acceptability, leaf-rolling, leaf-drying and spikelet fertility in between cluster II and III. Cluster mean of 30 rice genotypes was the highest (8.167) in phenotypic acceptability at the reproductive stage ranging from 1.267 to 8.167 (Table 3). Differences in cluster means existed for almost all the characters studied. Inter and intra cluster distance varied from cluster to cluster (Table 3). Inter cluster distance was the highest (10.936) in between cluster II and III that was followed by cluster I and III (7.245) and the lowest was in cluster I and II (5.952). Intra cluster distances were calculated from the value of distance matrix of tested 30 rice genotypes. Genotypes in cluster I showed the highest intra cluster distance (0.745), followed by cluster III (0.615) and cluster II (0.382). Relative contribution towards divergence is presented in Table 4. Among characteristics for drought tolerance, the value of phenotypic acceptability at vegetative, leaf-rolling and leaf-drying at vegetative and reproductive stage of the genotypes showed positive divergence in vector I (Table 4). It indicated that these characters contributed more towards divergence among the genotypes. In contrast, the values of phenotypic acceptability at vegetative stage and spikelet sterility were negative in vector I contributed less toward divergence. All the parameters scored at reproductive stage showed positive value in vector-II while it was negative in case of scored recorded at vegetative stage (Table 4). The double positive values generally contributed higher in divergence. In the present study, three characters such as phenotypic acceptability, leaf-rolling and leaf-drying at reproductive stage showed double positive value in both the vectors indicated that those characters contributed most towards divergence. In contrast, single character phenotypic acceptability at vegetative showed double negative value in both the vectors. Spikelet sterility showed positive value in vector-II and negative value in Vector-I indicated that it also contributed remarkably for divergence.

3.3 Genotypic variation on yield, yield attributes and agronomic parameters under drought stress

Significant genotypic difference existed among the rice cultivars for grain yield, yield components and agronomic parameters in both the 2009 and 2010WS (Table 5). Across the genotypes, IR83377-B-B-93-3 attained the highest grain yield (3.65 t ha^{-1}) followed by IRRI 123 (3.53 t ha^{-1}) and IR74371-70-1-1 (3.52 t ha^{-1}) in 2009WS under severe drought stress. Quite the reverse, locally popular mega variety Guti Swarna produced the lowest grain yield (1.30 t ha^{-1}) followed by BRRI dhan49 (1.36 t ha^{-1}). The genotype NERICA4 gave 2.10 and 2.71 t ha^{-1} grain yield during 2009 and 2010WS, respectively. In general, yield of the tested genotypes was lower in 2009WS than 2010 WS as the crop of 2009 WS faced more drought stress at reproductive phase compared to 2010 WS (Fig. 6).
Grain yield ranged from 1.28 to 3.65 t ha^{-1} in 2009WS while it was 2.44 to 4.51 t ha^{-1} in 2010WS. Similarly, percentage of grain yield reduction in 2009 over 2010 ranged from 14 to 57.0% (Table 5). Grain yield reduction was the highest (57.0%) in the Guti Swarna while the lowest (14%) was in IR74371-70-1-1 followed by IR83377-B-B-93-3 (19%) and IRRI 123 (20%) in 2009WS over 2010WS. In general, harvest index was lower than the optimum level of high yielding variety and it was also lower in 2009WS than 2010WS. Across the genotypes and years, most of the genotypes contained lower harvest index with an average of 0.37 ranging from 0.25 to 0.45 in 2009WS while it was 0.41 ranging from 0.33 to 0.47 during 2010WS. Harvest index was the highest (0.45) in IR83377-B-B-93-3 followed by IR74371-70-1-1 (0.44) and IRRI (0.44) in 2009WS. It was the lowest (0.25) in Guti Swarna in 2009WS while it was the lowest (0.27) in BRRI dhan49 in 2010WS. Days required to maturity and plant height remarkably affected by the genotypes (Table 5). Days to maturity ranged from 102 to 134 during 2009WS while it was 105 to 136 days in 2010WS. In general, soil water tension was higher in 2009WS compared to 2010WS (Fig. 5).



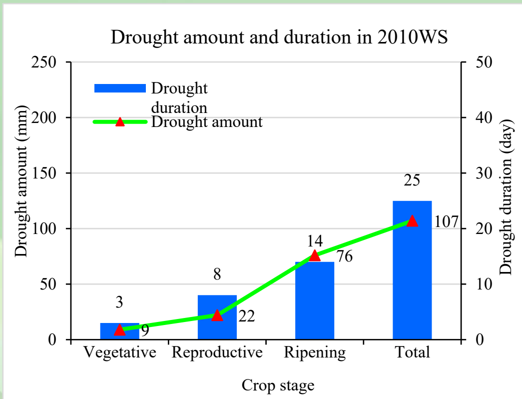


Figure 6. Drought amount and drought duration in the experimental field during 2009 and 2010WS at Godagari, Rajshahi, Bangladesh.

