



International Journal of Zoology, Environment and Life Sciences

Content Available at www.lapinjournal.com ISSN (P):3048-9598
(An International online peer reviewed Referred Journal)



Research Article

Open Access

FUNNELIFORMIS MOSSEAE AND SOIL-APPLIED POTASSIUM SILICATE FOR EGGPLANT IRRIGATED WITH SALINE WELL WATER: Na^+/K^+ BALANCE, PHOSPHORUS UPTAKE AND FRUIT YIELD

ALI MOHSEN ESSA

Department of Chemistry, College of Education, University of Al-Qadisiyah, Al-Diwaniyah, Iraq

***Corresponding author**
Ali Mohsen Essa

DOI: <https://doi.org/10.70604/ijzels.v3i2.230>

Article History: Received: 04 Aug 2026, Revised: 11 Sep 2026, Accepted: 07 Oct 2026

ABSTRACT

Saline groundwater has become a routine irrigation source in dry regions, but it lowers vegetable yield through sodium load, potassium loss and weak phosphorus nutrition. We tested whether the arbuscular mycorrhizal fungus *Funneliformis mosseae* and soil-applied potassium silicate (K_2SiO_3) protect eggplant (*Solanum melongena* L.) irrigated with saline well water. A pot trial combined three water salinities (EC_w 1.2, 3.5 and 6.0 dS m^{-1}), two inoculation levels and three silicate doses (0, 50 and 100 mg Si kg^{-1} soil) in four randomized complete blocks. Raising EC_w from 1.2 to 6.0 dS m^{-1} cut the fruit yield of untreated plants by 53%, raised the leaf Na/K molar ratio thirteen-fold and lowered leaf P by 31%. Across salinities, inoculation raised fruit yield by 15.5%, leaf P by 15.6% and recovered P by 23.8%, and lowered leaf Na/K by 20%. Silicate at 100 mg Si kg^{-1} raised leaf Si about fourfold and yield by 13.8%, and lowered leaf Na/K by 28%. At EC_w 6.0 dS m^{-1} the combined inputs gave 1.93 instead of 1.23 kg plant $^{-1}$ (+57%), with 45% lower leaf Na/K and 61% more recovered P. Their effects were additive (inoculation $\times$ silicate for yield, $P = 0.19$). Salinity reduced root colonization from 64% to 42%, while final soil EC_e was unaffected by either input. Because the silicate also supplied potassium, its benefit cannot be credited to silicon alone. Co-applying *F. mosseae* and potassium silicate is a practical option for eggplant grown with moderately saline well water.

Keywords: arbuscular mycorrhizal fungi; potassium silicate; saline irrigation water; *Solanum melongena*; Na^+/K^+ ratio; phosphorus uptake; groundwater.

This article is licensed under a Creative Commons Attribution-Non-commercial 4.0 International License. Copyright © 2026 Author(s) retains the copyright of this article.



INTRODUCTION

Salt is building up in irrigated soils across the dry belt of the world, and projections suggest the problem will grow over this century [1,2]. More than a quarter of all land and about one third of irrigated land are already affected by salinity or sodicity [3]. With fresh water in limited supply, farmers are turning to brackish or saline groundwater. A global meta study estimated the mean yield loss from such water at 17.3%, with greater losses above 3 dS m^{-1} [4]. Iraq is a case in point. Surface-water limitations have driven producers to wells and various surveys report use of local well water as inappropriate for irrigation due to its salinity [5–7]. Eggplant (*Solanum melongena* L.) is a traditional summer food in these regions, but its growth and yield decrease with increasing water salinity from 2 to 5 dS

m^{-1} [8,9]. Tolerant genotypes preserve low leaf Na and high leaf K [10, 11]. This is consistent with the more general concept that the Na^+/K^+ balance is crucial to salt tolerance [12,13]. Salinity also reduces the soil P availability and P absorption [14,15].

Two inputs could act on these weak points. The arbuscular mycorrhizal (AM) fungus *Funneliformis mosseae* improves growth under salt, and its benefit tends to grow with salinity [16]. Mycorrhizal plants often take up more P and keep a better K^+/Na^+ ratio [17,18]. Silicon can limit Na^+ entry and support ion balance [19], and it may complement AM fungi in P acquisition [20]. Combined tests are still few, and we found none on eggplant irrigated with saline well water. Potassium silicate adds a twist, because it supplies K as

well as Si, and K and Si applied together improved salt-stressed bell pepper [21]. We therefore asked whether *F. mosseae* and soil-applied K_2SiO_3 , alone or together, protect the Na^+/K^+ balance, P uptake and fruit yield of eggplant irrigated with saline well water, and whether their effects are additive or synergistic.

2. MATERIALS AND METHODS

2.1. Site, plant material and growing medium

The pot trial was run at the research station of the College of Agriculture, University of Al-Qadisiyah, Al-Diwaniyah, Iraq (31°59'12" N, 44°55'48" E; 18 m a.s.l.) during March–September 2024 under open-air conditions with an average daily temperature of 28–45 °C and relative humidity of 15–30% during the growing season. Seedlings of a medium-fruited commercial eggplant cultivar (Black Beauty, Bakeer Seeds Co., Baghdad, Iraq) were raised in peat moss and perlite (2:1, v/v) and transplanted at the 4–5-leaf stage, one plant per pot. Each pot (about 25 L) held 15 kg of air-dried sandy loam. Its main properties are given in Table 1. The medium was sterilized by autoclaving at 121 °C and 1.1 atm for 1 h on two consecutive days before filling. All pots received the same basal nutrients: 150 mg N, 50 mg P and 100 mg K per kg of dry soil, as urea (46% N), triple superphosphate (46% P_2O_5) and potassium sulfate (50% K_2O), mixed into the soil before transplanting. Other nutrients were supplied at adequate rates (Fe-EDDHA at 5 mg Fe kg^{-1} and a micronutrient mix (Fetrilon Combi, BASF) at 2 mg kg^{-1} , applied at 30 and 60 DAT).

Table 01: Properties of the growing medium and the irrigation waters.

Property	Value	Note
Growing medium (before planting)		
Texture	Sandy loam	62/22/16%
pH	7.5	1:1 soil–water
EC _e (dS m^{-1})	1.2	saturated-paste extract
Olsen-P (mg kg^{-1})	10	
Organic matter (%)	0.91	
CaCO ₃ (%)	23.8	
Available K (mg kg^{-1})	132	
Basal N, P, K added (mg kg^{-1} dry soil)	150, 50, 100	same in all pots
Dry soil per pot (kg)	15	~25 L pot
Saline well water		
EC _w (dS m^{-1} , 25 °C)	8.74	February 2024
pH	7.2	
Na ⁺ , Ca ²⁺ , Mg ²⁺ , K ⁺ (mmol _e L ⁻¹)	52.3, 14.6, 8.2, 0.4	
Cl ⁻ , SO ₄ ²⁻ , HCO ₃ ⁻ (mmol _e L ⁻¹)	41.8, 28.1, 5.6	
SAR ((mmol L ⁻¹) ^{0.5})	15.5	
B (mg L ⁻¹)	0.82	
Treatment waters		
Target EC _w (dS m^{-1})	1.2, 3.5, 6.0	1.18 ± 0.04, 3.53 ± 0.08, 5.96 ± 0.12
Leaching fraction (nominal)	0.20	

2.2. Treatments and experimental design

Three factors were crossed in a full factorial. They were irrigation-water salinity (EC_w 1.2, 3.5 and 6.0 dS m^{-1} at 25 °C), AM inoculation (none or *F. mosseae*) and K_2SiO_3 dose (0, 50 and 100 mg Si kg^{-1} dry soil). The 18 treatments (T01–T18; Table 2) were laid out in a randomized complete block design with four blocks. Inside each block the 18 pots took random positions (Fig. 1c). One pot, holding one plant, was the experimental unit, which gave 72 pots in total. Fig. 1 summarizes the set-up and the schedule.

