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Root Characteristics and Its Correlation with Yield of Some Maize (*Zea mays* L.) Genotypes in Bangladesh

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Abstract: The growth capacity and yield characteristics of crop plants are significantly influenced by their roots. To determine the influence of root characteristics and its correlation with yield of maize genotypes, an experiment was conducted at the experimental field of Department of Crop Botany and Tea Production Technology, Sylhet Agricultural University (SAU), Bangladesh during December 2014 to May 2015. The experimental materials were ZM 0001, ZM 0002, ZM 0003, ZM 0004, ZM 0005, ZM 0006, ZM 0007 and BARI Maize 6. Three replications and a Randomized Complete Block Design (RCBD) were used to set up the experiment. Necessary cultural practices were followed as and when require during the growing period. Data were recorded on number of roots plant^{-1}, root length, root spreading until grain filling stage (90 days after germination) and dry matter accumulation of roots at 30 days interval until harvest. The results indicated that root number of maize genotypes increased from 30 to 90 DAG at a constant rate and in the grain filling stage and it was limited within 32.33 to 42.67. Root length was also increased from 30 to 90 DAG at a constant rate and in the grain filling stage it was limited within 25.33 to 31.1 cm. Root spreading was continued to increase from germination stage to 90 DAG and it was varied from 22 to 27.73 cm. Dry matter accumulation of roots increased gradually from 30 to 60 and 90 DAG up to harvest. In this study, root shoot ratio (RSR) and root weight ratio (RWR) had significant correlation with maize yield. From the root length and root spreading data, it is suggested that moderate tillage and a plant to plant distance spacing of 25-30 cm can be maintained for better yield of maize.

Keywords: Root characteristics; Correlation; Maize; Dry matter; Yield; Root shoot ratio.

INTRODUCTION

Maize (*Zea mays* L.) is a crop that is highly valued and plays a significant role in the global food economy. It is a versatile crop which can be used as both food and feed. It is superior to rice and wheat in terms of nutritional value (Rohman *et al.*, 2011). Due to its unique photosynthetic mechanism (C_4 crop) and larger leaf size it produces higher grain yield as compared to other *Gramineae* family members and is called as 'Queen of Cereals'. Furthermore, it can be grown effectively in rainfed conditions with little management methods and capital requirements. As a result, global maize production is rising daily and has surpassed other cereals to take the top spot in terms of annual production. The globe produced 959 million tons of maize in 2013–14, which is greater than wheat (709 million tons) and rice (473 million tons) (GMR, 2014). The annual demand of maize is 1.6 million metric tons for Bangladesh

(Ahmed, 2013). But only 1.02 million metric ton maize is produced in the country per annum (BBS, 2011). Bangladesh must therefore produce more maize in order to meet its annual needs for a variety of purposes. Plant root systems are essential for plant anchoring, nutrition absorption, and water absorption (Lynch *et al.,* 2021). The effectiveness of nitrogen fertilizer uptake and the impact the root system of maize has on yield during droughts make it a significant factor in commercial maize production (Bänziger *et al*., 2000). Drought stresses can be prominent at different levels such as shoot, root and tissues (Hasan, M. R.,*et al.,* 2023). The size and dispersion of root systems have a major role in determining how adaptable they are to changing weather patterns. The fibrous root system of maize is widely dispersed, deeply ingrained, and highly branching. In addition, modifications to the architecture of the root system and the amount of water absorbed in proportion to plant density have been demonstrated to be reliable indicators of maize yield (Hammer *et al*., 2009). Alongside, different root characters e.g. root number plant^{-1}, root length and horizontal root spreading are important determiner of plant spacing and tillage depth. Other root characters such as root dry matter, root shoot ratio (RSR) and root weight ratio (RWR) also play vital role in the growth and development of maize. However, in Bangladesh, there is a lack of information on root systems of maize from field experiments. Therefore, an experiment was conducted to evaluate the root characteristics and examine the relationships between root characters with the yield of maize genotypes.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the experimental field of the Department of Crop Botany and Tea production Technology, Sylhet Agricultural University (SAU), Bangladesh from December 2014 to May 2015. The location of the experiment was at 24.9092°N latitude and 91.9020°E longitude. The soil type of the experiment was grey silty clay loams, which is found beneath the agro-colonial zone of the Surma-Kushiyara floodplain.