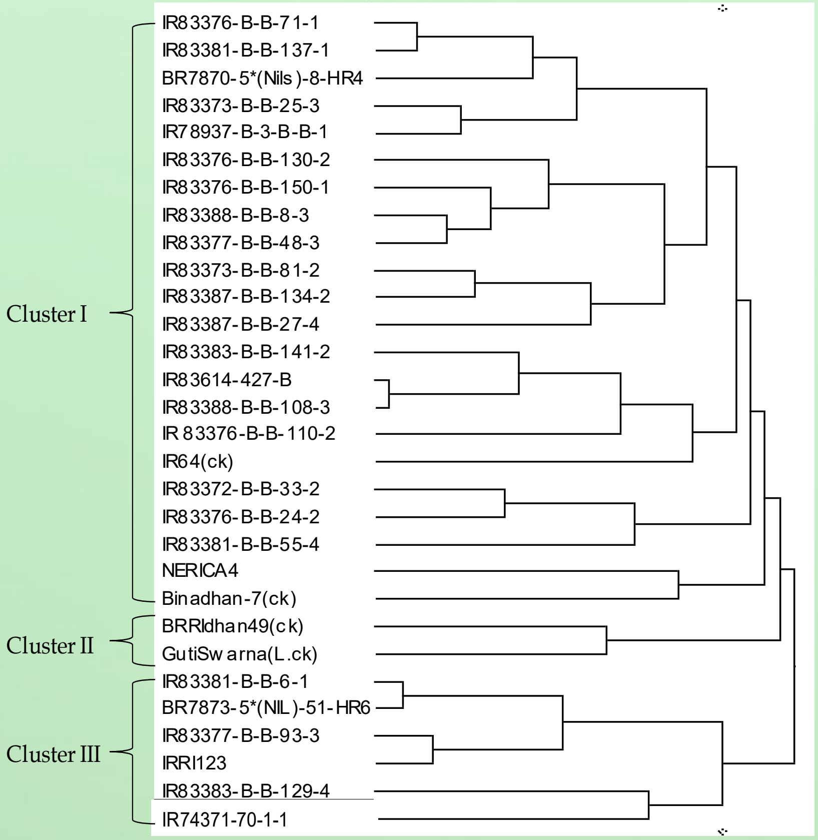


Figure 7. Dendogram of 30 rice genotypes based on phenotypic acceptability, leaf rolling, leaf drying and spikelet fertility under drought prone rainfed environment.

Table 2. Intra-cluster (Diagonal) and inter-cluster (D^2) divergence values of 30 rice genotypes.

Clusters	Cluster I	Cluster II	Cluster III
Cluster I	**0.745**		
Cluster II	5.952	**0.382**	
Cluster III	7.245	10.936	**0.615**

NB: Bold figures denote intra cluster distance

Table 3. Cluster means of the characteristics of 30 rice genotypes.

Characteristics	Cluster mean		
	I	II	III
Phenotypic acceptability at vegetative stage	3.887	6.189	2.333
Phenotypic acceptability at reproductive stage	6.133	8.167	2.550
Leaf rolling at vegetative stage	1.778	1.953	0.200
Leaf rolling at reproductive stage	3.900	4.044	1.267
Leaf drying at vegetative stage	1.533	1.589	0.267
Leaf drying at reproductive stage	3.444	3.993	1.433
Spikelet fertility	4.511	4.560	3.667

Table 4. Characters contribution towards divergence among the 30 rice genotypes.

Characteristics	Vector I	Vector II
Phenotypic acceptability at vegetative stage	-0.0511	-0.7070
Phenotypic acceptability at reproductive stage	0.2904	0.1821
Leaf rolling at vegetative stage	0.5026	-0.9340
Leaf rolling at reproductive stage	0.1956	0.2377
Leaf drying at vegetative stage	0.6383	-1.7975
Leaf drying at reproductive stage	1.2135	0.9422
Spikelet fertility	-0.2526	0.3186

Table 5. Phenology, yield and yield components of the rice genotypes under drought prone rainfed environment at Godagari, Rajshahi Bangladesh during 2009 and 2010WS.

