

The integrated amendment of sodic-saline soils using biochar and plant growth-promoting rhizobacteria enhances maize (*Zea mays* L.) resilience to water salinity

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Table S1: Activity of soil dehydrogenase and urease enzymes and count of some microbial groups at 80 days after seed sowing of maize plants irrigated with fresh and saline water in sodic-saline soil after the application of biochar and PGPR during 2018 season [§].

Treatment		Urease (mg TPF g ⁻¹ dry soil d ⁻¹)	Dehydrogenase (mg NH ₄ ⁺ g ⁻¹ dry soil d ⁻¹)	Bacteria (Log cfu g ⁻¹ soil)	<i>Azotobacter</i> (Log cfu g ⁻¹ soil)	<i>Bacillus spp</i> (Log cfu g ⁻¹ soil)
Fresh water	Control	120.70 ± 2.39 de	60.42 ± 3.06 g	2.79 ± 0.05 c	0.91 ± 0.02 f	1.72 ± 0.02 d
	PGPR [†]	154.44 ± 3.74 c	91.42 ± 1.15 d	3.36 ± 0.04 b	1.74 ± 0.02 c	3.22 ± 0.09 b
	Biochar [‡]	172.44 ± 1.84 b	111.22 ± 2.11 c	3.38 ± 0.03 b	1.76 ± 0.01 c	3.32 ± 0.03 b
	Combined [¥]	220.15 ± 2.41 a	146.78 ± 4.07 a	5.87 ± 0.10 a	2.12 ± 0.02 a	3.71 ± 0.04 a
Saline water	Control	90.33 ± 1.74 f	38.12 ± 2.04 h	1.54 ± 0.05 e	0.62 ± 0.03 g	1.02 ± 0.01 e
	PGPR	113.74 ± 2.18 e	70.26 ± 0.77 f	2.53 ± 0.04 d	1.22 ± 0.02 e	1.66 ± 0.02 d
	Biochar	123.62 ± 3.42 d	84.38 ± 0.74 e	2.74 ± 0.12 c	1.36 ± 0.01 d	1.74 ± 0.04 d
	Combined	158.14 ± 2.37 c	117.89 ± 1.86 b	3.27 ± 0.08 b	1.85 ± 0.03 b	2.85 ± 0.04 c
F-test						
<i>P</i> Water		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
<i>P</i> Treatment		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
<i>P</i> Water × Treatment		< 0.0001	= 0.0265	< 0.0001	< 0.0001	< 0.0001

[§] Data presented are means ± standard deviation (mean ± SD) of three biological replicates. Presented pairwise differences connecting letters (significance letters) were generated based on the *p*-value of the interaction between water type (as the main plots) and treatments (as subplots) that were mentioned as (*p*_{Water × Treatment}). Means followed by different letters indicate statistically significant differences among treatments according to Tukey's honestly significant difference (HSD) test (*p* ≤ 0.05), whereas means followed by the same letters indicate no statistically significant differences among them.

[†] PGPR (*Azotobacter chroococcum* SARS 10 and *Pseudomonas koreensis* MG209738) added at a 1:1 ratio

[‡] Biochar is added at the rate of 1.0 kg m⁻² (10 ton ha⁻¹)

[¥] PGPR at a 1:1 ratio + Biochar at the rate of 1.0 kg m⁻² (10 ton ha⁻¹)

Means followed by different letters indicate statistically significant differences among treatments according to Tukey's honestly significant difference (HSD) test (*P* ≤ 0.05), whereas means followed by the same letters indicate no statistically significant differences among them.

Table S2: Yield and yield components of maize plants irrigated with fresh and saline water in sodic-saline soil in presence of biochar and PGPR during 2018 season [§].