Experimental treatments and design

The experimental materials included eight maize genotypes: ZM 0001, ZM 0002, ZM 0003, ZM 0004, ZM 0005, ZM 0006, ZM 0007, and BARI Maize-6 (control). Among them, BARI Maize-6 was collected from Bangladesh Agricultural Research Institute (BARI) and rests of the genotypes were collected from abroad. The experiment was laid out in a randomized complete block design (RCBD) with three replications. The unit plot size was 2.5 m × 1.5 m, row to row and plant to plant distances were 50 cm and 25 cm, respectively. Crop husbandry was carried out in accordance with BARI recommendations to guarantee optimal plant growth and development.

Methods of data collection

For data collection, five plants were randomly selected from each plot and uprooted. Then the inert matters were removed from the roots and data on root number plant^{-1}, root length (longest root of a plant) and horizontal root spreading (after uprooting, the plants were kept in normal condition and distance between the far most root tips was determined) were recorded until grain filling stage (90 DAG). Then the root samples were kept into a drying oven at 80 ± 2 ºC for 72 hours and the dry weights were recorded. Each of the procedure was followed at every 30 days interval from seed germination until harvesting.

Analysis of data

The MSTAT-C computer package was used to tabulate and evaluate the data that were gathered during the experimental period. To determine the statistical significance of the experimental results, the data were statistically examined with regard to influence of root characteristics and its correlation with yield of maize genotypes. The T variance test was used to do an analysis of variance for each character under examination after the means for each treatment were determined. The Least Significant Difference (LSD) test was used to determine the mean separation (Gómez-Rico *et al.,* 2008).

RESULTS AND DISCUSSION

Number of roots plant^{-1}

The number of roots plant^{-1} varied significantly in different genotypes at 60 days after germination (DAG) but didn't show any variation at 30 and 90 DAG (Fig. 1). The number of roots plant^{-1} increased sharply almost in every genotype except BARI Maize 6 from 30 to 90 DAG. This might be due to varietal effect. At 30 DAG, number of roots plant^{-1} varied from 8.227 to 12.11. The highest number of roots plant^{-1} was produced in BARI Maize 6 (12.11) while least number of roots was found in ZM 0007 (8.227). At 60 DAG, an average number of roots plant^{-1} were increased 125.82% from 30 DAG and 12.65 new roots were produced by the genotypes i.e. a single root is produced in every 2.37 days at 30 to 60 DAG. The highest number of roots plant^{-1} was produced in ZM 0001 (26.17) while least number of roots was found in BARI Maize 6 (12.11). At 90 DAG, root number increased 67.34% and 15.29 new roots were produced from 60 DAG i.e. a single root is produced in every 1.96 days. However, the highest number of roots plant^{-1} was produced in ZM 0001 (42.67) followed by ZM 0007 (42.00) at this stage whereas least number of roots was produced in the genotype ZM 0006 (32.33). Correlation between the number of roots plant^{-1} and yield of eight maize genotypes are presented in Table 1, which represents that root number at 60 DAG is significantly and negatively correlated with the yield (-0.51). Root number at 30 DAG showed positive but non-significant and 90 DAG showed negative and non-significant correlation with yield. Nielsen *et al.,* (2018) found that maize plants with a higher number of roots per plant demonstrated significantly greater yields, particularly in nutrient-deficient soils. The study highlighted that an increased root quantity enables better soil exploration, facilitating improved access to nutrients and moisture.