Genotype	Grain yield (t ha^{-1})		Yield reduction (%) in 2009 over 2010	Harvest Index		Growth duration (day)		Plant height cm)		Panicles m^{-2} (no.)		Sterility (%)		1000-grain wt. (g)	
	2009	2010		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
IR 83376-B-B-71-1	1.68	2.92	43	0.34	0.40	110	112	102	104	190	206	46	38	22.6	23.5
IR 83381-B-B-137-1	1.87	3.02	38	0.36	0.41	111	113	103	105	192	212	45	39	23.1	23.8
IR 83373-B-B-25-3	1.50	2.57	42	0.31	0.38	109	111	108	109	187	203	47	40	22.8	23.3
IR 83376-B-B-130-2	2.20	3.12	29	0.37	0.39	109	110	106	107	201	226	38	35	22.7	23.2
IR 83381-B-B-6-1	3.11	4.07	22	0.41	0.43	108	110	104	109	212	235	29	24	23.3	23.7
IR 83372-B-B-33-2	1.46	2.58	44	0.33	0.36	107	109	95	97	188	210	51	41	22.7	23.4
IR 83381-B-B-55-4	1.35	2.38	43	0.31	0.37	110	113	104	106	174	190	52	43	22.3	23.2
IR 83373-B-B-81-2	1.89	3.01	37	0.36	0.41	105	108	95	96	196	220	45	40	22.6	22.9
IR 83383-B-B-141-2	2.55	3.78	33	0.41	0.45	108	111	102	104	213	233	35	30	22.9	23.3
IR 83376-B-B-150-1	2.35	3.25	26	0.39	0.41	109	110	108	111	206	222	37	32	23.2	23.5
IR 83376-B-B-110-2	2.76	3.87	29	0.43	0.46	111	113	103	105	220	242	34	29	22.7	23.5
IR 83376-B-B-24-2	1.41	2.44	42	0.30	0.35	109	111	92	93	167	199	52	42	22.4	22.7
IR 83383-B-B-129-4	2.91	3.92	26	0.42	0.46	113	115	103	108	220	233	31	27	23.0	23.3
IR74371-70-1-1	3.52	4.11	14	0.44	0.47	105	108	106	110	228	251	26	23	23.2	23.4
IR 83387-B-B-27-4	2.14	3.07	30	0.36	0.39	111	114	92	97	213	229	42	37	23.8	24.3
IR83614-427-B	2.28	3.17	27	0.37	0.40	103	105	87	90	219	235	41	35	22.5	23.2
IR 83388-B-B-108-3	2.37	3.41	31	0.39	0.42	109	112	100	104	217	235	37	31	22.7	23.2
IR 83377-B-B-93-3	3.65	4.51	19	0.45	0.47	112	115	103	110	245	261	26	22	23.3	23.6
IR 83388-B-B-8-3	2.36	3.26	28	0.37	0.40	112	115	103	106	213	231	43	34	22.6	23.4
IR 83387-B-B-134-2	2.17	3.08	29	0.35	0.38	113	116	102	107	197	217	44	35	22.9	23.4
IRRI 123	3.53	4.40	20	0.44	0.47	116	120	103	109	245	267	28	24	23.2	23.7
IR 83377-B-B-48-3	2.21	3.10	29	0.38	0.41	105	108	102	103	206	222	37	32	23.3	23.5
IR78937-B-3-B-B-1	2.08	3.27	36	0.36	0.42	112	115	101	104	204	217	42	33	22.6	22.8
BR7870-5*(NIL)-8-HR4	2.52	3.61	30	0.38	0.42	112	117	94	100	226	242	39	29	21.0	21.6
BR7873-5*(NIL)-51-HR6	3.04	4.01	24	0.42	0.44	102	105	99	102	252	267	28	25	20.7	21.0
NERICA 4	2.10	2.71	23	0.36	0.35	115	118	93	98	201	215	35	33	22.3	22.7
IR64 (Check)	2.38	3.50	32	0.41	0.44	107	110	88	91	219	240	37	28	22.2	22.5
Binadhan-7 (Ck)	2.60	4.16	38	0.40	0.46	112	115	91	97	249	265	41	26	22.8	23.3
BRRI dhan49 (Ck)	1.36	2.52	46	0.27	0.33	126	130	96	100	235	252	61	42	22.0	22.5
Guti Swarna (L. Ck)	1.30	3.01	57	0.25	0.36	134	136	103	109	240	258	62	41	22.6	23.0
$LSD_{0.05}$	0.33	0.24	-	0.03	0.02	1.2	1.5	1.3	1.0	9	7	4	3	0.6	0.5
F-test	***	***	-	***	***	***	***	***	***	***	***	***	***	***	***

***P≤0.001 (Strongly significant)

Table 6. Correlation coefficients among the traits of 30 genotypes under rainfed environment

Parameters	Grain yield (t ha^{-1})	Panicles m^{-2} (no.)	Sterility (%)	Grain wt. (g)	Plant ht (cm)	Biomass (t ha^{-1})	Harvest index
Wet season 2009							
Grain yield	1						
Panicles m^{-2}	0.661**	1					
Sterility (%)	-0.919**	-0.483**	1				
Grain weight	0.226*	-0.062 ns	-0.214ns	1			
Plant ht (cm)	0.206*	-0.025 ns	-0.151ns	0.310**	1		
Biomass	0.963**	0.707**	-0.831**	0.198ns	0.207ns	1	
Harvest index	0.919**	0.504**	-0.937**	0.231*	0.142ns	0.793**	1
Wet season 2010							
Grain yield	1						
Panicles m^{-2}	0.778**	1					
Sterility (%)	-0.928**	-0.689**	1				
Grain weight	0.175ns	-0.087ns	-0.059ns	1			
Plant ht (cm)	0.348**	0.160ns	-0.291**	0.312**	1		
Biomass	0.924**	0.840**	-0.854**	0.108ns	0.340**	1	
Harvest index	0.913**	0.572**	-0.851**	0.231*	0.317**	0.691**	1

*Significant at P≤0.05, **Significant at P≤0.01 and ns=not significant.