Treatment		Number of Grains ear ⁻¹	100-Grain weight (g)	Grain yield (ton/ha)	Stover yield (ton/ha)	Harvest index (%)
Fresh water	Control	416.38 ± 1.10 e	29.16 ± 0.82 cd	4.49 ± 0.03 e	8.66 ± 0.12 d	34.12 ± 0.23 cd
	PGPR [†]	432.13 ± 1.41 c	31.83 ± 0.52 b	5.16 ± 0.04 c	9.66 ± 0.09 b	34.82 ± 0.52 bc
	Biochar [‡]	436.76 ± 1.10 b	33.11 ± 0.65 b	5.51 ± 0.02 b	9.74 ± 0.07 b	36.14 ± 0.47 a
	Combined [¥]	443.04 ± 0.60 a	35.50 ± 0.79 a	5.83 ± 0.01 a	10.47 ± 0.11 a	35.77 ± 0.36 ab
Saline water	Control	403.74 ± 1.48 f	23.39 ± 0.76 e	4.15 ± 0.04 f	8.27 ± 0.11 e	33.42 ± 0.72 d
	PGPR	416.79 ± 1.18 e	27.35 ± 0.56 d	4.61 ± 0.05 d	8.58 ± 0.09 de	34.94 ± 0.25 bc
	Biochar	419.15 ± 0.65 e	28.48 ± 0.93 cd	4.65 ± 0.04 d	8.70 ± 0.11 d	34.85 ± 0.14 bc
	Combined	423.21 ± 0.86 d	29.86 ± 0.22 c	5.23 ± 0.02 c	9.21 ± 0.15 c	36.22 ± 0.27 a
F-test						
<i>P</i> Water		< 0.0001	< 0.0001	< 0.0001	< 0.0001	= 0.0488
<i>P</i> Treatment		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
<i>P</i> Water × Treatment		= 0.0002	= 0.0275	< 0.0001	< 0.0001	= 0.0078

[§] Data presented are means ± standard deviation (mean ± SD) of three biological replicates. Presented pairwise differences connecting letters (significance letters) were generated based on the *p*-value of the interaction between water type (as the main plots) and treatments (as subplots) that were mentioned as (*p*_{Water × Treatment}). Means followed by different letters indicate statistically significant differences among treatments according to Tukey's honestly significant difference (HSD) test (*p* ≤ 0.05), whereas means followed by the same letters indicate no statistically significant differences among them.

[†] PGPR (*Azotobacter chroococcum* SARS 10 and *Pseudomonas koreensis* MG209738) added at a 1:1 ratio

[‡] Biochar is added at the rate of 1.0 kg m⁻² (10 ton ha⁻¹)

[¥] PGPR at a 1:1 ratio + Biochar at the rate of 1.0 kg m⁻² (10 ton ha⁻¹)

Means followed by different letters indicate statistically significant differences among treatments according to Tukey's honestly significant difference (HSD) test (*P* ≤ 0.05), whereas means followed by the same letters indicate no statistically significant differences among them.

Table S3: Physicochemical characteristics of the experimental soil in the two growing seasons 2018 and 2019

Character		2018	2019
pH (1:2.5 soil:water suspension)			
Soil depth (cm)	0-20	8.22 ± 0.02 [†]	8.28 ± 0.03
	20-40	8.19 ± 0.02	8.21 ± 0.03
	40-60	8.16 ± 0.04	8.18 ± 0.02
Electrical conductivity (ECe, dS m ⁻¹) [‡]			
Soil depth (cm)	0-20	5.61 ± 0.01	5.66 ± 0.02
	20-40	5.56 ± 0.02	5.59 ± 0.05
	40-60	5.36 ± 0.03	5.54 ± 0.04
ESP [‡] (%)			
Soil depth (cm)	0-20	22.61 ± 0.42	21.50 ± 0.32
	20-40	22.52 ± 0.02	21.36 ± 0.22
	40-60	22.46 ± 0.04	21.21 ± 0.35
Soil organic matter (g kg ⁻¹)		11.2 ± 0.03	11.7 ± 0.05
Particle size distribution (%)			
Sand		27.22 ± 1.88	27.17 ± 1.98
Silt		25.23 ± 2.02	25.55 ± 1.99
Clay		47.55 ± 2.32	47.28 ± 2.03
Texture grade		clayey	clayey
Soluble cations (mEq L ⁻¹) [‡]			
Ca ⁺⁺		7.29 ± 0.87	9.42 ± 0.96
Mg ⁺⁺		5.23 ± 1.32	6.34 ± 1.78
Na ⁺		22.63 ± 3.08	21.08 ± 3.45
K ⁺		0.39 ± 0.02	0.39 ± 0.02
Soluble anions (meq L ⁻¹) [‡]			
CO ₃ ²⁻		nd [‡]	nd
HCO ₃ ⁻		3.34 ± 0.68	3.05 ± 0.56
Cl ⁻		18.21 ± 1.15	16.89 ± 1.23
SO ₄ ²⁻		11.15 ± 3.04	10.74 ± 3.45
Available macronutrients (mg kg ⁻¹)			
N		9.70 ± 0.91	10.33 ± 1.71
P		8.24 ± 1.33	8.94 ± 1.54
K		344 ± 26.42	387 ± 24.33
Total counts of soil microbes			
Bacteria (CFU ×10 ⁷ g ⁻¹ dry soil)		33 ± 1.2	39 ± 1.5
Fungi (CFU ×10 ⁴ g ⁻¹ dry soil)		12 ± 0.9	18 ± 1.1
Actinomycetes (CFU ×10 ⁵ g ⁻¹ dry soil)		23 ± 1.1	24 ± 1.4