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Table 1. Correlation matrix of number of roots plant-1 with grain yield at different days after germination (DAG)

Characters	60 DAG	90 DAG	Yield
30 DAG	-0.47*	-0.09^{NS}	0.40^{NS}
60 DAG		0.56**	-0.51*
90 DAG			-0.14^{NS}

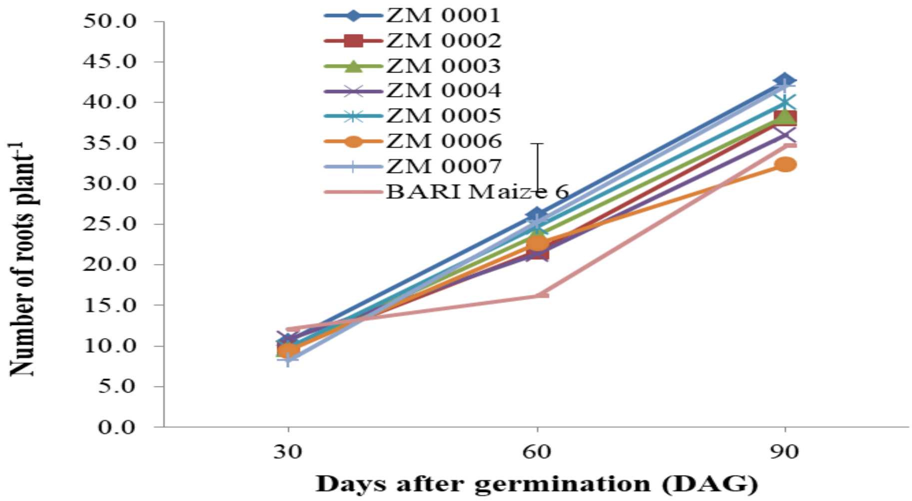

Fig. 1: Number of roots plant^{-1} of different maize genotypes at different DAG. [Vertical bar represents lsd $_{(0.05)}$]

Root length (cm)

The length of roots of the plants showed significant variation in different genotypes at 30 and 60 DAG but didn't show any variation at 90 DAG (Fig. 2). The length of roots increased gradually with the progress of the days. At 30 DAG, root length varied from 6.833 to 15.84 cm. The longest root was produced in BARI Maize 6 (15.84 cm) while least number of roots was found in ZM 0007 (6.833 cm). At 60 DAG, an average root length was increased 80.36% from 30 DAG and 8.72 cm longer root was produced by the genotypes i.e. the roots become longer at 0.29 cm day^{-1} at 30 to 60 DAG. Here, the longest root was produced in ZM 0004 (23.17 cm) while the shortest roots were found in ZM 0007 (13.83 cm). At 90 DAG, root length increased 41.04% and roots became 8.03 cm longer than that of 60 DAG i.e. the roots become longer at 0.27 cm day^{-1} at 60 to 90 DAG. However, the longest root was produced in ZM 0001 (31.10 cm) at this stage whereas shortest root was produced in the genotype ZM 0003 (25.33 cm). Correlation between the root length and yield of eight maize genotypes are presented in Table 2. From the table, it is observed that correlation between the root lengths at different DAG with yield is not significant. Root length at 30 DAG showed positive but root length at 60 and 90 DAG showed negative correlation. Zheng *et al.* (2017) found that genotypes with deeper roots consistently yielded higher in water-limited environments compared to those with shallower roots. This suggests that selecting for root depth could be a critical factor in breeding drought-resistant maize varieties.

Table 2. Correlation matrix of root length with grain yield at different days after germination (DAG)

Characters	60 DAG	90 DAG	Yield
30 DAG	0.44^{*}	0.16^{NS}	0.31^{NS}
60 DAG		0.36^{NS}	-0.04^{NS}
90 DAG			-0.07^{NS}