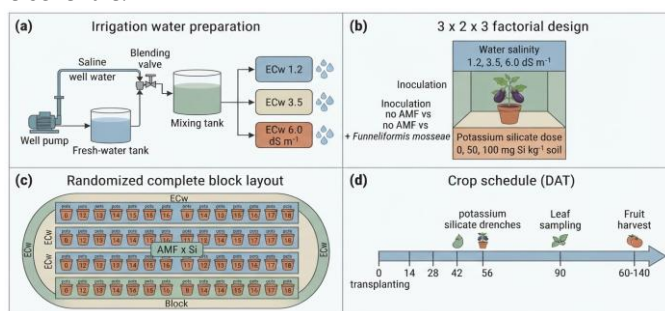


Figure 01: Overview of the experiment. (a) Saline well water was blended with fresh water to three target EC_w levels. (b) The 3 × 2 × 3 factorial of water salinity, *F. mosseae* inoculation and soil-applied K_2SiO_3 . (c) Randomized complete

block layout with the pot positions recorded in the dataset; the outer ring shows EC_w and the centre shows the AMF $\times$ Si combination. (d) Schedule in days after transplanting (DAT). Bracketed items are details still to be inserted by the authors.

Table 02: Treatment combinations and potassium silicate dose accounting (seasonal totals per pot of 15 kg dry soil).

AMF	Si dose (mg kg ⁻¹)	Si (mg pot ⁻¹)	K ₂ SiO ₃ (g pot ⁻¹)	Per drench (g)	K from silicate (mg kg ⁻¹)	Total K (mg kg ⁻¹)	Codes at EC _w 1.2 / 3.5 / 6.0
–	0	0	0	0	0	100	T01 / T07 / T13
–	50	750	4.12	1.03	139	239	T02 / T08 / T14
–	100	1500	8.24	2.06	278	378	T03 / T09 / T15
+	0	0	0	0	0	100	T04 / T10 / T16
+	50	750	4.12	1.03	139	239	T05 / T11 / T17
+	100	1500	8.24	2.06	278	378	T06 / T12 / T18

K₂SiO₃ amounts are anhydrous pure-salt equivalents ($M = 154.28 \text{ g mol}^{-1}$); commercial products need their own Si and K analysis. Total K includes the uniform basal 100 mg K kg⁻¹. AMF –, sterilized inoculum plus filtrate; AMF +, *F. mosseae*, 500 propagules pot⁻¹. Drenches at 14, 28, 42 and 56 DAT.

2.3. Saline well water and irrigation

Saline water was obtained from a well on a private property close to the station (depth 35 m). Its chemistry is shown in Table 1 (see values below). Treatment waters were made by blending the well water with fresh water (the university campus supply, EC_w 0.42 dS m⁻¹) to the three targets, and the EC of each batch was checked with a Hanna HI-9835 multi-parameter meter (Hanna Instruments, Italy) before use. Plants received non-saline water until establishment. From 14 days after transplanting (DAT) the salinity was raised in steps (+0.5 dS m⁻¹ every 3 days) to the target levels. At each irrigation enough water was given to drain about 20% of the applied volume, a nominal leaching fraction of 0.20. EC_w alone does not define the ionic make-up of the water, so the SAR, Cl^- , HCO_3^- and B values in Table 1 are needed to read the results correctly.

2.4. Mycorrhizal inoculation

The *F. mosseae* inoculum (isolate BGIV01, Biogreen Agri-Tech, Amman, Jordan) consisted of a sand-vermiculite carrier containing spores ($\approx 45 \text{ spores g}^{-1}$), extraradical hyphae and colonized sorghum root fragments. At transplanting, 500 viable propagules (wet-sieving and decanting followed by sucrose centrifugation) were placed in the planting hole of each inoculated pot. Non-inoculated pots received the same mass of sterilized inoculum plus a filtrate of the inoculum (25 μ m). The filtrate returned the accompanying microflora without the fungus.

2.5. Potassium silicate application

Potassium silicate was applied as a soil drench in four equal portions at 14, 28, 42 and 56 DAT. Doses were set as elemental Si per kg of dry soil and converted with the molar masses of K₂SiO₃ (154.28 g mol⁻¹) and Si (28.09 g mol⁻¹). For 15 kg of soil this gave 4.12 and 8.24 g K₂SiO₃ per pot over the season (anhydrous basis), or 1.03 and 2.06 g per drench (Table 2). The same salt added 139 and 278 mg K kg⁻¹ soil on top of the uniform basal 100 mg K kg⁻¹. No K-only control was included. The silicate treatment is therefore treated here as a joint K + Si input. The commercial product used was AgriSil K50 (PQ Corporation, USA; analysed 23.4% SiO₂ and 12.7% K₂O). Each drench was delivered in 250 mL of deionized water per pot should be stated, since product rates differ from the pure-salt equivalents.

2.6. Yield and biomass

Fruits were picked at commercial maturity from 60 to 140 DAT. Fruit number and fresh mass were recorded at every harvest. Total yield per plant was the product of fruit number and mean fruit mass. Fruits free of sunscald, insect damage and blossom-end rot, and weighing $\geq 80 \text{ g}$ were counted as marketable, and marketable yield is reported as part of total yield. Fruit dry matter was measured on subsamples from each harvest dried at 70 °C to constant mass; the mass-weighted value was used to convert fresh yield to fruit dry weight. At 140 DAT the shoots (without fruits) and roots were cut, washed, dried at 70 °C to constant mass and weighed.

2.7. Chemical analyses

Diagnostic leaves (the youngest fully expanded leaf, fourth from the apex) were sampled at 90 DAT, dried and ground. Leaf Na and K were measured by flame photometry (Jenway PFP7 flame photometer, Cole-Parmer, UK) after wet digestion in a 5:1 HNO₃–HClO₄ mixture. The Na/K molar ratio was computed for each pot from the molar masses of Na (22.990 g mol⁻¹) and K (39.098 g mol⁻¹). Phosphorus in leaves, bulk shoot, roots and fruits was determined colorimetrically (the vanadomolybdophosphoric acid method at 420 nm, Shimadzu UV-1800). Leaf Si was extracted by hot alkaline digestion and measured by the molybdenum-blue method [22]. The P mass of each organ was its dry mass

multiplied by its P concentration. Recovered P was the sum of shoot, root and cumulative fruit P. This is an operational uptake estimate. It is not corrected for P already present in the transplants or lost in fallen leaves and exudates, and it is not a fertilizer recovery efficiency. Leaf P is a diagnostic concentration and was not scaled to whole-plant mass. Final soil salinity was measured as EC_e in saturated-paste extracts after the last harvest.

2.8. Root colonization

Fine roots were cleared in KOH, stained with 0.05% trypan blue in lactoglycerol and scored by the magnified-intersections approach [23], using 150 intersections per sample. Colonization is expressed as the percentage of root length colonized. Colonization of non-inoculated plants was recorded as zero (confirmed by examining 150 intersections; no colonization was detected).

2.9. Statistical analysis

The data were analysed as a three-factor factorial in a randomized complete block design (block + $EC_w \times AMF \times Si$), with 51 error degrees of freedom. Leaf Na, leaf Na/K and leaf Si were log-transformed to stabilize the variance. Residuals of the other traits were close to normal (Shapiro–Wilk $P \geq 0.05$). Variances were mildly unequal for shoot dry weight and final EC_e (Brown–Forsythe test, $P < 0.05$), but for these two traits every effect had $P < 0.001$ or $P > 0.14$, so the conclusions do not hinge on this. Colonization was analysed for inoculated plants only (block + $EC_w \times Si$). Within each EC_w level, means were separated by Tukey's HSD at $P \leq 0.05$ using the pooled error mean square. Additivity of the two inputs was checked with single-degree-of-freedom interaction contrasts at each EC_w . Slopes of yield on final EC_e were compared by analysis of covariance. Pearson correlations were computed on the 72 pots, both pooled and as partial correlations after removing the EC_w effect. All analyses were run in Python with statsmodels 0.15. Values are means $\pm$ SD of four pots.

3. RESULTS AND DISCUSSION

3.1. Treatment checks: root-zone salinity and silicon uptake

The salinity treatments worked as planned. Final soil EC_e averaged 1.70, 4.52 and 7.83 $dS\ m^{-1}$ at EC_w 1.2, 3.5 and 6.0 $dS\ m^{-1}$, about 1.3–1.4 times the water EC (Fig. 2b). Neither inoculation ($P = 0.62$) nor silicate ($P = 0.64$) changed it (Table 3). Any benefit of the two inputs therefore came from the plants, not from a lower salt load in the pots.

Silicate raised leaf Si from 1.31 $mg\ g^{-1}$ without silicate to 3.58 and 5.45 $mg\ g^{-1}$ at 50 and 100 $mg\ Si\ kg^{-1}$ (Fig. 2a; Table 4). Leaf Si fell slightly with salinity ($P = 0.001$), by about 10% at EC_w 6.0 $dS\ m^{-1}$, and inoculated plants held a little more Si (+4.9%, $P = 0.041$). These checks are important because they reveal that the injected Si reached the leaves at all salinity levels. Previous silicon research on eggplant has investigated growth and insect pressure [24] and root rot [25]; data on uptake under saline irrigation adds to that picture.