Across the experimental years and genotypes, plant height varied from 87 to 111 cm due to water stress. Panicle production m^{-2} ranged from 167 to 252 in 2009 while it was 190 to 267 during 2010WS. Moreover, the mega variety BRRI dhan49 and Guti Swarna produced significantly lower panicles m^{-2} than the highest one. The tested genotypes expressed high significant variability regarding spikelet sterility (Table 5). Sterility percentage was the highest (62%) in Guti Swarna during 2009WS despite the fact that the highest percentage of sterility (42%) was found in BRRI dhan49 and IR83376-B-B-24-2 in 2010WS. In contrast, IR74371-70-1-1 and IR83377-B-B-93-3 performed better with the lowest sterility 26 and 22%, respectively. Strong significant differences in respect of 1000-grain weight of the genotypes found in both the experimental years. Among the cultivars, IR83387-B-B-27-4 produced grain with highest 1000-grain weight (23.8 and 24.3 g in 2009 and 2010, respectively) at the same time as the genotype BR7873-5*(NIL)-51-HR6 gave constantly the lowest 1000-grain weight of 20.7 and 21.0 g in 2009 and 2010, respectively.

3.4 Relationship of grain yield and yield attributes

Correlation between yield and yield parameters was highly significant in both the experimental years (Table 6). Moreover, Fig.8 and 9 showed the relationship among grain yield with panicles m^{-2}, spikelet sterility, 1000-grain weight, plant height, biomass and harvest index during 2009 and 2010WS. The highest R^2 values (0.927 and 0.853 in 2009 and 2010Ws, respectively) found in the relation of yield and biomass followed by harvest index (Fig 7 and 8). Compound interrelationship among various traits was found between yield and yield components determining one depended variable such as grain yield. Grain yield showed positive association with all the parameters except spikelet sterility. Panicles m^{-2}, biomass and harvest index were high positively related with grain yield while plant height and 1000-grain weight low positively related. In contrast, spikelet sterility was high negatively related with grain yield during both the experimental years.

3.5 Root Biomass

Root biomass varied significantly across the genotypes in both experimental years. Most of the roots of all the genotypes existed in 0 to 10 cm soil depth and, thereafter reduced the root biomass into 10 to 40 cm depth. Among the 30 rice genotypes, the highest mean root dry matter (4.21 g/0.015 cm^3) was observed in the genotype IR74371-70-1-1 which was statistically similar to NERICA 4 (4.19 g/0.015 cm^3), IR83377-B-B-93-3 (4.15 g/0.015 cm^3), IRRI 123 (4.13 g/0.015 cm^3) and IR83381-B-B-6-1 (3.80 g/0.015 cm^3) across the two seasons. (Fig. 10). Root biomass ranged from 2.05 to 4.21 g/0.015 cm^3. Thereby, the five IR74371-70-1-1, NERICA, IR83377-B-B-93-3, IRRI 123 and IR83381-B-B-6-1 found drought tolerant.

4. Discussion

4.1 Drought stress quantifying based on rainfall, soil moisture and soil water potential

Different intensities of drought stress occurred in each season of the study, where drought severity was higher in 2009WS compared to 2010WS (Henry et al., 2011). Rainfall received by the crops of the experiments was considerably lower at the northwest region of Bangladesh (Karmakar et al., 2010). Moreover, the rains were very much unevenly distributed (Fig. 1) within the years and seasons (Haefele et al., 2006). Mean annual rainfall of the experimental years (744 and 897 mm in 2009 and 2010, respectively) were much lower than the country average 2300 mm ranged from 1000 to 5000 mm (Saleh et al., 2000; Karmakar et al., 2012).