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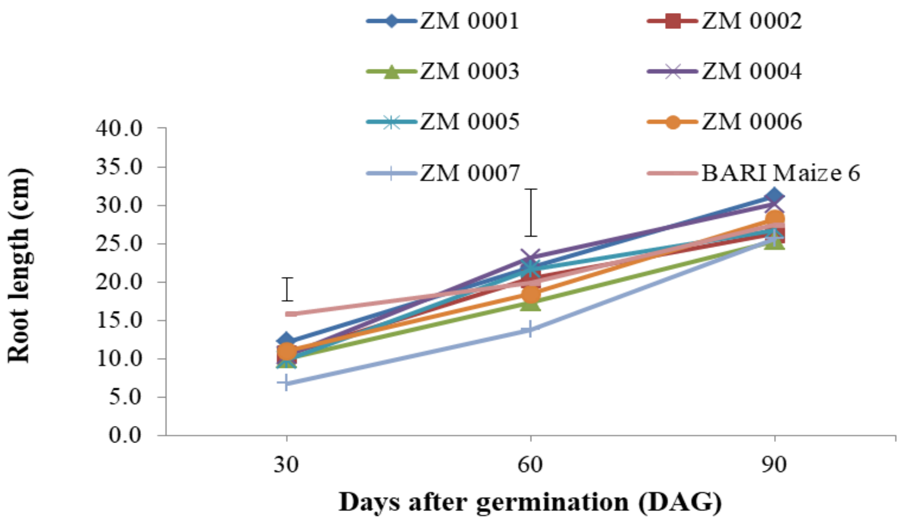

Fig. 2: Root length of different maize genotypes at different DAG.
[Vertical bars represent lsd $_{(0.05)}$]

Root spreading (cm)

Different genotypes showed significant variation in terms of root spreading at 30 DAG but didn't show any variation at 60 and 90 DAG (Fig. 3). Root spreading of a plant increased gradually with the progress of the days. At 30 DAG, root spreading varied from 6.89 to 9.957 cm. The highest spreader root was found in ZM 0006 (9.957 cm) while least spreader root was found in ZM 0007 (6.89 cm). At 60 DAG, an average root spreading was increased 105.83% from 30 DAG and 9.21 cm more spreader root was produced by the genotypes i.e. the roots were spreader at 0.0.31 cm day^{-1} at 30 to 60 DAG. Here, the highest spreader root was found in ZM 0003 (20.70 cm) while least spreader root was found in BARI Maize 6 (14.06 cm). At 90 DAG, root spreading increased 36.4% and roots became 6.52 cm more spreader than that of 60 DAG i.e. the roots become longer at 0.22 cm day^{-1} at 60 to 90 DAG. However, the most spreader root was found in ZM 0003 (27.73 cm) at this stage whereas least spreader root was found in ZM 0001 (22.00 cm). Correlation between root spreading and yield of eight maize genotypes are presented in Table 3. From the table, it is observed that correlation between the root spreading at different DAG with yield is not significant. Root spreading at 30 and 90 DAG showed positive but root spreading at 60 DAG showed negative correlation. Ning, P., *et al.*, 2014 and Lynch, J. P., *et al.*, 2013 found that more roots were distributed in the deep soil (20–60 cm), which could promote increased yield. Increasing the proportion of roots in the deep soil can effectively increase soil exploration capacity and reduce nutrient competition between plants (Bates, T. R. *et al.*, 2001).

Table 3. Correlation matrix of root spreading with grain yield at different days after germination (DAG)

Characters	60 DAG	90 DAG	Yield
30 DAG	0.15^{NS}	0.08^{NS}	0.40^{NS}
60 DAG		0.40^{NS}	-0.27^{NS}
90 DAG			0.11^{NS}

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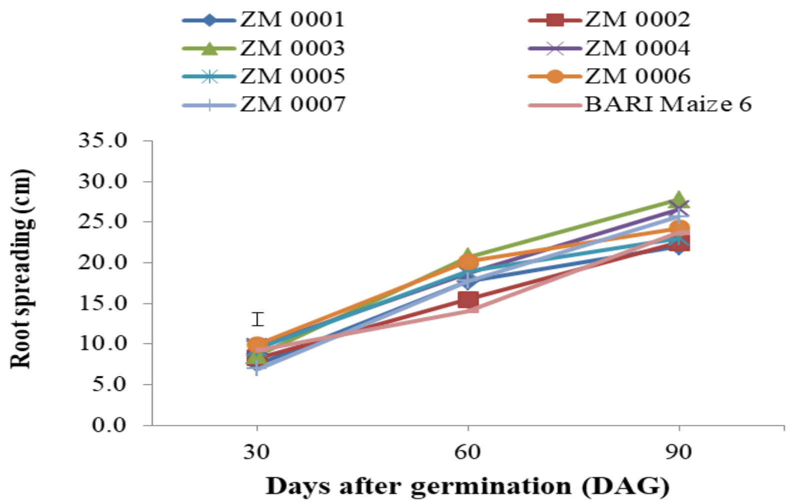