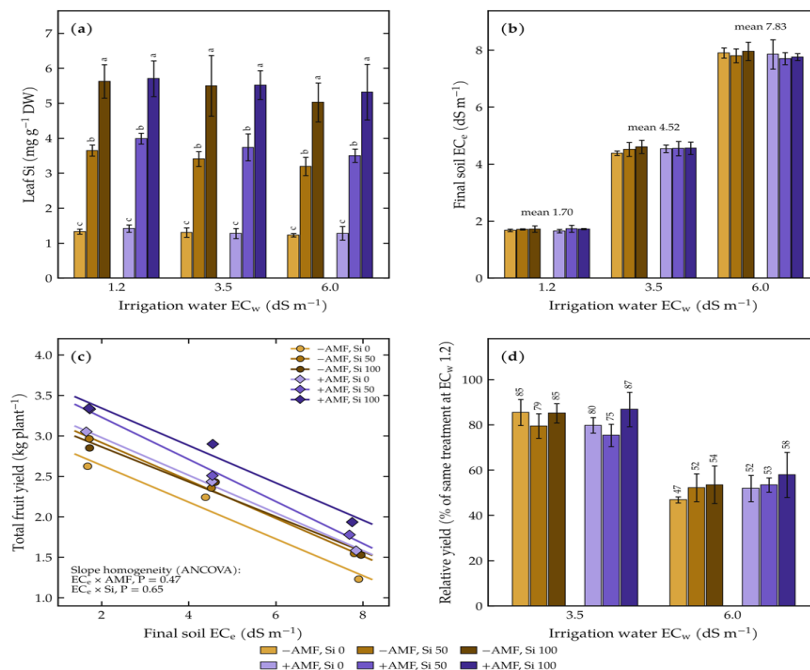


Figure 02: Silicon uptake, root-zone salinity and the yield response to salinity. (a) Leaf Si; (b) final soil EC_e with the mean of each EC_w level; (c) total fruit yield against final EC_e , with symbols for treatment means and lines fitted to the 12 pots of each AMF $\times$ Si combination; (d) relative yield, as % of the same AMF $\times$ Si combination at EC_w 1.2. Bars are means $\pm$ SD ($n = 4$). Within each EC_w level, bars sharing a letter do not differ (Tukey's HSD, $P \leq 0.05$; leaf Si tested on the log scale).

Table 03: F values from the analysis of variance (randomized complete block design, 51 error df).

Trait	Block	EC _w	AMF	Si	EC _w × AMF	EC _w × Si	AMF × Si	EC _w × AMF × Si	CV (%)
df	3	2	1	2	2	4	2	4	
Total yield	4.6**	317.5***	53.6***	15.0***	0.9 ns	1.2 ns	1.7 ns	0.2 ns	8.4
Marketable yield	3.8*	334.5***	52.1***	11.9***	1.1 ns	1.0 ns	1.9 ns	0.3 ns	9.8
Fruits per plant	4.1*	214.0***	40.9***	10.2***	0.4 ns	0.3 ns	2.0 ns	0.2 ns	6.9
Mean fruit mass	1.4 ns	106.1***	12.2*	5.0*	0.4 ns	2.4 ns	1.5 ns	1.3 ns	5.3
Marketable share	0.4 ns	270.6***	24.3***	0.5 ns	0.1 ns	0.8 ns	3.9*	1.3 ns	2.1
Shoot DW	8.5***	463.4***	70.2***	2.0 ns	0.3 ns	0.2 ns	0.0 ns	0.8 ns	6.0
Root DW	3.9*	279.5***	53.5***	3.3*	0.4 ns	2.2 ns	0.2 ns	0.9 ns	7.1
Leaf Na ^a	5.6**	3589***	33.3***	35.5***	4.0*	0.9 ns	0.8 ns	0.6 ns	8.7
Leaf K	0.8 ns	249.5***	31.9***	16.6***	0.2 ns	0.9 ns	0.7 ns	2.7*	5.1
Leaf Na/K ^a	3.9*	2755***	48.3***	41.2***	2.5 ns	1.3 ns	0.7 ns	0.3 ns	11.4
Leaf P	0.2 ns	255.8***	129.4***	7.0**	2.1 ns	1.2 ns	0.1 ns	0.6 ns	5.4
Recovered P	9.0***	535.9***	155.2***	16.9***	1.8 ns	1.1 ns	0.8 ns	0.4 ns	7.3
Leaf Si ^a	1.2 ns	7.6**	4.4*	1429***	0.2 ns	0.2 ns	0.9 ns	0.2 ns	9.5
Final EC _e	0.3 ns	4848***	0.2 ns	0.4 ns	0.9 ns	0.6 ns	0.4 ns	0.2 ns	4.6
Colonization ^b	0.2 ns	45.1***	—	1.0 ns	—	1.6 ns	—	—	11.1

**P < 0.001; *P < 0.01; P < 0.05; ns, not significant. ^aAnalysed after natural-log transformation; CV given as $100 \sqrt{(\exp(\text{MSE}) - 1)}$. ^bInoculated pots only (block + EC_w × Si; 24 error df).

3.2. Fruit yield and its components

Salinity was the dominant factor for every yield trait (Table 3). In untreated plants total yield dropped from 2.63 kg plant⁻¹ at EC_w 1.2 to 2.24 at 3.5 and 1.23 kg plant⁻¹ at 6.0 dS m⁻¹, losses of 15% and 53% (Fig. 3a). Marketable yield fell harder, by 60% at the top salinity, because the marketable share of the crop shrank from 94% to 81% (Fig. 3b). Fruit number (−36%) and mean fruit mass (−27%) both declined (Fig. 3c, d). The size of the loss is in line with field reports. Abbas et al. [8] recorded falling eggplant growth and yield between 2 and 5 dS m⁻¹, and Seema et al. [9] found that water of 5.0 dS m⁻¹ reduced fruit yield and NPK uptake. Among heirloom cultivars the relative yield under salt ranged from 52% to 114% [10], so genotype choice will shift the numbers reported here.

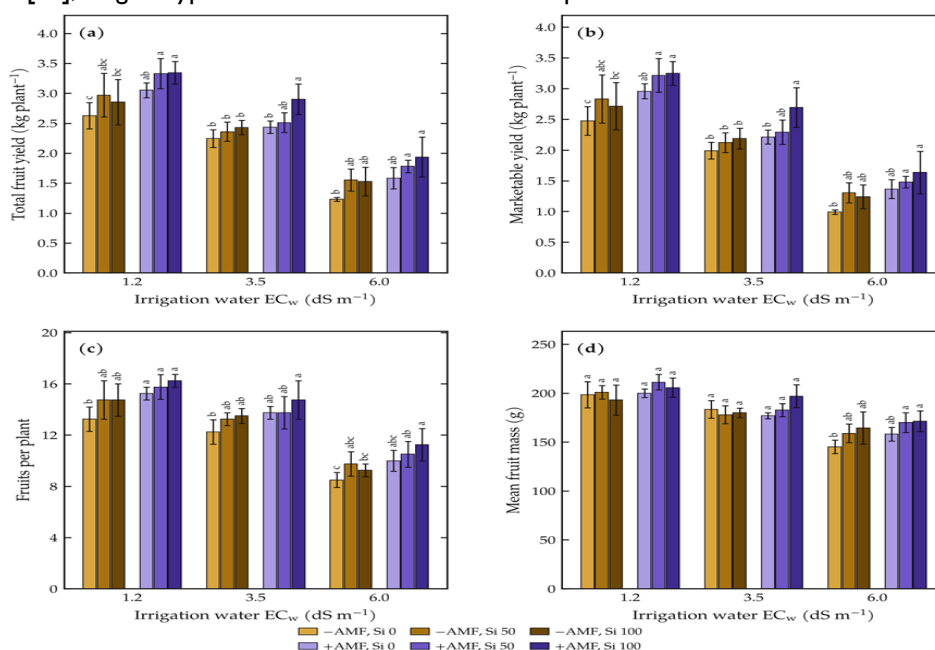


Figure 03: Yield components of eggplant irrigated with saline well water. (a) Total fruit yield; (b) marketable yield; (c) fruits per plant; (d) mean fruit mass. Bars are means $\pm$ SD ($n = 4$). Within each EC_w level, bars sharing a letter do not differ (Tukey's HSD, $P \leq 0.05$).