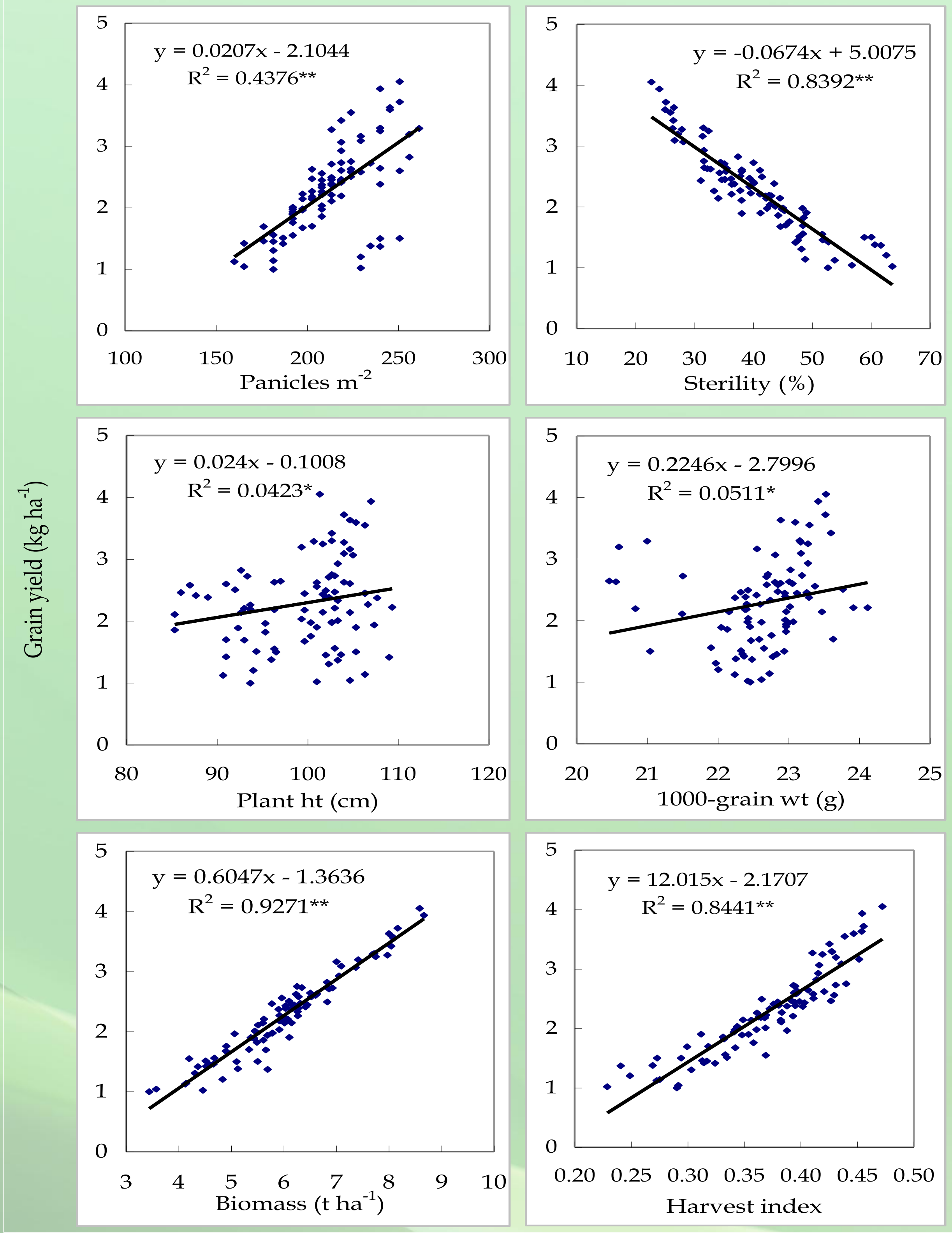


Figure 8. Relationship of grain yield and yield attributes of 30 rice genotypes under drought prone rainfed environment during 2009WS.