Fig. 3 Root spreading of different maize genotypes at different DAG.
[Vertical bars represent lsd $_{(0.05)}$]

Root dry matter (g)

The dry weight of roots of different genotypes showed significant at 30 and 60 DAG but didn't show any variation at 90 DAG and at harvest (Fig. 4). It is observed that the dry weight of roots increased gradually from 30 to 60 DAG and 90 DAG to at harvest. But from 60 to 90 DAG it increased sharply as compared to other growth stages. This was might be due to rapid increase in root diameter at this growth stage. At 30 DAG, root dry matter varied from 0.337 to 0.8 g. The highest amount of root dry matter was found in ZM 0006 (0.8 g) while least amount was found in ZM 0003 (0.337 g). At 60 DAG, an average dry matter was increased 946.95% from 30 DAG and 5.04 g more dry matter was produced by the genotypes i.e. dry matter production rate was 0.17 g day^{-1} at 30 to 60 DAG. Here, the highest dry matter was found in ZM 0005 (7.083 g) while least amount of dry matter was found in BARI Maize 6 (2.967 g). At 90 DAG, dry matter increased 371.06% and 20.69 g more dry matter was produced by the genotypes than that of 60 DAG i.e. root dry matter production rate was 0.69 g day^{-1}at 60 to 90 DAG. Here, the highest dry matter was found in ZM 0002 (28.98 g) while least amount of dry matter was found in ZM 0006 (23.67 g). At harvesting stage, dry matter increased 29.46% and 7.74 g more dry matter was produced by the genotypes than that of 90 DAG i.e. root dry matter production rate was 0.26 g day^{-1}at 90 DAG to at harvest. Here, the highest dry matter was found in ZM 0007 (36.03 g) while least amount of dry matter was found in ZM 0006 (31.83 g). Correlation between root dry matter and yield of eight maize genotypes are presented in the Table 4. From the table, it is observed that correlation between dry matters at different DAG with yield is non-significant and negative. Nielsen and Bächtold (2019) indicated that under optimal conditions, increased root dry matter led to enhanced maize yields.

Table 4. Correlation matrix of root dry matter with grain yield at different days after germination (DAG)

Characters	60 DAG	90 DAG	Harvest	Yield
30 DAG	0.13^{NS}	-0.44*	-0.39^{NS}	-0.23^{NS}
60 DAG		0.19^{NS}	0.23^{NS}	-0.21^{NS}
90 DAG			0.39^{NS}	-0.34^{NS}
Harvest				-0.07^{NS}

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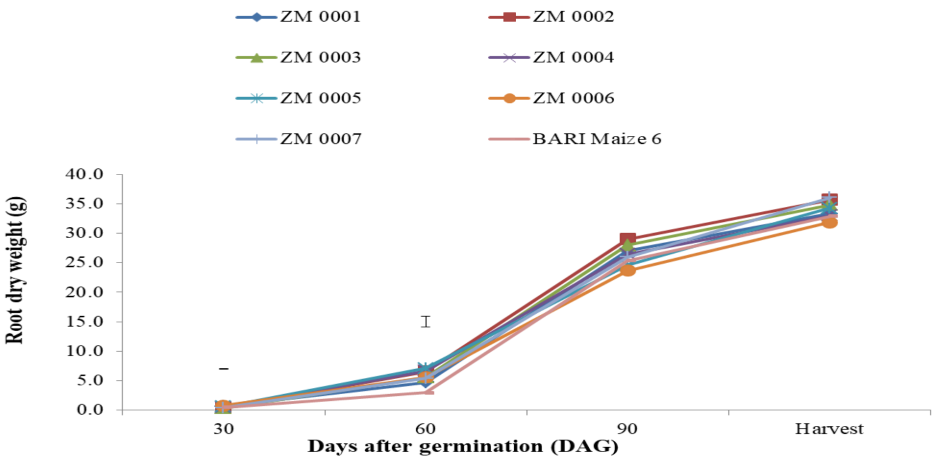