Both inputs raised yield, and neither interacted with salinity (Table 3). Averaged over all salinities, inoculation lifted total yield from 2.20 to 2.54 kg plant⁻¹ (+15.5%) and marketable yield by 18.1%. Silicate raised total yield by 10.1% at 50 and by 13.8% at 100 mg Si kg⁻¹; the two doses did not differ (Table 4). Fruit number carried most of the gain (+11.0% with inoculation, +9.2% with the high silicate dose), while fruit mass rose by only 4–5%. The combination gave the largest

yields at every salinity: 3.34 kg plant⁻¹ at EC_w 1.2, 2.90 at 3.5 and 1.93 at 6.0 dS m⁻¹. Against the untreated plants of the same salinity, these were gains of 27%, 29% and 57%. Within EC_w 3.5 and 6.0 dS m⁻¹, neither input alone separated from the control by Tukey's test. The combination with 100 mg Si did so at both levels, and the one with 50 mg Si at 6.0 dS m⁻¹ (Fig. 3a).

Table 04: Main-effect means of water salinity, inoculation and silicate dose.

Trait	EC _w 1.2	EC _w 3.5	EC _w 6.0	-AMF	+AMF	Si 0	Si 50	Si 100
Total yield (kg plant ⁻¹)	3.03 a	2.48 b	1.60 c	2.20 b	2.54 a	2.19 b	2.42 a	2.50 a
Marketable yield (kg plant ⁻¹)	2.91 a	2.25 b	1.34 c	1.98 b	2.34 a	2.00 b	2.21 a	2.29 a
Fruits per plant	15.0 a	13.5 b	9.9 c	12.1 b	13.5 a	12.2 b	13.0 a	13.3 a
Mean fruit mass (g)	202 a	183 b	161 c	178 b	186 a	177 b	184 ab	185 a
Leaf Na (mg g ⁻¹)	0.64 c	2.54 b	5.19 a	2.99 a	2.58 b	3.15 a	2.71 b	2.51 b
Leaf K (mg g ⁻¹)	39.3 a	34.1 b	28.1 c	32.7 b	35.0 a	32.3 b	34.1 a	35.1 a
Leaf Na/K (mol mol ⁻¹)	0.028 c	0.127 b	0.318 a	0.176 a	0.140 b	0.188 a	0.151 b	0.135 c
Leaf P (mg g ⁻¹)	3.18 a	2.72 b	2.22 c	2.51 b	2.90 a	2.62 b	2.74 a	2.77 a
Recovered P (mg plant ⁻¹)	1482 a	1130 b	721 c	993 b	1229 a	1037 b	1126 a	1170 a
Leaf Si (mg g ⁻¹)	3.62 a	3.46 ab	3.26 b	3.36 b	3.53 a	1.31 c	3.58 b	5.45 a

Each EC_w and Si mean is over 24 pots and each AMF mean over 36 pots. Within a factor, means followed by the same letter do not differ (Tukey's HSD, $P \leq 0.05$); leaf Na, Na/K and Si were compared on the log scale.

The absolute AM benefit did not grow with salinity; it was 0.42, 0.27 and 0.33 kg plant⁻¹ at the three EC_w levels. In relative terms it was largest at 6.0 dS m⁻¹ (+23%), because the baseline there was so low. This pattern matches the meta-analytic finding that the AM growth benefit becomes more visible as salinity rises [16]. Responses of eggplant to AM fungi are not universal, though. Gains of 23.7% in total and 36.4% in marketable yield were reported when an AM inoculum was paired with a protein hydrolysate in the field [26], and *Rhizophagus irregularis*, with or without *Azotobacter chroococcum*, upheld production under low fertilization [27]. In an organic soilless system, by contrast, inoculation had no effect [28]. A soil medium with low Olsen-P, as used here, probably favoured a response.

Vegetative growth told a similar story. Final shoot dry weight fell from 188 g plant⁻¹ at EC_w 1.2 to 109 g plant⁻¹ at 6.0 dS m⁻¹ (-42%), and root dry weight from 38.2 to 23.2 g plant⁻¹ (-39%). Inoculation added 12.7% to shoot and 13.1% to root mass. Silicate had no clear effect on shoot mass ($P = 0.14$) and only a marginal one on roots (about +5%, $P = 0.047$). The silicate gain in fruit yield was therefore not just a matter of a bigger plant. It appeared mainly as more fruits per plant, which points to an effect on fruit set and retention under salt rather than on canopy size.

3.3. Leaf Na, K and the Na/K balance

Salinity drove leaf Na up from 0.73 to 6.25 mg g⁻¹ and leaf K down from 37.8 to 24.7 mg g⁻¹ in untreated plants (Fig. 4a, b). The Na/K molar ratio therefore rose from 0.033 to 0.431 (Fig. 4c). Both inputs pulled the ratio back. Across salinities, inoculation lowered leaf Na by 13.8% and raised leaf K by 7.0%, which cut Na/K by 20%. Silicate at 100 mg Si kg⁻¹ lowered leaf Na by 20.2%, raised leaf K by 8.8% and cut Na/K by 28% (Table 4). The AM effect on leaf Na grew with salinity (EC_w × AMF on the log scale, $P = 0.025$). At EC_w 6.0 dS m⁻¹ the combined treatment held leaf Na at 4.20 mg g⁻¹ and leaf K at 30.3 mg g⁻¹, so Na/K fell to 0.238, 45% below the untreated plants.

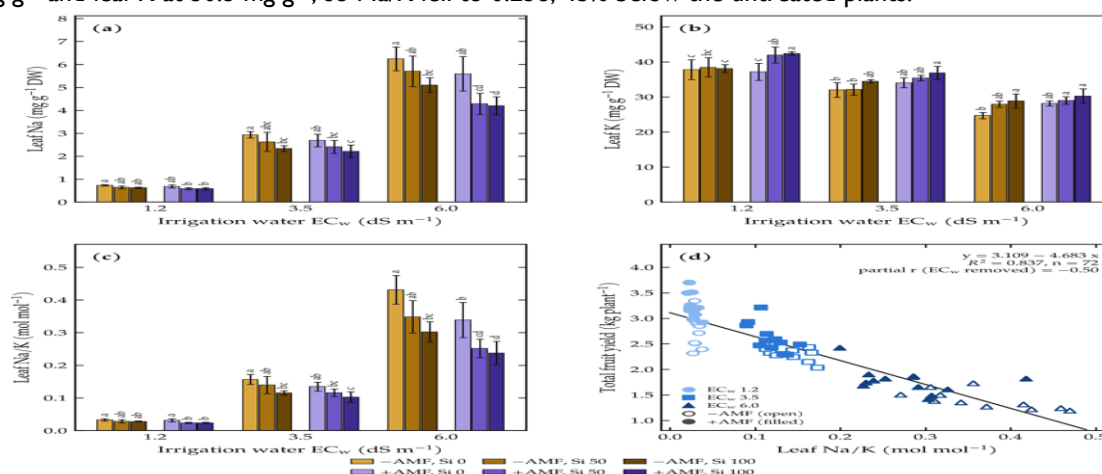


Figure 04: Leaf ion status. (a) Leaf Na; (b) leaf K; (c) leaf Na/K molar ratio; (d) total fruit yield against leaf Na/K for all 72 pots (open symbols -AMF, filled +AMF), with the pooled least-squares line. Bars are means $\pm$ SD ($n = 4$). Within each EC_w level, bars sharing a letter do not differ (Tukey's HSD, $P \leq 0.05$; Na and Na/K tested on the log scale).

Leaf Na/K tracked yield closely. Across the 72 pots, yield fell linearly with Na/K ($R^2 = 0.84$; Fig. 4d). The pooled relation mostly reflects the salinity gradient, yet a clear link remained after the EC_w effect was removed (partial $r = -0.50$, $P < 0.001$). This agrees with work on eggplant, tomato and pepper, where low leaf Na and a stable leaf K ratio marked the tolerant cultivars, and Na^+ exclusion was the key trait in eggplant [10]. A screen of cultivated eggplants and their wild relatives also linked tolerance to low leaf Na^+ [11]. Leaf Na exclusion is not the whole story, since some crops tolerate high leaf Na while keeping it out of reproductive tissue [13]. We did not measure fruit Na, which would be worth adding.

