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Araştırma Makalesi

Responses of Alkali Grass (*Puccinellia ciliata* Bor) Genotypes to Geothermal Water

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ABSTRACT

The increasing use of geothermal resources for generating electrical energy has brought the negative impact of geothermal fluids on the surrounding agricultural areas in Turkey. Alkali grass is a halophyte plant that spreads in marginal areas such as waterlogged, excessively alkaline, and salty areas. A study was conducted to test the response of 12 different alkaline grass genotypes improved by us to geothermal and mineral water used as irrigation water in the Faculty of Agriculture of Aydın Adnan Menderes University. Geothermal water had significantly higher values than mineral water in terms of EC and mineral content. In a Split-Plot Completely Randomized Design, irrigation treatment was assigned in the main plots and genotypes were assigned in the sub-plots. The treatment of geothermal water reduced the panicle length and seed yield by 14.01% and 64.21%, respectively. Genotypes II, VI and VII produced the highest biomass despite geothermal water. The highest seed yield and harvest index were recorded in genotypes IX and XI under geothermal water conditions, although they had low biomass values. The determinant traits were the number of tillers per plant for biomass, the number of panicles per plant, and plant height for seed yield. Genotypes XII and XI were seed-type, whereas genotypes IX and VIII were biomass-type, according to the Biplot graph.

Keywords: Alkali grass genotypes, biomass, biplot, geothermal water, seed yield

Çorak Çimi (*Puccinellia ciliata* Bor) Genotiplerinin Jeotermal Su Uygulamasına Tepkisi

ÖZ

Elektrik enerjisi üretimi için jeotermal kaynakların artan kullanımı, Türkiye'de jeotermal akışkanların çevredeki tarım alanları üzerindeki olumsuz etkilerini de beraberinde getirmiştir. Alkali çim su göllenmiş, aşırı alkali ve tuzlu olarak tanımlanan bu marjinal alanlarda yayılan halofit bitki türlerinden biridir. Tarafımızdan ıslah edilen 12 farklı alkali çim genotipinin sulama suyu olarak kullanılan jeotermal ve mineral suya tepkisini test etmek için Aydın Adnan Menderes Üniversitesi Ziraat Fakültesinde bir çalışma yürütülmüştür. Jeotermal su, EC ve mineral içeriği açısından mineralli sudan önemli ölçüde daha yüksek değerlere sahipti. Tesadüf parsellerinde bölünmüş parseller deneme desenine göre yürütülen çalışmada, sulama uygulamaları ana parsellere, genotipler ise alt parsellere yerleştirilmiştir. Jeotermal su uygulaması salkım uzunluğunu ve tohum verimini sırasıyla %14,01 ve %64,21 oranında azaltmıştır. Biyokütle için kardeş sayısı, tohum verimi için ise salkım sayısı ve bitki boyu belirleyici özellikler olmuştur. Biplot grafiğine göre XII ve XI genotipleri tohum tipi olarak belirlenirken, IX ve VIII genotipleri biyokütle tipi olarak saptanmıştır.

Anahtar kelimeler: Biplot, biyokütle, çorak çimi genotipleri, jeotermal su, tohum verimi

INTRODUCTION

Water resources have started to be used in many ways, such as drinking water, agricultural irrigation, energy production, transportation and recreation with the advancement of technology (Hacisalihoğlu et al., 2023). The climate irregularities experienced in recent years have necessitated more efficient and effective use of soil and water resources and all natural resources (Coşkun et al., 2020). Türkiye has many geothermal resources with different contents and characteristics that can be used for energy production, medical purposes and other fields (Doğanay and Soylu, 1999; Akbulut, 2010; Karatepe et al., 2023). As an inevitable consequence of industrialization, the recharge of wastewater in agricultural areas is increasing day by day (Ali et al., 2020). When geothermal resources are used, discharge water is released directly or indirectly uncontrolled. Büyük Menderes basin is rich in geothermal resources, and the fluids mostly flow into the Büyük Menderes River (Koç, 2007). This situation harms the heavy metal pollution of drainage waters that could be used for irrigation, groundwater, soil, and plants (Derin et al., 2020).