Fig. 4: Root dry weight of different maize genotypes at different DAG. [Vertical bars represent lsd $_{(0.05)}$]

Root shoot ratio (RSR)

The data on root shoot ratio (RSR) presented in Figure 5 indicated significant variations among the genotypes at all growth stages except at 60 DAG. The highest root shoot ratio was found in ZM 0006 (0.1818) at 30 DAG which was statistically similar to BARI Maize 6 (0.1739) and ZM 0002 (0.1629) and least ratio was found in ZM 0007 (0.1051) which was closely followed by ZM 0004 (0.109) and ZM 0005 (0.1105). From the figure, it was observed that the graph of RSR value of all genotypes showed a zigzag pattern. This was due to the variation in dry weight of roots and shoots of the genotypes. Correlation between RSR and yield of eight maize genotypes are presented in Table 5, which revealed that correlation between the RSR at 90 DAG and harvest with yield is significant but negative RSR at 30 DAG showed positive and RSR at 60 DAG showed negative non-significant correlation. Zhang *et al.* (2019) found that maize plants with a higher root biomass relative to shoot biomass demonstrated improved nutrient acquisition, particularly in nitrogen-poor soils. This indicates that a favorable RSR can enhance the plant's ability to forage for nutrients, directly influencing yield.

Table 5. Correlation matrix of RSR with grain yield at different days after germination (DAG)

Characters	60 DAG	90 DAG	Harvest	Yield
30 DAG	-0.25^{NS}	0.18^{NS}	-0.19^{NS}	0.01^{NS}
60 DAG		0.32^{NS}	0.27^{NS}	-0.09^{NS}
90 DAG			0.62**	-0.50*
Harvest				-0.62**

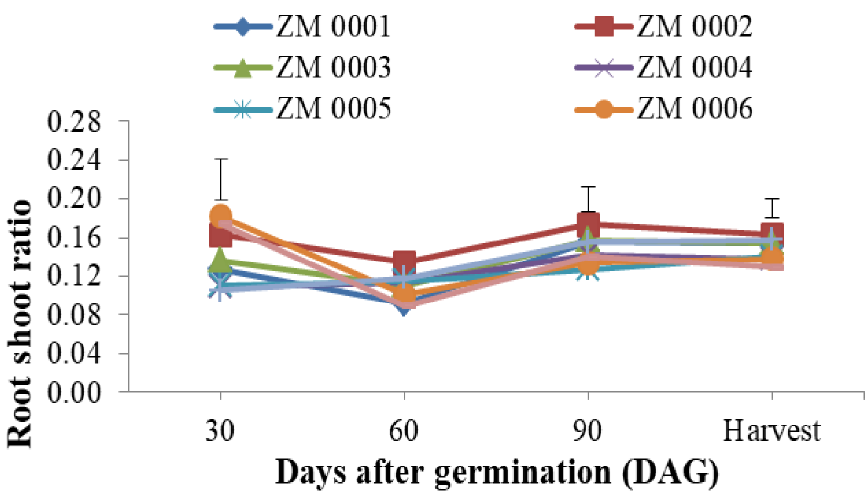

Fig. 5 Root shoot ratio of different maize genotypes at different DAG. [Vertical bars represent lsd $_{(0.05)}$]

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Root weight ratio (RWR)