[†]Standard deviation; [‡] not detected; [‡] measured in soil paste extract; [‡] exchangeable sodium percentage, mEq L⁻¹: milliequivalents per liter.

Table S4: Characterization of irrigation water during 2018 and 2019 growing seasons

Character	2018		2019	
	Fresh water	Saline water [*]	Fresh water	Saline water [*]
pH	7.28 ± 0.81	8.36 ± 0.17	7.34 ± 0.76	8.39 ± 0.15
EC (dS m ⁻¹)	0.55 ± 0.02	3.93 ± 0.09	0.51 ± 0.01	3.97 ± 0.11
SAR	1.46 ± 0.04	7.79 ± 0.23	1.42 ± 0.06	7.88 ± 0.26
Na ⁺ (mg L ⁻¹)	1.98 ± 0.06	16.3 ± 1.42	1.92 ± 0.04	16.81 ± 1.31
Cl ⁻ (mg L ⁻¹)	3.45 ± 0.07	11.62 ± 0.82	3.38 ± 0.05	11.90 ± 0.91
SO ₄ ²⁻ (mg L ⁻¹)	0.12 ± 0.01	7.93 ± 0.21	0.14 ± 0.02	8.23 ± 0.25
NH ₄ ⁺ (mg L ⁻¹)	1.71 ± 0.03	2.12 ± 0.06	1.83 ± 0.05	2.33 ± 0.05
COD (mg L ⁻¹)	12.00 ± 0.92	nd [‡]	11.00 ± 1.09	nd
BOD (mg L ⁻¹)	5.42 ± 0.39	nd	5.22 ± 0.62	nd
SS (mg L ⁻¹)	187 ± 12.5	18 ± 1.5	181 ± 13.1	17 ± 1.6
DS (mg L ⁻¹)	388 ± 32	2940 ± 126	393 ± 35	2922 ± 121

COD: Chemical Oxygen Demand; BOD: Biological Oxygen Demand; SS: Suspended solids; DS: Dissolved solids. ^{*}Well water at a depth of 20 m; [‡]not detected.