The AM effect on Na and K is consistent with earlier studies. In maize, *F. mosseae* lowered shoot Na^+ and the root-to-leaf Na^+/K^+ gradient, along with changes in *SOS1*, *HKT1* and *NHX* expression [18]. In pistachio, AM inoculation raised the K/Na ratio by 87.5% under salt [29]. In bean, *F. mosseae* raised K^+ uptake and the K^+/Na^+ ratio, and the study pointed to *KUP*-family K^+ transporters [30]. Our data hold only concentrations, so the transporter route remains a working hypothesis. Silicon supplementation is reviewed as a way to raise salt tolerance, partly through its interactions with other ions [19]. Here, however, every gram of Si came with about 2.8 g of K. Potassium fertilizer alone lowered sodium content by 42% in sugar beet on saline soil [31] and lift the K^+/Na^+ ratio of a salt-stressed vegetable [32], and Si and K together improved bell pepper under salt [21]. Part of the silicate effect on leaf K is therefore likely a K effect, and a K-only control is needed to split them.

3.4. Phosphorus nutrition and root colonization

Salinity cut leaf P from 3.18 to 2.22 $mg\ g^{-1}$ and recovered P from 1482 to 721 $mg\ plant^{-1}$ on average (-30% and -51% ; Table 4). A meta-analysis of 87 studies found that salinization lowers available soil P by 11.2% [14], and in alfalfa higher salinity reduced P-uptake efficiency and deepened P deficiency [15]. Inoculation was the strongest lever on P. It raised leaf P by 15.6% ($F = 129$; Table 3) and recovered P by 23.8%, from 993 to 1229 $mg\ plant^{-1}$. The leaf P gain was 14–18% at every salinity level. Silicate added a smaller rise, 5.7% in leaf P and 12.8% in recovered P at the high dose. At EC_w 6.0 $dS\ m^{-1}$ the combination raised recovered P from 545 to 879 $mg\ plant^{-1}$ ($+61\%$; Fig. 5b). Fruits held 63–71% of recovered P in all treatments, so the extra P went mainly to the crop.

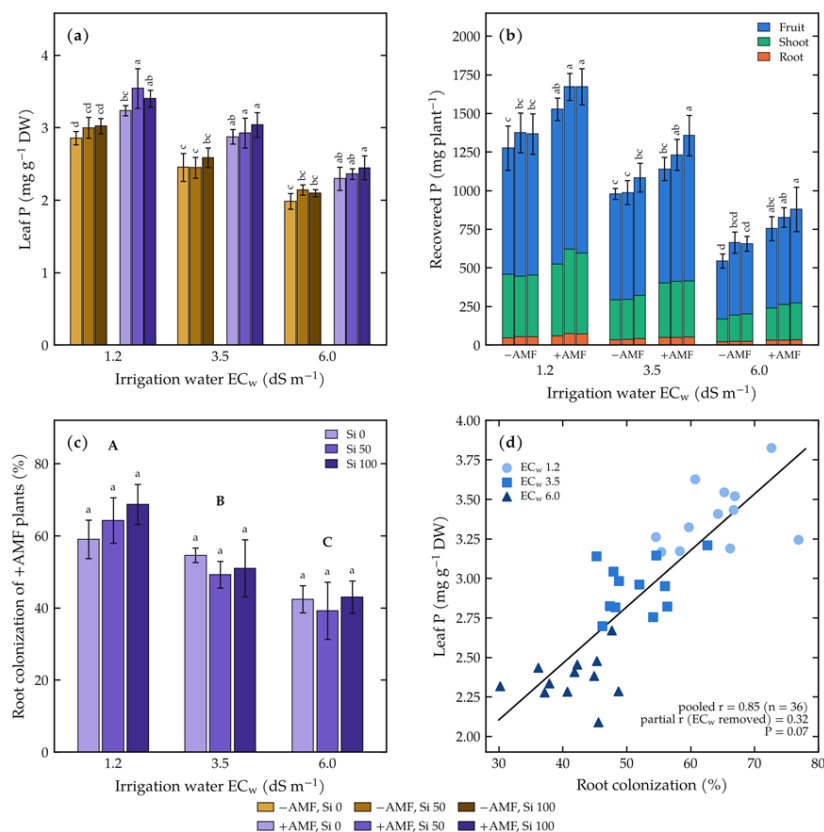


Figure 05: Phosphorus nutrition and root colonization. (a) Leaf P; (b) recovered P split into root, shoot and fruit fractions (within each EC_w , -AMF bars on the left and +AMF bars on the right, Si 0, 50 and 100 from left to right); (c) root colonization of inoculated plants (lowercase letters compare Si doses within an EC_w level, capitals compare EC_w levels); (d) leaf P against colonization in inoculated plants. Bars are means $\pm$ SD ($n = 4$); letters from Tukey's HSD ($P \leq 0.05$).

These P gains fit the general record. A meta-analysis of 187 studies found that AM inoculation raises whole-plant P uptake by 105% on average and that the response grows with colonization [33]. *F. mosseae* switches on the mycorrhiza-inducible *Pt4* phosphate transporters [34], and an AM inoculum kept soybean P uptake high under saline-alkaline stress

[35]. Silicon can raise P availability, and a recent review argues that Si and AM fungi may work better together than alone [20]. Although we did not quantify soil P fractions, the tiny Si influence on leaf P here is consistent with that hypothesis.

The injected root colonisation decreased from 64.0% at EC_w 1.2 to 51.6% at 3.5 and 41.5% at 6.0 dS m⁻¹ (-35%; Fig. 5c) and was not affected by silicate ($P = 0.37$). Othman et al. [36] reported that the colonisation loss in gerbera irrigated with salty water was 12–25%. The loss in this study was higher which might be attributed to the higher root-zone salinity (EC_e 7.8 versus 4.4 dS m⁻¹). Salt also suppressed *F. mosseae* colonisation in hemp [37]. The trend is not all-encompassing. In tomato, salt inhibited colonisation by *R. irregularis* but encouraged *F. mosseae* [38]. Across salinities, leaf P increased with colonisation ($r = 0.85$, $n = 36$; Fig. 5d). Most of that relationship stemmed from the common salinity gradient. Without the EC_w effect, the partial r was 0.32 ($P = 0.07$). That is, the inoculation status was more important than the precise colonisation level and even 40% colonisation was sufficient to maintain a clear P advantage at the greatest salinity.

3.5. Relations among traits

All pots were combined and most features were substantially associated (Fig. 6). This is to be expected, because salinity drove them all together. The partial correlations, with the EC_w impact eliminated, tell us more. Total yield nevertheless increased with leaf K ($r=0.67$), leaf P ($r=0.65$) and leaf Si ($r=0.47$), and decreased with leaf Na/K ($r=-0.50$), all significant at $P<0.001$. The final EC_e was not partially correlated to yield ($r = -0.04$), further indicating that the treatments were acting on the plant not the soil. That pair should not be regarded as independent evidence because recovered P correlates almost by construction with yield, as fruit P is determined from fruit dry weight.