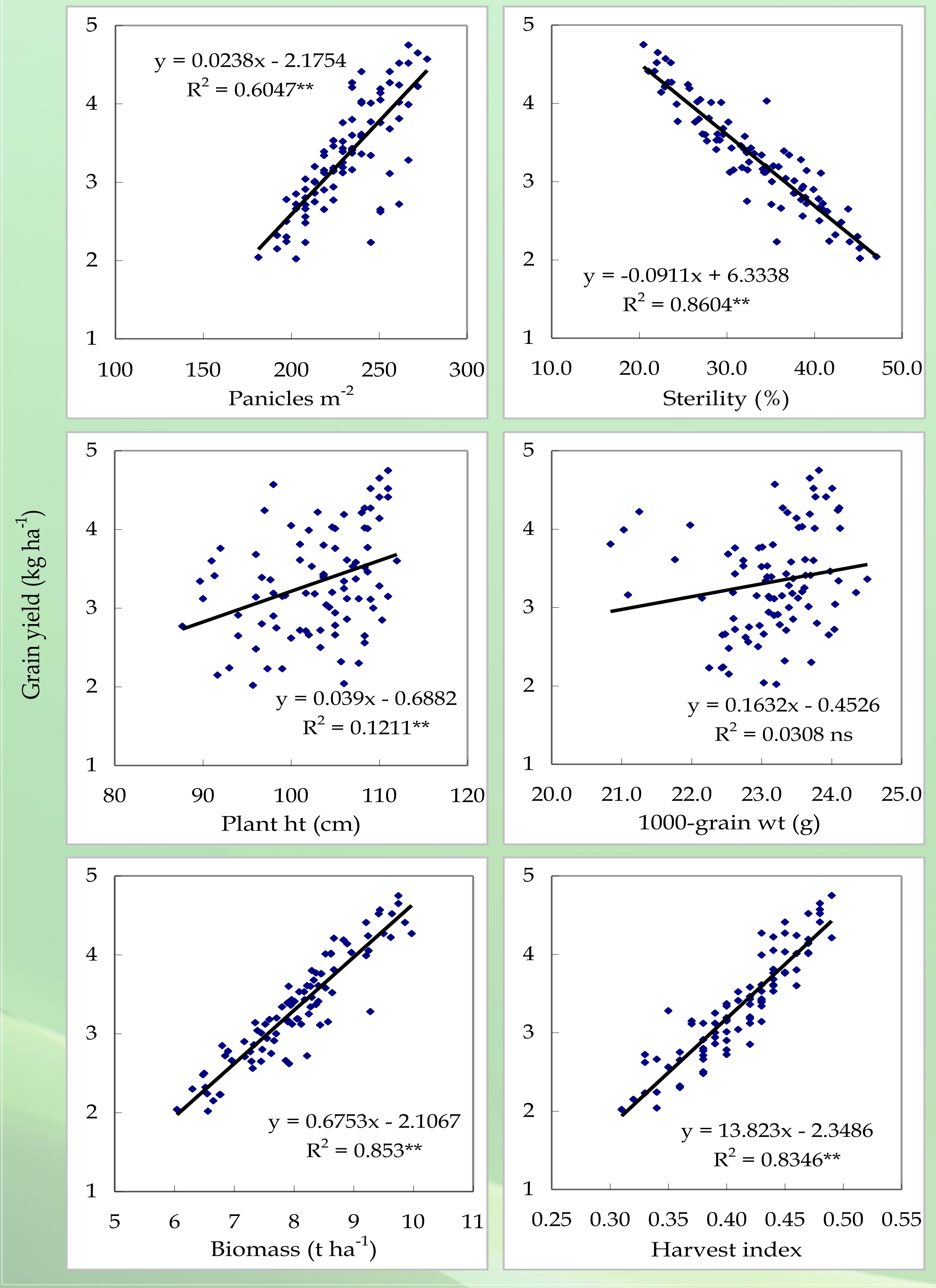


Figure 9. Relationship of grain yield and yield attributes of 30 rice genotypes under drought prone rainfed environment during 2010WS.

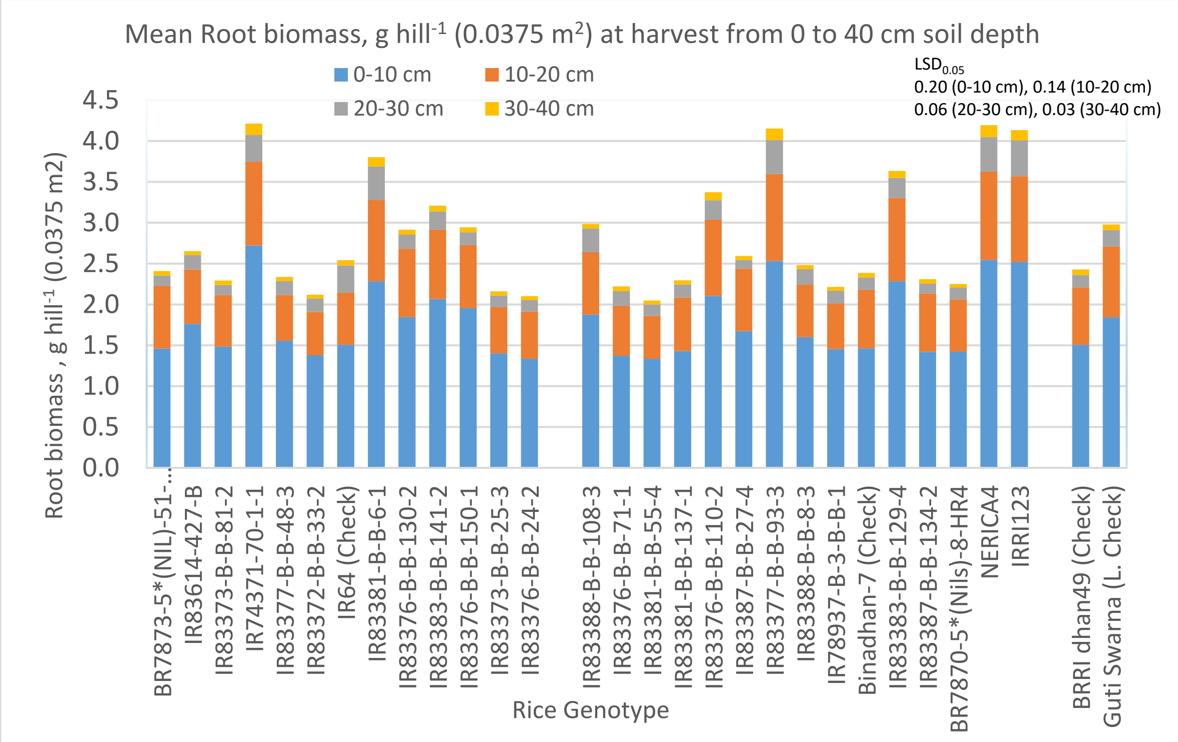


Figure 10. Mean Root biomass, g hill^{-1} (0.0375 m^2) of the rice genotypes in 0 to 40 cm soil depth at harvest under drought prone rainfed environment during 2009 and 2010WS

Meteorological data shows that much less rains occurred in 2009WS while 2010WS was moderately rainy (Fig. 1& 2). Consequently, the crop experienced substantial and intermittent drought stress in 2009 and 2010WS, respectively. Rainfall distribution, groundwater level (Haefele and Bouman, 2008) and soil moisture content and soil water tension (Henry et al., 2011) during reproductive phase of crop indicated a higher water stress for the trials conducted under rainfed environment. Consequently, no doubt that rainfall is an important determinant of the yield of rainfed lowland rice (Wade et al., 1998). Drought amount and duration varied in different crop stage as well as cropping years. Crop at vegetative stage did not face drought stress in both the years. However, severe drought stress existed in reproductive and ripening stage caused higher spikelet sterility (Islam and Islam, 2010) in 2009WS while it was moderate in 2010WS. Drought amount and duration was significantly higher in 2009WS than 2010WS that caused higher grain yield reduction (14 to 57%) in 2009WS over 2010WS. This result corroborates with Islam and Islam (2010) found that yield was reduced by 30 to 55% due to drought stress. Moreover, crop experienced severe drought stress with 43 drought days amounting 247 mm drought in 2009 while it was only 25 days and 107 mm in 2010, respectively. These findings are alignment with Islam et al. (2007) who reported maximum drought of 40 days and minimum drought of 22 days in northwest Bangladesh.