The genotypes revealed significant variations among them at all growth stages except at 60 DAG for root weight ratio (RWR) (Fig. 6). The highest ratio was recorded in the genotype ZM 0006 (0.1536) at 30 DAG which was statistically similar to BARI Maize 6 (0.1481) and ZM 0002 (0. 14) and minimum ratio was found in ZM 0007 (0.0951) which was closely followed by ZM 0004 (0.0982) and ZM 0005 (0.09933). From the figure, it was observed that the graph of RWR value of all genotypes showed a zigzag pattern. This was due to the variation in dry weight of roots and total dry matter at different DAG. Correlation between RWR and yield of eight maize genotypes are presented in Table 6. From the table, it is observed that correlation between the RSR at 90 DAG and harvest with yield is significant but negative. RSR at 30 DAG showed positive and RSR at 60 DAG showed negative non-significant correlation. Smith *et al.* (2023) investigated the impact of root weight ratio (RWR) on maize yield, revealing critical insights into how root system characteristics can enhance productivity in varying environmental conditions. The study found that RWR serves as a reliable indicator of root development, with higher RWR associated with better nutrient and water uptake efficiency. Root weight ratio had significant correlation with maize yield.

Table 6. Correlation matrix of RWR with grain yield at different days after germination (DAG)

Characters	60 DAG	90 DAG	Harvest	Yield
30 DAG	-0.25^{NS}	0.19^{NS}	-0.19^{NS}	0.01^{NS}
60 DAG		0.31^{NS}	0.27^{NS}	-0.09^{NS}
90 DAG			0.62**	-0.50*
Harvest				-0.62**

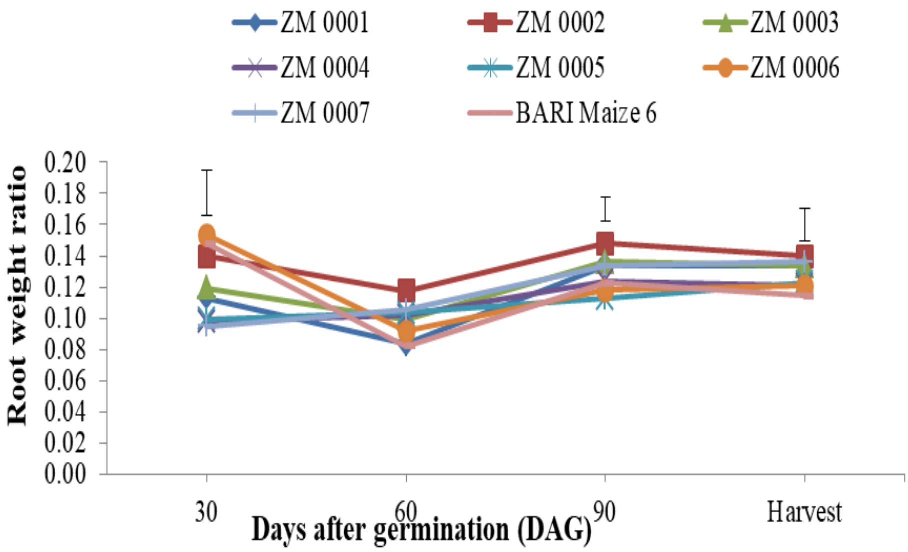

Fig. 6. Root shoot ratio of different maize genotypes at different DAG.
[Vertical bars represent lsd $_{(0.05)}$]

CONCLUSION

It was revealed from the study that, ZM 0001 performed best among the studied genotypes in respect of number of roots plant^{-1} and root length. But ZM 0003; ZM 0007; ZM 0006 and BARI Maize 6; ZM 0006, ZM 0002 and BARI Maize 6 also showed good potentials in respect of root spreading, root dry matter accumulation, root shoot ratio and root weight ratio, respectively. It was evident from the study that the maize genotypes had a widely spreading, deeply penetrating, and profusely branching root system. Root length and spreading is limited at 25.33 to 31.1 cm and 22 to 27.73 cm, respectively. So, it is supposed that, a moderate tillage and a plant to plant spacing of 25-30 cm can be maintained for these maize genotypes for better yield in Bangladesh. These genotypes could be used as potential material in the future research works and varietal improvement.

Conflict of Interest

There are no conflicts of interest declared by the authors.

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