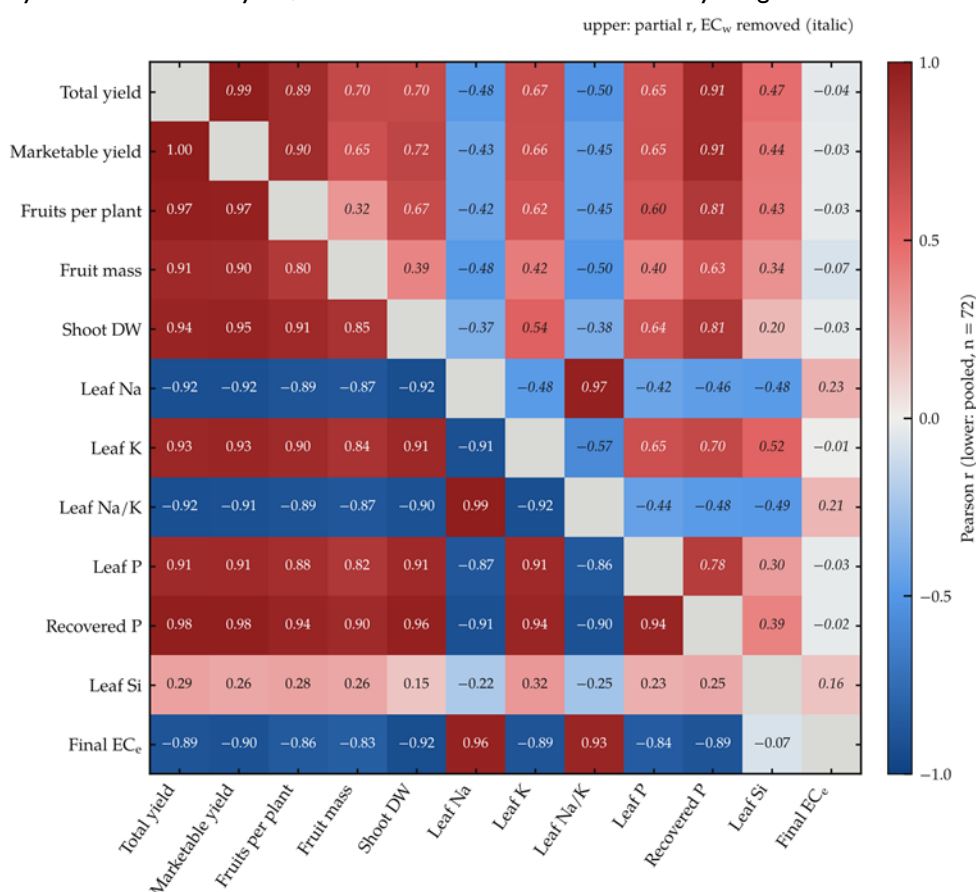


Figure 06: Pearson correlations among yield, growth, ion and soil traits. Lower triangle: pooled correlations over the 72 pots. Upper triangle (italic): partial correlations after removing the EC_w effect. $|r| \geq 0.24$ is significant at $P < 0.05$, $|r| \geq 0.31$ at $P < 0.01$ and $|r| \geq 0.39$ at $P < 0.001$. Recovered P includes fruit P and is not independent of yield.

3.6. Additive action of the two inputs

The AMF $\times$ Si interaction was not significant for total or marketable yield, fruit quantity, fruit mass, leaf Na/K, leaf P or recovered P ($P = 0.15$ – 0.88 ; Table 3). It was significant only for the marketable part of the crop ($P=0.027$). Silicate increased the share up to 2 percentage points in non-infected plants but not in inoculated ones, which had a greater share without silicate (91% vs 88%). The interaction contrasts were similar (Table 5). Inoculation only contributed 0.35 kg plant⁻¹ and 0.30 kg plant⁻¹ for the high silicate dose at EC_w 6.0 dS m⁻¹. Simple addition predicts 1.88kg plant⁻¹, while the combined plants produced 1.93, an opposite contrast of +0.05kg plant⁻¹ (95% CI -0.34 to 0.45). There was a weak

three-way interaction for leaf K ($P = 0.042$). At EC_w 1.2 dS m^{-1} the joint treatment held about 4–5 $mg\ g^{-1}$ more K than expected ($P \leq 0.02$), but this did not carry over to the saline levels.

Table 05: Additivity check for inoculation and the high silicate dose (100 $mg\ Si\ kg^{-1}$) at each water salinity.

Trait	EC_w	Control	AMF alone	Si alone	Additive expect.	Observed combined	Contrast (95% CI)	P
Total yield (kg plant ⁻¹)	1.2	2.63	3.05	2.85	3.28	3.34	0.07 (–0.33 to 0.46)	0.74
	3.5	2.24	2.43	2.43	2.62	2.90	0.28 (–0.12 to 0.68)	0.16
	6.0	1.23	1.58	1.53	1.88	1.93	0.05 (–0.34 to 0.45)	0.78
Marketable yield (kg plant ⁻¹)	1.2	2.47	2.96	2.71	3.20	3.25	0.05 (–0.37 to 0.48)	0.81
	3.5	1.99	2.21	2.19	2.41	2.69	0.28 (–0.14 to 0.71)	0.19
	6.0	0.99	1.36	1.24	1.61	1.63	0.02 (–0.40 to 0.45)	0.91
Recovered P (mg plant ⁻¹)	1.2	1276	1527	1367	1619	1674	55 (–107 to 217)	0.50
	3.5	979	1140	1084	1245	1357	112 (–50 to 273)	0.17
	6.0	545	755	657	867	879	11 (–150 to 173)	0.89
Leaf K (mg g ⁻¹)	1.2	37.8	37.1	38.1	37.4	42.4	4.9 (1.4 to 8.4)	0.007
	3.5	32.0	34.0	34.4	36.5	36.8	0.3 (–3.1 to 3.8)	0.84
	6.0	24.7	28.2	28.8	32.3	30.3	–2.0 (–5.5 to 1.4)	0.25

Control, –AMF Si 0; additive expectation = AMF alone + Si alone – control. The contrast is observed – expected, with a 95% confidence interval from the pooled error mean square (51 df). A contrast near zero means the two effects simply add up. Leaf Na/K is not shown because it was analysed on the log scale (AMF × Si, $P = 0.52$; Table 3).

The salt-response lines in Fig. 2c are close to parallel. Neither inoculation ($P = 0.47$) nor silicate ($P = 0.65$) changed the slope of yield on final EC_e , which ranged from –0.22 to –0.26 $kg\ plant^{-1}$ per dS m^{-1} . The inputs raised the whole line rather than flattening it. Relative to the same treatment without salt, yield at EC_w 6.0 dS m^{-1} was 47% for untreated plants and 58% for the combination (Fig. 2d). Combined AM and Si treatments have helped other crops under stress, for example sunflower under salt [39] and *Matthiola incana* under drought, where potassium silicate also raised colonization [40]. We saw no rise in colonization with silicate and no synergy in yield. The two inputs seem to act through partly separate routes, mainly P supply for the fungus and ion balance for the silicate, so their gains simply added up (Fig. 7).

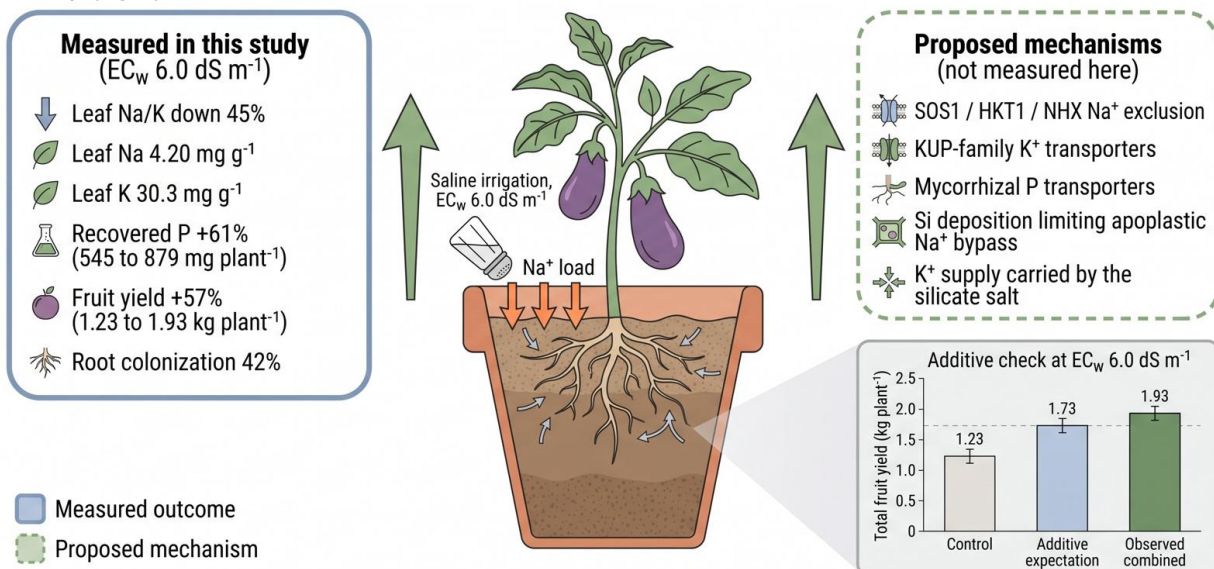


Figure 07: Working model for eggplant inoculated with *F. mosseae* and treated with K_2SiO_3 under saline irrigation. The solid box lists outcomes measured in this study (EC_w 6.0 dS m^{-1}); the dashed box lists mechanisms proposed in the literature that were not measured here. The inset bar chart compares the observed yield of the combined treatment with the additive expectation.