Alkaline grass (*Puccinellia ciliata* Bor) is a natural habitat where the mineral content in the soil reaches toxic levels, waterlogged, saline and marshy (Zhang et al., 2021), and is especially widespread in areas close to geothermal water sources in Aegean Region, Türkiye (Tan and Sorger, 1986; Yavaş and Ünay, 2017; Yavaş et al., 2020; Çınar and Ünay, 2020). Geothermal fluids are saline and alkali waters with a dissolved matter content of 2-4 g l^{-1}, which contain large amounts of Ca, Na, SO_4 and Cl (Lee et al., 1996; Haddad et al., 2003), Zn, Fe and Al (Poyraz, 2016). The most crucial problem with geothermal water fluids in the Büyük Menderes River is B content (Koç, 2007), while B content in Puccinellia distribution areas is above toxic levels (Yavaş, 2017).

Meriç et al. (2021) show that using geothermal fluid in irrigation is a promising and economical method, provided that caution is exercised regarding its potential to be harmful to the plant. It was emphasized that EC and exchangeable sodium will increase the use of geothermal water; therefore, the irrigation method is important, and the leaching irrigation method should be preferred (Stanley and Schmitt, 1980). In studies where geothermal water was used, the response of different plant species was investigated during the germination, early seedling and advanced development periods. As the geothermal water dose increased, plant height, root length, number of leaves and dry matter content decreased with the decrease in the number of conduction bundle fractions in the early seedling period of rice (Lee et al., 1996). It was determined that the mahogany (*Swietenia macrophylla* King) plant formed a density around the geothermal fluids and that the main problem in this plant in the geothermal water applied in this plant was due to salinity and firstly, the edges of the old leaves dried up and then leaf fall occurred with complete drying (Tuyor et al., 2005). In another study, geothermal water decreased chlorophyll fragments and carotenoids in the early growing stages of wheat and barley while B, Mg and Na significantly increased (Karatepe et al., 2023).

The initial origin of the alkaline grass genotypes we studied is mainly in the Söke (37°49'N, 27°30'E) and Germencik/Aydın locations (37°50'N, 27°50'E), which are close to geothermal electricity production facilities and areas where geothermal water is used in greenhouses. Studies on the effects of geothermal water on the spreading areas of alkaline grass are lacking. Therefore, this study was conducted to investigate the effect of geothermal water on biomass and seed yield in different genotypes.

MATERIAL and METHODS

A pot study was carried out in Aydın Adnan Menderes University Faculty of Agriculture Research and Training areas. The alkali grass (*Puccinellia ciliata* Bor) seeds used in this study belonged to 12 superior genotypes developed through recurrent selection by us (Yavas et al., 2017). Pots with 20 cm wide, 51 cm long and 17 cm wide were filled with ½ torf and ½ perlite (Hosseini et al., 2023). Each pot received 4 g of 15-15-15 composed fertilizer before planting.

Water source and treatments

The experimental design was a split-plot arrangement in a Completely Randomized Design (CRD) with three replications. Two irrigation treatments were assigned to the main plots, while twelve genotypes were assigned to the sub-plots. Pots were irrigated to field capacity (10% w/w) by checking the soil moisture meter (ProCheck, Decagon Devices, Inc., United States). Fifty seeds were sown in pots and thinned to 25 seeds ten days after emergence. Irrigation was continued every ten days according to the field capacity until the pre-harvest period in the plots of each irrigation treatment.

Table 1 represents the geothermal and mineral water characteristics. The results of the analyses showed that the mineral water is suitable for irrigation, whereas the thermal water is salty and extremely rich in macro and micro elements containing high salts.

Data collection

Before harvesting, ten plants in the center of each pot were sampled. Plant height (PH; cm), the number of tillers per plant (TN), panicle length (PL; cm) and the number of panicles per plant (PN) were measured. In the harvest period, sampled plants in each pot were cut to determine the total dry biomass (BM; mg plant^{-1}) and seed yield (SY; mg plant^{-1}) according to recommended by Tarasoff et al. (2007) and Liu and Coulman (2015). After separating the seeds, other parts were dried at 105 °C for 48 hours to determine dry biomass. The harvest index (HI; %) was calculated by proportioning seed weight to total dry biomass.

Data analysis

The observed data were subjected to analysis of variance (ANOVA) (Steel et al., 1997) following the split-plot design in CRD using the 'agricolae' package (Mendiburu and Mendiburu 2019) in R free software environment for statistical computing. Fisher's LSD (Least Significant Difference; Fisher, 1935) test was used to compare the means of water treatments and Tukey's HSD (Honestly Significant Difference; Tukey, 1949) test was used to compare the means of water treatments × genotypes interaction at $p \leq 0.05$ level.