4.2 Genotype clustering through dendogram regarding phenotypic acceptability, leaf-rolling, leaf-drying and spikelet sterility

Dendogram of the rice genotypes showed drought stress severity that drawn based on phenotypic acceptability, leaf-rolling and leaf-drying score, and spikelet fertility. Genotypes belonging to the distant clusters maintained highest genetic variation. Genotypic variability in any crop is requirement for selection of superior genotypes over the existing cultivars (Murthy et al., 2011). The genotypes having lower inter cluster distances values in cluster I and III could be used as parents for the development of drought-resistant varieties. The other cluster (II) had the highest inter cluster mean value indicated that materials of this cluster are highly susceptible to drought. These results indicated, selection of genotype(s) from cluster III have positive impact and selection of genotype from cluster I and II have negative impact for drought resistant. It was preferential to make a decision that intra-cluster diversity was the highest in cluster I indicated more heterogeneous genotypes had in this cluster. Higher inter and intra cluster distances indicate higher genetic variability among genotypes between and within clusters, respectively. Phenotypic acceptability, leaf-rolling and leaf-drying at reproductive stage had positive impact in both the vectors. The characters that showed positive value in both vectors contributed most towards divergence. Spikelet sterility had negative impact in vector I and positive impact in vector II towards divergence. Double negative value of phenotypic acceptability at vegetative stage in vector I and II contributed lowest for divergence in the studied materials. Generally, positive value of the parameters like phenotypic acceptability, leaf rolling, leaf drying and spikelet sterility towards the vectors contributed higher for divergence while the negative value had lower contribution.

4.3 Genotypic variation on yield, yield attributes and agronomic parameters under drought stress

The tested genotypes varied significantly in respect of grain yield, yield attributes and agronomic parameters under drought stress (Murthy et al., 2011). It was might be due to the genotypic variability in response to drought stress of the genotypes (Sakai et al., 2010; Sarvestani et al., 2008). In general grain yield was lower in 2009WS compared to 2010WS as because drought stress was more in 2009WS than 2010WS. Genotypes responded differently under different drought stress conditions and habitually reduced grain yield of rainfed rice (Pantuwan et al., 2002b). Grain yield reduction varied from 14 to 57% due to drought stress across the cropping years and genotypes. Kumar et al., (2007) reported that drought stress at the flowering stage reduced yield by an average of 80% relative to a non-stressed control condition. Sarvestani et al. (2008) reported that grain yield reduced by 21, 50 and 21% due to water deficit at vegetative, flowering and grain filling stages, respectively. Yield of second year was higher than first year due to higher number of panicles m^{-2}, higher grain weight and lower spikelet sterility in 2010 compared to 2009. Genotypes performed differently in terms of yield and yield attributes under drought stress (Sakai et al., 2010). Long duration varieties like Guti Swarna and BRRI dhan49 suffered severely due to late season drought stress so that yield of these mega varieties reduced much more due to less panicle development and panicle exertion. Sarvestani et al. (2008) also found lower yield in the long duration cultivar Nemat due to late season drought. The low yield obtained in the genotypes was generally caused by a large percentage of unfilled grains per panicle due to reproductive phase drought (Wopereis et al., 1996). The main reasons for yield reduction was late season drought that were not suitable for panicle development impaired with reduced grain filling, grain number and weight (Sarvestani *et al.,* 2008; Islam et al., 1994; Bouman and Toung, 2001). Grain yield reduction resulted from greatly reduction of filled grain per panicle (Pantuwan et al., 2002a). Across the genotypes and years, harvest index fluctuated from 0.25 to 0.45 among the genotypes. These findings are in conformity with those of Fageria et al., 2010 and Kiniry et al., 2001. Harvest index varied significantly among cultivars ranging from 0.36 to 0.52 (Fageria et al., 2010) and from 0.35 to 0.62 (Kiniry et al., 2001) indicating the importance of this variable for yield stimulation. Harvest index generally was lower than the optimum level of high yielding variety in 2009 (more drought stress existed) but it was comparatively higher in 2010WS. Extremely low harvest index values related to drought stress resulted higher sterility, lower spikelet fertility, lower grain filling and lower grain weight and thereby grain yield (Haefele et al., 2003). Genotypes produced comparatively higher yield even under drought stress contained higher harvest index. These results are in accordance with Jearakongman et al. (1995) who reported that cultivars suitable for rainfed conditions are those with high yield potential resulting from high harvest index. Spikelet sterility and harvest index are the important parameters to quantify drought stress. Higher value of sterility and lower value of harvest index indicate susceptibility to drought tolerance (IRRI, 2002; Lafitte et al., 2002).