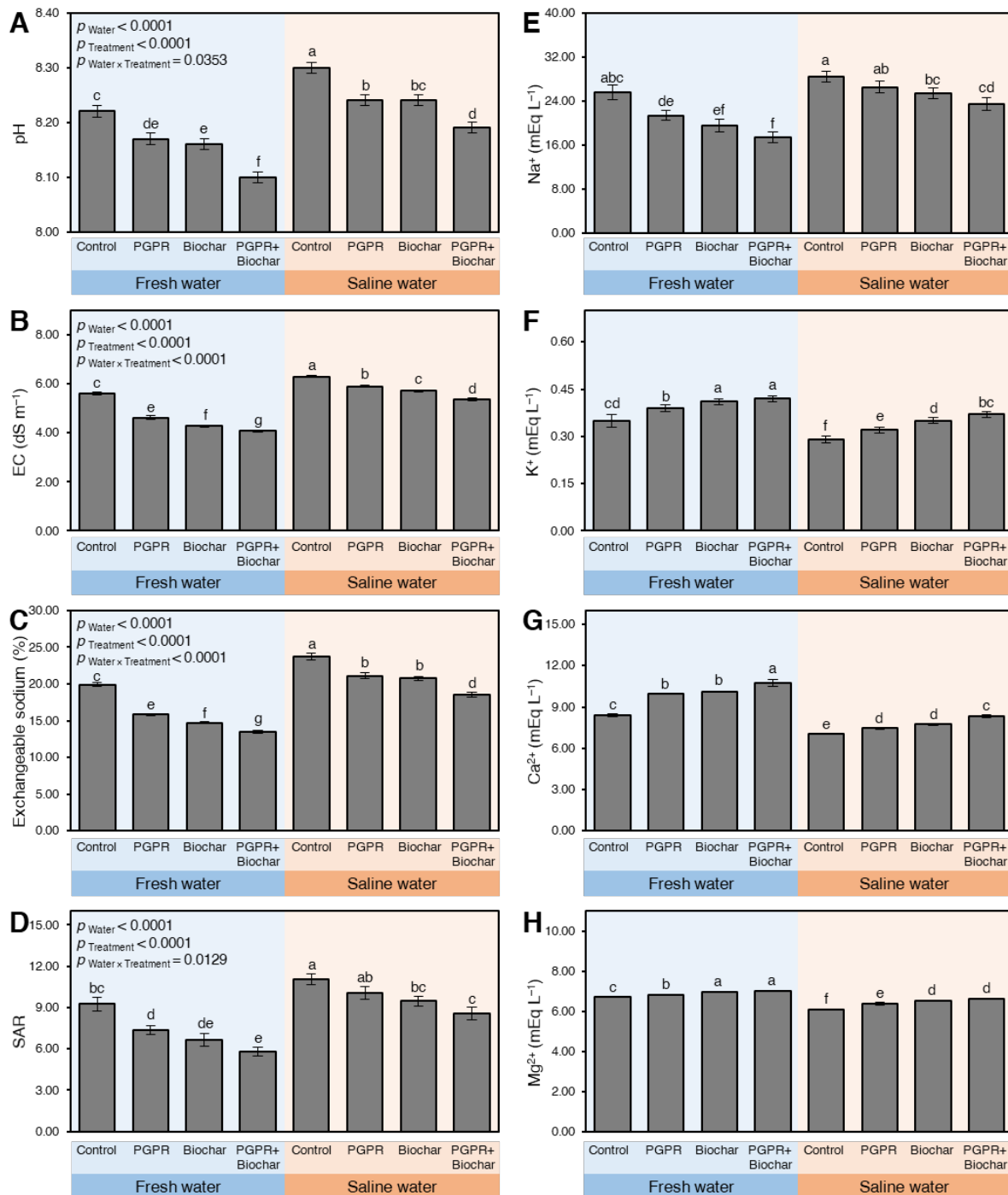


Figure S1: Soil chemical properties at the harvest time of maize plants growing in sodic-saline soil and irrigated with fresh and saline water after the application of biochar and PGPR during 2018 season. Data presented are means \pm standard deviation (mean \pm SD) of three biological replicates. Presented pairwise differences connecting letters (significance letters) were generated based on the p -value of the interaction between water type (as the main plots) and treatments (as subplots) that were mentioned as ($p_{\text{Water} \times \text{Treatment}}$). Means followed by different letters indicate statistically significant differences among treatments according to Tukey's honestly significant difference (HSD) test ($P \leq 0.05$), whereas means followed by the same letters indicate no statistically significant differences among them. EC: Electrical conductivity; SAR: Sodium adsorption ratio; mEq L⁻¹: milliequivalents per liter.