Table 1. Biochemical analysis results for geothermal and mineral water

Characters	Geothermal Water	Mineral Water
pH	6.33	7.65
EC	4.39	0.50
K (mg lt^{-1})	97.68	0.10
Na (mg lt^{-1})	1093.36	4.51
Ca (mg lt^{-1})	51.28	13.00
Mg (mg lt^{-1})	37.67	0.03
HCO_3 (mg lt^{-1})	2697.83	11.62
CO_3 (mg lt^{-1})	123.47	0.00
SO_4 (mg lt^{-1})	130.98	4.07
SiO_2 (mg lt^{-1})	173.34	
Fe (ppb)	174.26	
Cu	29.67	
B	2.69	
Cr	6.09	
Mn	8.92	
Co	0.26	
Cd	TE	
Ni	TE	
Pb	TE	
Zn	TE	

RESULTS and DISCUSSION

Genotypic differences were significant for all examined traits, while water treatment significantly affected all parameters except the number of tillers per plant (Table 2). It has been reported in many studies that interspecific and intraspecific variation in Puccinellia plants against abiotic stress factors was high (Kenkel et al., 1991; Tarasoff et al., 2007; Gilbert and Fraser, 2016). It was also emphasized that stress did not reduce variation in Puccinellia species (Hill, 1990). Significant interactions showed that the genotypes differed in their responses to water treatments for the traits studied. The application of geothermal water affected all traits significantly and negatively (Table 3). The negative effect of agriculturally used geothermal water on crop yields has been emphasized in many studies (Elyakoubi, 1992; Lee et al., 1996; Haddad et al., 2003). It has been reported that geothermal water, especially its high EC and sodium content, is the most important factor in reducing the examined traits by negatively affecting all metabolisms, such as photosynthesis and respiration in plants (Kenkel et al., 1991). Panicle length was the least affected trait (14.91%), while geothermal water reduced seed yield by 64.21%.

Table 2. The ANOVA for examined traits

SOV	df	PH	PL	PN	TN	BM	SY	HI
Water Tre. (WT)	1	2544.22**	232.92*	86.68*	107.56	122.62**	91734.70*	6.37**
Error-1	2	25.40	4.41	1.94	3.81	0.47	1914.64	0.18
Genotype (G)	11	385.67**	130.47**	25.83**	52.39**	9.60**	19673.70**	8.30**
WT × G	11	269.71**	52.18**	27.80**	34.07**	14.82**	18918.90**	9.85**
Error-2	44	28.02	3.27	1.10	2.96	1.08	1314.60	0.19
General	71							

*: $p \leq 0.05$; **: $p \leq 0.01$. PH: Plant height (cm), PL: Panicle length (cm); PN: The number of panicles per plant; TN: The number of tillers per plant, BM: Total dry biomass (mg plant^{-1}); SY: Seed yield (mg plant^{-1}); HI: Harvest index (%).

Since water treatment × genotype interaction was significant for all traits examined, it was compared genotypes under water treatment factors. While genotypes IX and XII had the highest plant height in normal irrigation, genotypes II and XI produced the highest in geothermal water treatment. V and VII genotypes exhibited the lowest plant height in geothermal water treatment plots. Geothermal water treatment positively affected panicle length in genotypes II, IX and XI compared to other genotypes, while there was no difference between both irrigation treatments in genotypes III and X. While the panicle number of many genotypes was negatively affected by geothermal water treatment, it increased in genotypes such as I, VI, VIII and XI. It was found that panicle number was the most affected yield component in many crops under stresses such as salinity and drought (Khatun et al., 1995; Hasanuzzaman et al., 2009).