3.7. Practical meaning and limits of the study

For growers who must utilise well water of roughly 3–6 dS m⁻¹, the results suggest a basic package. Inoculation of transplants with *F. mosseae* and drenching of 50–100 mg Si kg⁻¹ as K₂SiO₃ without modifying the soil salinity, restored a large part of salt loss. The 50 and 100 mg doses had identical results, therefore the smaller dose may be the better buy. Table 6 compares the major reactions with recent studies and they are within the range seen for other crops and inputs. There are several limits. The trial was a single season pot experiment with one cultivar. EC_w was the only water variable, and the whole ion make-up of the well water (Table 1) has not been reported yet. The silicate provided both K and Si and no K-only control was presented. Recovered P is not fertiliser recovery efficiency but an estimate of operational P. The colonisation of control plants was assumed to be nil. This would make it more solid if you had a K-only treatment with field experiments, measured water chemistry, and fruit Na.

Table 06: Main responses of this study beside recent reports.

Study	Crop and conditions	Treatment	Reported response
This study	Eggplant, pots, saline well water, EC _w 6.0 dS m ⁻¹	<i>F. mosseae</i> + K ₂ SiO ₃ (100 mg Si kg ⁻¹)	Yield +57%; leaf Na/K –45%; recovered P +61%; colonization 43%
Cheng et al. [4]	Many crops; meta-analysis of 120 publications	Salty vs fresh irrigation water	Yield –17.3% on average; larger losses at EC 3.0–15.7 dS m ⁻¹
Abbas et al. [8]	Eggplant; net house and open field; EC 2–5 dS m ⁻¹	Salinity levels	Yield 1.345 kg plant ⁻¹ (net house, lowest EC) vs 0.988 kg plant ⁻¹ (open field, highest EC)
Suarez et al. [10]	Eggplant, tomato and pepper cultivars	Salt vs control	Relative fruit yield of eggplant 52–114%; low leaf Na marked tolerance
Li et al. [14]	Terrestrial ecosystems; meta-analysis of 87 articles	Salinization	Available soil P –11.2%
Wu et al. [33]	Many plants; meta-analysis of 187 studies	AM inoculation	P concentration +27%; whole-plant P uptake +105%; response rises with colonization
Othman et al. [36]	Gerbera; saline irrigation up to 40 mM NaCl	AM inoculation	Colonization –12 to –25% and sporulation –53 to –62% at the high salinity
Abbaspour et al. [29]	Pistachio; NaCl	<i>R. irregularis</i>	P content +71.6%; K/Na +87.5% under salinity
Di Miceli et al. [26]	Eggplant; open field, two seasons	AM fungi + protein hydrolysate	Total yield +23.7%; marketable yield +36.4%
Abd El-Mageed et al. [31]	Sugar beet; saline soil, EC 9.28 dS m ⁻¹	K fertilizer, 144 kg K ha ⁻¹	Sodium content –42.0%; root yield +35.9%
Rady et al. [32]	Squash; saline soil, EC 9.38 dS m ⁻¹	Salinity; foliar nano-K	Salinity cut K ⁺ /Na ⁺ by 66.4–67.1%; nano-K raised it

Values are quoted from the abstracts of the cited papers.

4. CONCLUSION

Irrigation with saline well water at EC_w 6.0 dS m⁻¹ cut eggplant fruit yield by about half, mainly through fewer and smaller fruits, a thirteen-fold rise in leaf Na/K and a 31% drop in leaf P. Inoculation with *Funneliformis mosseae* improved P nutrition at every salinity and lowered leaf Na/K, even though salt reduced root colonization from 64% to 42%. Soil-applied potassium silicate raised leaf Si about fourfold and improved the Na/K balance, but part of this benefit probably came from the potassium it supplied. The two inputs acted additively. At the highest salinity, together they raised yield from 1.23 to 1.93 kg plant⁻¹, lowered leaf Na/K by 45% and increased recovered P by 61%. Root-zone salinity did not change, so the gains came from the

plant side. The 50 mg Si kg⁻¹ dose gave yields close to the 100 mg dose. Co-applying *F. mosseae* with a moderate silicate dose is a reasonable option for eggplant grown on saline well water, pending field tests that separate the K and Si effects.

5. FUNDING

This research received no external funding.

6. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

7. DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author on reasonable request.

8. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the College of Agriculture, University of Al-Qadisiyah, for providing the greenhouse facilities and laboratory space.

9. REFERENCES

- Hassani A, Azapagic A, Shokri N (2021). Global predictions of primary soil salinization under changing climate in the 21st century. *Nature Communications* 12(1): 6663. <https://doi.org/10.1038/s41467-021-26907-3>
- Corwin DL (2021). Climate change impacts on soil salinity in agricultural areas. *European Journal of Soil Science* 72(2): 842–862. <https://doi.org/10.1111/ejss.13010>
- Mohanavelu A, Naganna SR, Al-Ansari N (2021). Irrigation induced salinity and sodicity hazards on soil and groundwater: An overview of its causes, impacts and mitigation strategies. *Agriculture* 11(10): 983. <https://doi.org/10.3390/agriculture11100983>
- Cheng M, Wang H, Fan J, Wang X, Sun X, Yang L, Zhang S, Xiang Y, Zhang F (2021). Crop yield and water productivity under salty water irrigation: A global meta-analysis. *Agricultural Water Management* 256: 107105. <https://doi.org/10.1016/j.agwat.2021.107105>
- Makki ZF, Zuhaira AA, Al-Jubouri SM, Al-Hamd RKS, Cunningham LS (2021). GIS-based assessment of groundwater quality for drinking and irrigation purposes in central Iraq. *Environmental Monitoring and Assessment* 193(2): 107. <https://doi.org/10.1007/s10661-021-08858-w>
- Awad ES, Imran NS, Albayati MM, Snegirev V, Sabirova TM, Tretyakova NA, Alsahy QF, Al-Furaiji MH, Salih IK, Majdi HS (2022). Groundwater hydrogeochemical and quality appraisal for agriculture irrigation in Greenbelt Area, Iraq. *Environments* 9(4): 43. <https://doi.org/10.3390/environments9040043>
- Sahab MF, Abdullah MH, Hammadi GA, Hamad NS, Abdulazez AA, Fayyadh AH, Ayed DJ, Jalal AD, Sayl KN, Ramal MM (2024). Ground water quality evaluation for irrigation purpose: Case study Al-Wafaa Area, Western Iraq. *International Journal of Design & Nature and Ecodynamics* 19(4): 1415–1424. <https://doi.org/10.18280/ijedne.190434>
- Abbas F, Khan FU, Al-Naemi S, Al-Otoom A, Aljarrah M (2025). Assessing growth, physiological, and yield responses of eggplant (*Solanum melongena* L.) to salinity stress in controlled and field environments. *Scientific Reports* 15(1): 35444. <https://doi.org/10.1038/s41598-025-19357-0>
- Seema S, Dahiya R, Prakash R, Panghal VPS, Gora MK (2023). Effects of saline water and N levels on eggplant (*Solanum melongena* L.) fruit yield, water productivity, and nitrogen use efficiency by drip and surface flood irrigation. *Horticultural Science* 50(1): 32–44. <https://doi.org/10.17221/11/2022-HORTSCI>
- Suarez DL, Celis N, Ferreira JFS, Reynolds T, Sandhu D (2021). Linking genetic determinants with salinity tolerance and ion relationships in eggplant, tomato and pepper. *Scientific Reports* 11(1): 16298. <https://doi.org/10.1038/s41598-021-95506-5>
- Cebeci E, Boyaci HF, Kiran S, Ellialtioglu SS (2025). Comprehensive assessment to reveal the salt tolerance potential of cultivated eggplants and their wild relatives. *Frontiers in Plant Science* 16: 1483409. <https://doi.org/10.3389/fpls.2025.1483409>
- Hussain S, Hussain S, Ali B, Ren X, Chen X, Li Q, Saqib M, Ahmad N (2021). Recent progress in understanding salinity tolerance in plants: Story of Na⁺/K⁺ balance and beyond. *Plant Physiology and Biochemistry* 160: 239–256. <https://doi.org/10.1016/j.plaphy.2021.01.029>
- Garcia-Daga S, Roy SJ, Gilliam M (2025). Redefining the role of sodium exclusion within salt tolerance. *Trends in Plant Science* 30(2): 137–146. <https://doi.org/10.1016/j.tplants.2024.10.002>
- Li M, Petrie MD, Lü X, Wang J, Sun X, Hu N, Chen H (2025). Salinization decreases soil phosphorus availability and plant productivity in terrestrial ecosystems. *Earth's Future* 13(9): e2024EF005738. <https://doi.org/10.1029/2024EF005738>
- Su R, Zhang Z, Chang C, Peng Q, Cheng X, Pang J, He H, Lambers H (2022). Interactive effects of phosphorus fertilization and salinity on plant growth, phosphorus and sodium status, and tartrate exudation by roots of two alfalfa cultivars. *Annals of Botany* 129(1): 53–64. <https://doi.org/10.1093/aob/mcab124>
- Dastogeer KMG, Zahan MI, Tahjib-Ul-Arif M, Akter MA, Okazaki S (2020). Plant salinity tolerance conferred by arbuscular mycorrhizal fungi and associated mechanisms: A meta-analysis. *Frontiers in Plant Science* 11: 588550. <https://doi.org/10.3389/fpls.2020.588550>
- Dar MH, Razvi SM, Singh N, Mushtaq A, Dar S, Hussain S (2023). Arbuscular mycorrhizal fungi for salinity stress: Anti-stress role and mechanisms. *Pedosphere* 33(1): 212–224. <https://doi.org/10.1016/j.pedsph.2022.06.027>
- Wang H, An T, Huang D, Liu R, Xu B, Zhang S, Deng X, Siddique KHM, Chen Y (2021). Arbuscular mycorrhizal symbioses alleviating salt stress in maize is associated with a decline in root-to-leaf gradient of Na⁺/K⁺ ratio. *BMC Plant Biology* 21(1): 457. <https://doi.org/10.1186/s12870-021-03237-6>
- Dabravolski SA, Isayenkov SV (2024). The physiological and molecular mechanisms of silicon action in salt stress amelioration. *Plants* 13(4): 525. <https://doi.org/10.3390/plants13040525>
- Etesami H, Jeong BR, Glick BR (2021). Contribution of arbuscular mycorrhizal fungi, phosphate-solubilizing bacteria, and silicon to P