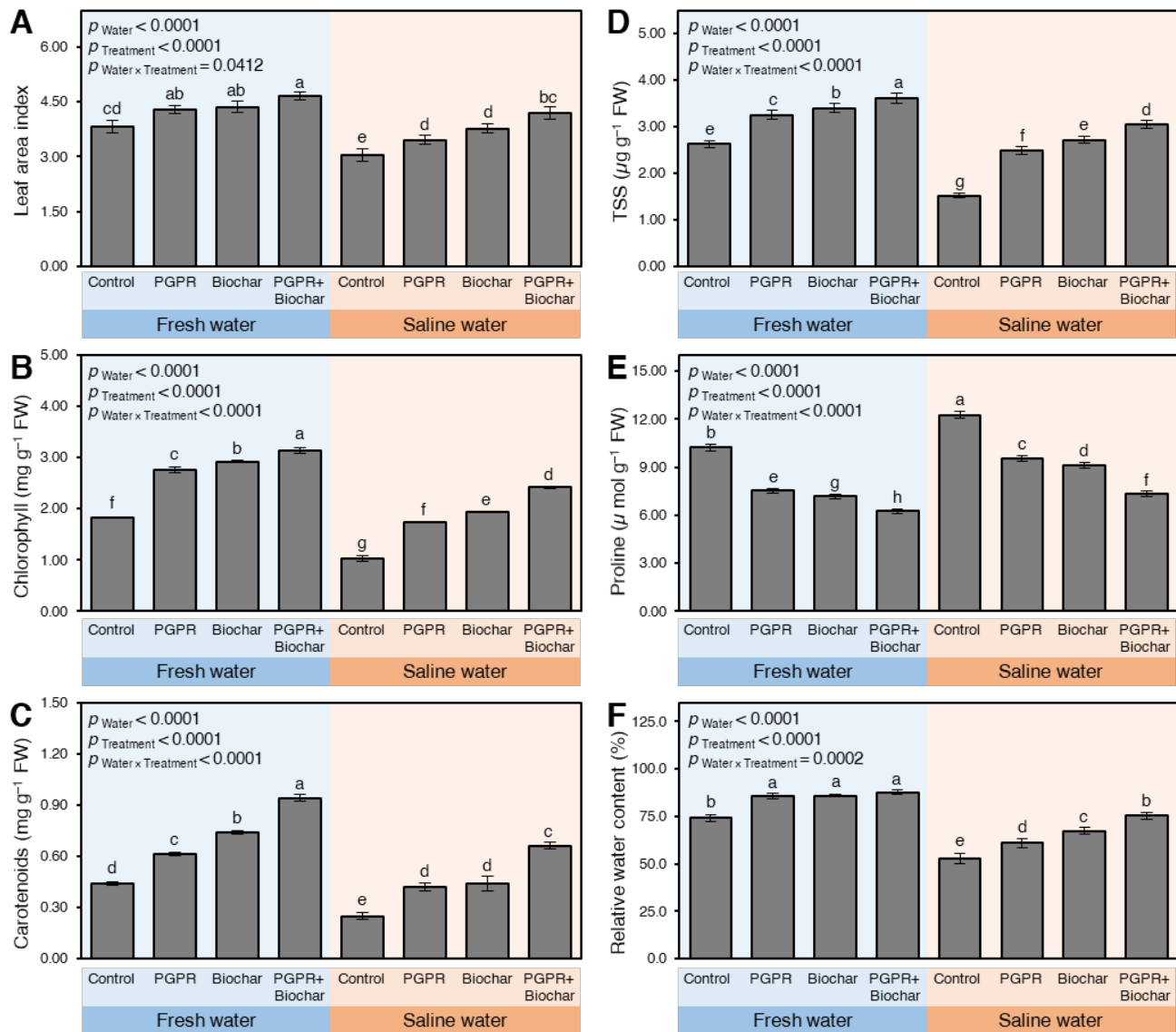


Figure S2: Leaf area index, photosynthetic pigments, and biochemical traits and of of maize plants growing in sodic-saline soil and irrigated with fresh and saline water after the application of biochar and PGPR during 2018 season. Data presented are means \pm standard deviation (mean \pm SD) of three biological replicates. Presented pairwise differences connecting letters (significance letters) were generated based on the p -value of the interaction between water type (as the main plots) and treatments (as subplots) that were mentioned as ($p_{\text{Water} \times \text{Treatment}}$). Means followed by different letters indicate statistically significant differences among treatments according to Tukey's honestly significant difference (HSD) test ($P \leq 0.05$), whereas means followed by the same letters indicate no statistically significant differences among them. **TSS:** Total soluble sugar.