Table 3. The mean values of treatments and genotypes for examined traits

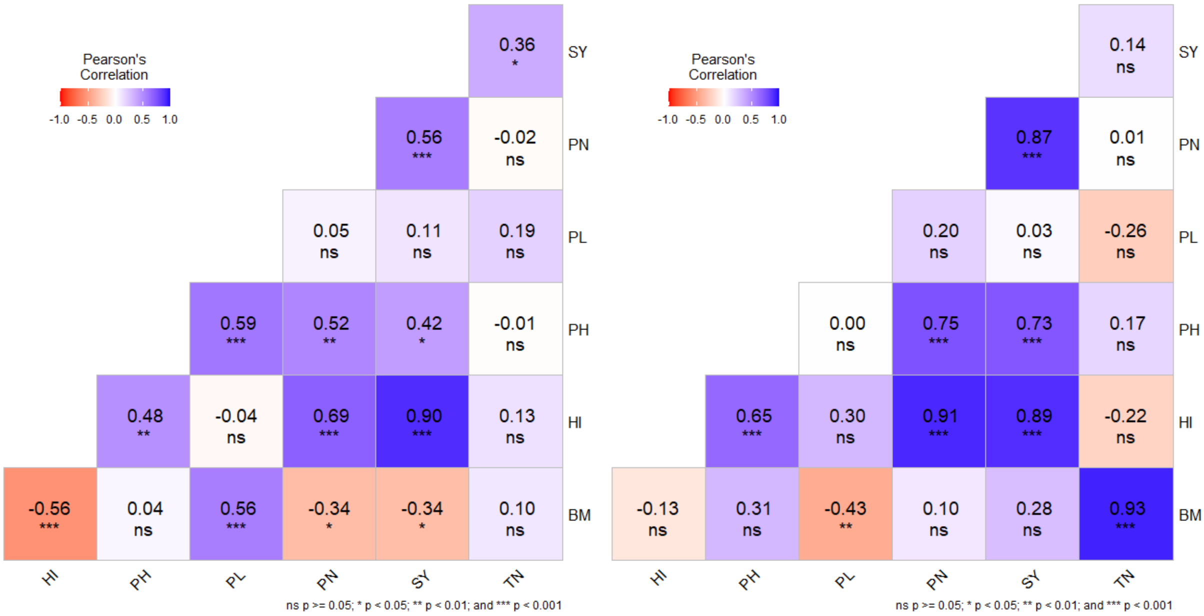
Water Tre.	Gen.	PH	PL	PN	TN	BM	SY	HI
Geothermal	I	35.67 c-e	22.33 e-i	7.67 b-e	6.67 c-e	3.68 f-h	56.67 de	1.60 c-g
	II	41.67 cd	31.17 ab	4.33 f-i	2.67 e	6.67 c-f	14.00 e	0.22 h
	III	26.67 d-g	22.17 f-i	3.33 hi	9.67 a-d	4.17 f-h	76.67 de	1.88 c
	IV	20.67 e-g	15.33 j-k	2.67 i	4.33 de	4.97 e-h	16.67 e	0.33 gh
	V	11.33 g	13.00 k	4.00 g-i	4.33 de	3.33 gh	16.67 e	0.49 d-h
	VI	20.33 e-g	16.00 jk	6.00 c-h	5.00 c-e	5.23 e-h	18.33 e	0.36 e-h
	VII	18.33 fg	23.00 e-h	5.00 d-i	6.00 c-e	5.13 e-h	25.00 e	0.49 d-h
	VIII	34.67 c-f	23.00 e-h	7.33 b-f	7.00 c-e	5.07 e-h	56.67 de	1.16 c-h
	IX	30.33 c-f	20.83 f-j	6.33 c-h	14.33 ab	4.25 f-h	76.67 de	1.82 cd
	X	27.00 c-g	17.00 i-k	4.33 f-i	3.00 e	3.28 gh	13.33 e	0.40 e-h
	XI	40.33 cd	18.00 g-k	10.33 b	3.00 e	2.30 h	90.00 b-e	3.92 b
	XII	29.67 c-f	24.67 c-f	4.67 e-i	9.67 a-d	5.40 e-h	16.67 e	0.31 gh
	Ave.	**28.06 B**	**20.54 B**	**5.50 B**	**6.31 B**	**4.46 B**	**39.78 B**	**1.08 B**
Mineral	I	34.67 c-f	28.00 a-e	5.00 d-i	7.00 c-e	5.21 e-h	46.67 de	0.91 c-h
	II	25.00 d-g	26.00 b-f	5.33 c-i	6.33 c-e	5.45 e-h	16.67 e	0.33 f-h
	III	43.67 bc	23.67 d-g	6.00 c-h	6.67 c-e	5.37 e-h	55.00 de	1.03 c-h
	IV	36.67 c-e	28.00 a-e	8.00 b-d	9.33 b-d	6.42 d-g	60.00 de	0.94 c-h
	V	29.00 c-f	20.50 f-j	4.67 e-i	3.33 e	3.91 f-h	23.33 e	0.68 c-h
	VI	29.67 c-f	24.17 c-f	5.67 c-i	4.33 de	4.86 e-h	36.67 e	0.76 c-h
	VII	33.67 c-f	29.67 a-c	6.33 c-h	12.67 ab	8.03 b-e	62.33 de	0.78 c-h
	VIII	41.67 cd	29.33 a-d	6.67 c-g	13.67 ab	9.88 a-c	86.67 c-e	0.86 c-h
	IX	60.00 ab	16.00 jk	10.33 b	15.00 a	11.56 a	203.33 b	1.71 c-e
	X	41.00 cd	17.33 h-k	8.33 bc	12.67 ab	10.15 ab	193.33 bc	1.93 c
	XI	41.67 cd	14.00 k	8.00 b-d	10.33 a-c	9.35 a-d	156.67 b-d	1.69 c-f
	XII	62.67 a	33.00 a	18.00 a	3.67 e	4.59 f-h	393.33 a	8.51 a
	Ave.	**39.94 A**	**24.14 A**	**7.69 A**	**8.75 A**	**7.07 A**	**111.17 A**	**1.68 A**