- uptake by plant. *Frontiers in Plant Science* 12: 699618. <https://doi.org/10.3389/fpls.2021.699618>
21. Bushra F, Mallick D, Hossain MB, Pal SC, Dash PK, Islam NK, Mannan MA, Das D (2025). Silicon and potassium fertilization upgrade resilience in bell pepper against salt stress through boosting root growth and fruit yield. *Silicon* 17(2): 377–390. <https://doi.org/10.1007/s12633-024-03202-6>
 22. Langenfeld NJ, Bugbee B (2023). An improved digestion and analysis procedure for silicon in plant tissue. *PLOS ONE* 18(9): e0289151. <https://doi.org/10.1371/journal.pone.0289151>
 23. Muta K, Takata S, Utsumi Y, Matsumura A, Iwamura M, Kise K (2022). TAIM: Tool for analyzing root images to calculate the infection rate of arbuscular mycorrhizal fungi. *Frontiers in Plant Science* 13: 881382. <https://doi.org/10.3389/fpls.2022.881382>
 - Bakhhat HF, Bibi N, Hammad HM, Shah GM, Abbas S, Rafique HM, Mohamed AKSH, Maqbool MM (2023). Effect of silicon fertilization on eggplant growth and insect population dynamics. *Silicon* 15(8): 3515–3523. <https://doi.org/10.1007/s12633-022-02279-1>
 24. Komeil DA, Draz IS, Badry HH (2025). Silicon soil amendment and arbuscular mycorrhizae inoculation enhance eggplant defense against *Rhizoctonia solani* by promoting growth and mitigating root rot stress. *Current Microbiology* 82(10): 449. <https://doi.org/10.1007/s00284-025-04428-2>
 25. Di Miceli G, Vultaggio L, Sabatino L, De Pasquale C, La Bella S, Consentino BB (2023). Synergistic effect of a plant-derived protein hydrolysate and arbuscular mycorrhizal fungi on eggplant grown in open fields: A two-year study. *Horticulturae* 9(5): 592. <https://doi.org/10.3390/horticulturae9050592>
 26. Sharma M, Delta A, Brar N, Yadav A, Dhanda P, Baslam M, Kaushik P (2022). *Rhizophagus irregularis* and *Azotobacter chroococcum* uphold eggplant production and quality under low fertilization. *International Journal of Plant Biology* 13(4): 601–612. <https://doi.org/10.3390/ijpb13040048>
 27. Shaik A, Singh S (2022). Influence of arbuscular mycorrhizal fungi on physiology and yield of eggplant in organic soilless production system. *HortScience* 57(7): 759–768. <https://doi.org/10.21273/HORTSCI16612-22>
 28. Abbaspour H, Pour FSN, Abdel-Wahhab MA (2021). Arbuscular mycorrhizal symbiosis regulates the physiological responses, ion distribution and relevant gene expression to trigger salt stress tolerance in pistachio. *Physiology and Molecular Biology of Plants* 27(8): 1765–1778. <https://doi.org/10.1007/s12298-021-01043-w>
 29. Alizadeh Z, Heidari P, Asghari HR (2026). The impact of symbiosis between arbuscular mycorrhizal fungi and beans on potassium absorption and transporters in response to salt stress. *BMC Plant Biology* 26(1): 851. <https://doi.org/10.1186/s12870-026-08584-w>
 30. Abd El-Mageed TA, Mekdad AAA, Rady MOA, Abdelbaky AS, Saudy HS, Shaaban A (2022). Physio-biochemical and agronomic changes of two sugar beet cultivars grown in saline soil as influenced by potassium fertilizer. *Journal of Soil Science and Plant Nutrition* 22(3): 3636–3654. <https://doi.org/10.1007/s42729-022-00916-7>
 31. Rady MM, Mossa ATH, Youssef AMA, Osman AS, Ahmed SMA, Mohamed IAA (2023). Exploring the reinforcing effect of nano-potassium on the antioxidant defense system reflecting the increased yield and quality of salt-stressed squash plants. *Scientia Horticulturae* 308: 111609. <https://doi.org/10.1016/j.scienta.2022.111609>
 32. Wu Y, Chen C, Wang G (2024). Inoculation with arbuscular mycorrhizal fungi improves plant biomass and nitrogen and phosphorus nutrients: A meta-analysis. *BMC Plant Biology* 24(1): 960. <https://doi.org/10.1186/s12870-024-05638-9>
 33. Chialva M, Patono DL, Perez de Souza L, Noviero M, Vercellino S, Maghrebi M, Morgante M, Lovisolo C, Vigani G, Fernie A, Fiorilli V, Lanfranco L, Bonfante P (2023). The mycorrhizal root–shoot axis elicits *Coffea arabica* growth under low phosphate conditions. *New Phytologist* 239(1): 271–285. <https://doi.org/10.1111/nph.18946>
 34. Peng ZC, Xing YX, Ma YH, Li SH, Jia YX, Yang HC, Zhang FH (2025). Arbuscular mycorrhizal fungi enhance soybean phosphorus uptake and soil fertility under saline-alkaline stress. *Scientific Reports* 15(1): 31792. <https://doi.org/10.1038/s41598-025-15910-z>
 35. Othman YA, Tahat M, Alananbeh KM, Al-Ajlouni M (2022). Arbuscular mycorrhizal fungi inoculation improves flower yield and postharvest quality component of gerbera grown under different salinity levels. *Agriculture* 12(7): 978. <https://doi.org/10.3390/agriculture12070978>
 36. Yuan H, Si H, Ye Y, Ji Q, Wang H, Zhang Y (2024). Arbuscular mycorrhizal fungi-mediated modulation of physiological, biochemical, and secondary metabolite responses in hemp (*Cannabis sativa* L.) under salt and drought stress. *Journal of Fungi* 10(4): 283. <https://doi.org/10.3390/jof10040283>
 37. Lidoy J, López-García Á, Amate C, García JM, Flors V, García-Garrido JM, Azcón-Aguilar C, López-Ráez JA, Pozo MJ (2023). Regulation of mycorrhizal colonization under stress in tomato depends on symbiotic efficiency. *Environmental and Experimental Botany* 215: 105479. <https://doi.org/10.1016/j.envexpbot.2023.105479>
 38. Islam MS, Rahman MA, Sultana MS, Islam MM, Halder M, Das D (2026). Enhancement of physio-biochemical attributes and seed yield of sunflower through integrated application of silicon and mycorrhizal fungi under salt stress. *Silicon* 18(3–4): 1417–1429. <https://doi.org/10.1007/s12633-025-03591-2>

39. Sharifian A, Mirzakhani A, Khaghani S, Kakhaki SFF (2022). The combined use of silicon and arbuscular mycorrhizal fungus mitigate the adverse effects of drought stress on *Matthiola incana*. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 50(4): 12947. <https://doi.org/10.15835/nbha50312947>