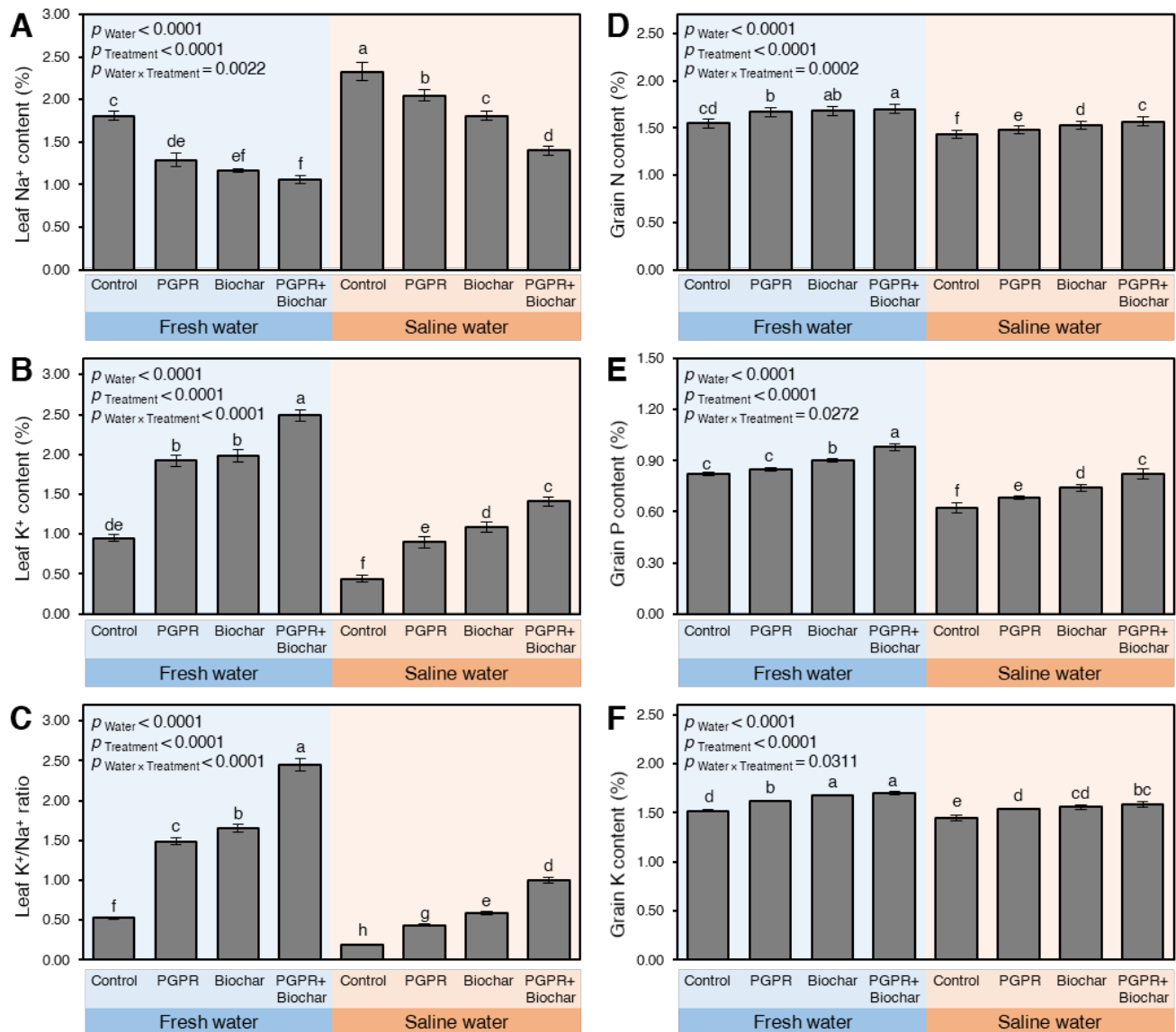


Figure S3: The leaf content of Na⁺, K⁺, K⁺/Na⁺ ratio, and the NPK content of grains of maize plants growing in sodic-saline soil and irrigated with fresh and saline water after the application of biochar and PGPR during 2018 season. Data presented are means \pm standard deviation (mean \pm SD) of three biological replicates. Presented pairwise differences connecting letters (significance letters) were generated based on the p -value of the interaction between water type (as the main plots) and treatments (as subplots) that were mentioned as ($p_{\text{Water} \times \text{Treatment}}$). Means followed by different letters indicate statistically significant differences among treatments according to Tukey's honestly significant difference (HSD) test ($p \leq 0.05$), whereas means followed by the same letters indicate no statistically significant differences among them.