PH: Plant height (cm), PL: Panicle length (cm); PN: The number of panicles per plant; TN: The number of tillers per plant, BM: Total dry biomass (mg plant^{-1}); SY: Seed yield (mg plant^{-1}); HI: Harvest index (%). Means not followed by the same letter(s) in the same column are significantly different. Upper- and lower-case letters were used to compare water treatments and water treatment × genotype interaction, respectively.

Biomass production of alkali grass is very important for animal feeding. In genotypes IX, X, VIII and XI, biomass was quite high in mineral water treatment, but these genotypes were the most affected by the negative effect of geothermal water. Genotypes II, XII and VI produced the highest biomass under geothermal conditions. Similar to the results of our study, Haider et al. (2013) emphasized that alkali grass can be successfully grown in saline and waterlogged conditions for animal feeding. Seed yield per plant is vital for spreading and establishing alkaline grass. Genotypes with substantial biomass also had higher seed yields. While genotype XI gave the highest yield in geothermal water treatment, it was determined that the negative effect of geothermal water triggered seed yields in genotypes I and III compared to mineral water. It was determined that genotype XI had the highest harvest index under geothermal water conditions, and genotype XII had the highest harvest index under mineral water conditions.

It was calculated the correlation coefficients to determine the plant type with high biomass and seed yield in alkaline grass and to determine the traits that can be selection criteria in breeding studies (Table 4). Plant height and the number of panicles per plant positively and significantly correlated with seed yield and harvest index under both water treatment conditions. A significant and positive correlation coefficient between plant height and the number of panicles per plant indicated that seed type was associated with longer plant height and a greater number of panicles per plant.

Table 4. Correlations between the examined traits under geothermal (left) and mineral (right) water treatments. PH: Plant height (cm), PL: Panicle length (cm); PN: The number of panicles per plant; TN: The number of tillers per plant, BM: Total dry biomass (mg plant^{-1}); SY: Seed yield (mg plant^{-1}); HI: Harvest index (%).



Extracted Eigenvalue>1 indicated that two components, PC1 and PC2, carried 50.33% and 24.51% of the supply of information input variables, respectively. Alkali grass genotypes and examined traits were positioned on the plot as vectors in the PC biplot (Figure 1). Vector lengths showed that all traits except panicle length had a wide variability. The number of tillers per plant and biomass versus other traits were found to be located in different regions. Plant height, panicle length, the number of panicles per plant and seed yield were close to each other. This finding confirmed the interpretations made for the correlations. Our results agree with those of Liu and Coulman (2015), who found a significant and positive correlation coefficient between the number of tillers per plant and biomass yield in alkaline grass. Moreover, in perennial ryegrass (Yamada et al., 2004) and Napier grass (Xia et al., 2009), the number of tillers per plant was the essential indicator of biomass. The negative and significant correlation between dry matter yield and seed yield in both water treatment conditions contradicted the findings of Liu and Coulman (2015). The biplot graph indicated that genotypes XII and XI were seed-type, whereas genotypes IX and VIII were biomass-type. Grime (1979) and Tarasoff et al. (2007) emphasized that Puccinellia species grown in normal soil are less competitive (i.e. shorter plants, fewer tillers, lower biomass and yield) than when grown in saline soil. Gray and Scott (1980) revealed that variation in the biomass-type, a measure of tillering rate, overall plant leaf size, and the tendency to produce several large or many small tillers was associated with variation in growth habit (erectness) and that genotypes collected from originally grazed salt marshes tended to be fast tillering, small, short-leaved, and prostrate.