Days to flowering and maturity of almost all the genotypes in generally reduced by 1 to 5 days in 2009WS due to drought stress compared to 2010WS prevailed less drought stress. In general, time required to flowering ranged to a great extent among the genotypes and experimental years (Henry et al., 2012). Drought stress started from panicle initiation to maturity of many cultivars. However, some short duration genotypes escaped some extent this drought stress. Rainfed rice is extremely sensitive to water deficit from about 12 days before 50% flowering to about 7 days after flowering (Fischer et al., 2012). Drought stress at reproductive phase enhanced crop to reach early maturity. It happened might be due to water stress at reproductive stage forced the plant to switch over from flowering to maturity very faster. In contrast, many researchers (Sakai et al., 2008) reported that drought stress prior to flowering delayed flowering and maturity. However, Atlin et al., (2006) reported that days to flowering of high yielding rice varieties was delayed by 15 days while it was 5 days earlier for *japonica* varieties in water stressed drought prone environment than well watered condition. Plant height, panicles m^{-2}, grains $panicle^{-1}$, grain weight, fertility were reduced while sterility increased significantly in the severe drought year compared to less drought year. These findings are in agreement with Pantuwan *et al.,* (2002a) who reported that unfilled grain in the drought stress condition was 48% compared with 20% in well watered condition while 1000-grain weight was 18% smaller in drought stress. It happened might be due to genetically variability of the genotypes and also affected by drought stress (Fageria and Filho, 2007; Peng et al., 2000). Spikelet fertility was judged the most practical character by which to score cultivar performance (Garrity and O'Toole, 1994). It increased in comparatively less drought year 2010 over severe drought year 2009WS.

Grain yield was significantly and positively associated with all the yield attributes like panicles m^{-2}, grains $panicle^{-1}$, grain weight, spikelet fertility under drought stress however; spikelet sterility had negative correlation with yield (Pantuwan et al., 2002a; Murthy et al., 2011; Yadav, 1992). Haider *et al.,* (2012) also found that thousand grain weight (0.476**), grains per panicle (0.733**), spikelet fertility (0.709**) had positive and significant association with grain yield under drought stress; whereas, spikelet sterility had significantly negative correlation with yield. Short-duration genotypes would be preferable for many drought-prone environments because this could reduce the late-season drought risk and open options for post-rice crops in favorable years (Haefele et al., 2006). However, short duration variety has limitation that could produce comparatively lower yield than the mega variety in the favorable years (Pantuwan et al., 2002a; Fischer et al., 2012). Drought resistant cultivars may be considered to be those produce higher grain yield under drought conditions (Pantuwan et al., 2002b).

4.4 Root biomass

Root biomass of the tested genotypes varied significantly across the genotypes (Fageria, 2010; Uddin et al., 2009). The highest root biomass (61.1%) of the genotypes located in the 0-10 cm soil depth followed by 10-20 cm (27.1%), 20-30 cm (8.8%) and the lowest (3.0%) was in 30-40 cm. These results are in alignment with the findings of Henry et al., 2011; Fageria, 2010; Uddin et al., 2009. That means most of the root system (88.2%) positioned to the top 20 cm of the soil layer. Similar findings also reported by Sharma et al. (1994) who found that 90% of the total root system restricted in the 0-20 cm soil depth. Some genotypes having more roots biomass extracted more water from deeper soil than others and acquired more drought tolerance.

5. Conclusion

Based on overall performances, the genotypes IR74371-70-1-1, NERICA4, IRRI 123, IR83377-B-B-93-3, and IR83381-B-B-6-1 were selected as drought tolerant and BR7873-5*(NIL)-51-HR6 was selected as drought escaping. From these findings, the genotypes IR74371-70-1-1 and BR7873-5*(NIL)-51-HR6 released as drought tolerant rice variety named BRRI dhan56 and BRRI dhan57, respectively through national variety release system. Rice cultivars having extensive deep root systems are proficient to mine moisture from deep soil layer indicated that more efficient in drought prone rainfed environments. Moreover, the selected genotypes could be utilized to improve varieties through classical breeding or using biotechnology linked with innovative agronomic management.

Declarations

Ethical Approval Certificate

The experimental procedures of this study were approved by the authority of Bangladesh Rice Research Institute, 1701, Gazipur, Bangladesh.

Author Contribution Statement

Biswajit Karmakar: Conceptualization, methodology, Research work execution, investigation and data collection; writing up original draft

Amelia Henry: Writing up original draft, Review and editing of the manuscript

Stephan M Haefele: Review and editing of the manuscript

Md. Habibur Rahman Mukul: Data compilation, curation validation and formal analysis

Mir Mehedi Hasan: Data compilation, curation validation and formal analysis

Arvind Kumar: Review and editing of the manuscript

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Conflict of Interest: The authors declare no conflict of interest.

Data availability statement: All the data supporting the findings of this study are included in this article.

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Abbreviations and Units:

AEZ: Agro-ecological Zone, AYT: Advanced yield trials, BRRI: International Rice Research Institute, DAT: date after transplanting, DT: Drought tolerant, DS: Drought susceptible, ET: Evapotranspiration, IRRI: International Rice Research Institute, OYT: Observational yield trial, PVC: Polyvinyl chloride, SMS: Soil moisture storage, SWS: Surface water storage, WS: Wet season.