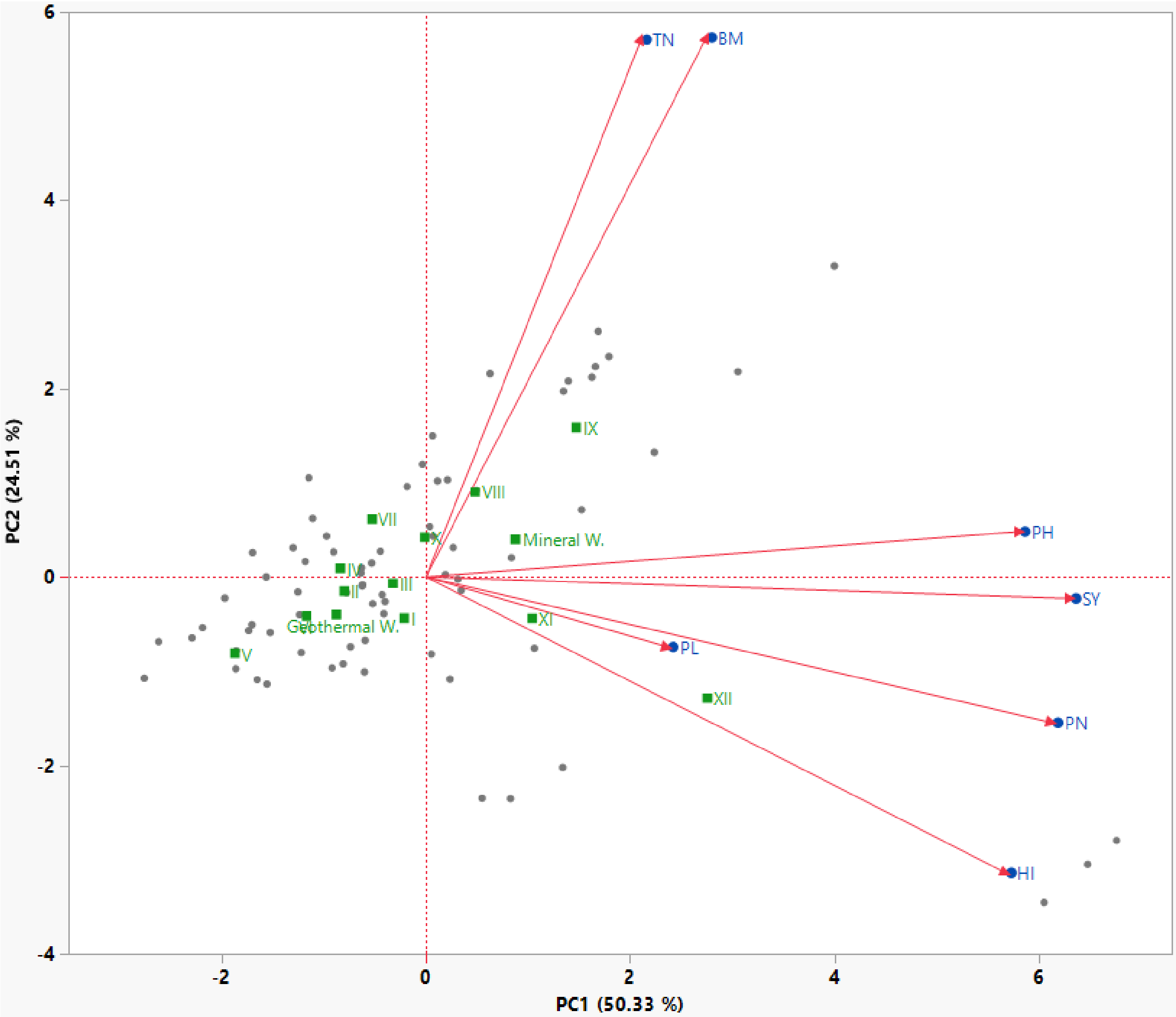


Figure 1. PCA biplot graph for pooled water treatment data

CONCLUSION

The present study revealed the difference between genotypes's responses to adverse conditions caused by geothermal water in the alkaline grass plant. Seed yield, hence the spread of alkali grass and the possibility of establishing new areas, was most affected by geothermal water. Biomass-type genotype IX and seed-type genotype XII distinguished sharply over other alkaline grasses. It was observed that the number of tillers per plant for biomass and the number of panicles per plant for seed yield were the most important selection criteria.

Conflicts of Interest: The authors declare that they have no conflict of interest.

Authorship Contribution Statement: The authors declare that their contributions are equal.

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