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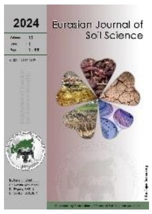




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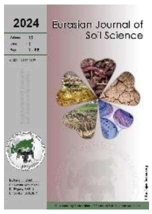


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# Tomato varieties superiority assessment under organic and inorganic (granular and foliar) fertilization in sandy clay soil

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## Abstract

Tomato is valued for its nutritional importance and contribution to countries' GDP. Despite the importance of tomatoes, tomato cultivation remains a challenge in some cities, particularly Kumba, Cameroon. This results from a vast knowledge gap for a suitable variety and agronomic management practices. Thus this work was set out to investigate the response of three tomato varieties under organic, foliar, and granular inorganic fertilization at the Kumba I subdivision. This work comprised two factors; variety having three levels (Cobra $F_1$, Rio Grande, and Kiara tomato varieties) and fertilization having four levels (control, NPK 20:10:10 granular fertilizer, Foliar NPK 20:10:10 inorganic fertilizer, and Poultry manure) given twelve treatment combinations replicated three times randomly in a factorial design. Data was collected on soil physicochemical properties, plant growth parameters and fruit yield. The results showed that the variety did not significantly affect soil physicochemical properties, but soil physicochemical properties were significantly affected by fertilization. Poultry manure had the best OC (5.22 %), $N_{tot}$ (1.73 g/kg), and $P_{avail}$ (14.63 mg/kg), while K was highest (2.93 meq/100g) in NPK 20:10:10 granular fertilization. Rio grande, in combination with poultry manure, had the best plant growth; plant height (77.3 cm), number of branches (17), number of leaves (197), and leaf area (47.1 $cm^2$). Cobra $F_1$, in combination with foliar NPK 20:10:10 granular and poultry manure, had the best fruit yield; 13.42 $tha^{-1}$ and 13.56 $tha^{-1}$, respectively while Kiara variety at the control treatment had the lowest yield (8.36 $tha^{-1}$). Thus Cobra $F_1$ variety in combination with poultry manure yielded the best result from this study and offers the best option for tomato cultivation in the sandy clay soils of Kumba, Cameroon.

**Keywords:** Soil fertility, varieties, synthetic fertilizer, yield.



## Introduction

The mainstay of Cameroon's economy is agriculture, which harbors 44 % of the country's GDP serving the role of employment and food production (BCA, 2019). Tomato is a fruit vegetable grown in Cameroon. Tomato has massive economic value through its huge exportation and local consumption rate, significantly improving farmers' standard of living and adding to Cameroon's agricultural GDP (FAOSTAT, 2018). It is endowed with numerous nutritional benefits solely or in combination with other foodstuffs that have drifted so much production and consumption attention towards itself (Ingenbleek et al., 2017). With an increasing production of above 130 million tons annually, tomato is the largest vegetable category worldwide due to it nutritional and economic benefits (Ravindran et al., 2019). China, the EU, India, the US, and Turkey are the top 5 tomato-producers, accounting for about 70% of global production (ED, 2016). With an anticipated 889,800 tons of

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production and a 9.4% yearly growth rate, Cameroon is ranked as Africa's fifth-largest tomato producer (Tolly and Kamtchouing, 2016).

Tomato is grown in Cameroon's third, fourth, and fifth agro-ecological zones (Kirui and Abiodun, 2017) due to their favorable climatic and edaphic factors (Norbert et al., 2017). Nonetheless, tomato production in some cities like Kumba in the meme division of the fourth agro-ecological zone is challenging (Kimengsi and Tosam, 2013). This is because Kumba is characterized by unfavourable climatic conditions, high ambient temperatures, drought, soil fertility challenges, and a high incidence of diseases and pests (Kimengsi and Tosam, 2013; Okolle et al., 2014). Also, inadequate knowledge of tomato production reduces farmers' yield in Kumba, which could be attributed to wrong variety, fertilization, and management choices (Okolle, 2019; Nkongho et al. 2022). Therefore, farmers tend to abandon tomato cultivation and go for the production of other crops while buying tomatoes from other cities like Limbe, Buea, Bamenda, Tiko, Foumbot, and Dschang, which also suffer quality losses over time (Mengui et al., 2019). Thus this warrants the development of an adaptive tomato variety, fertilization, and management regime for tomato production to alleviate the population of Kumba from the tomato inland transportation challenges while enhancing their tomato production knowledge (Naz et al., 2018; Ngosong et al., 2018; Agbor et al., 2022a). Therefore, this work seeks to evaluate the growth and yield performance of three tomato varieties under different fertilizer regimes in the sandy clay soils of Kumba I Municipality in the Southwest Region of Cameroon.

## Material and Methods

### Research area description

This research was done in the Kumba I subdivision, Meme division of the Southwest Region, in Cameroon, with geographical coordinates: 4°38′N 9°27′E, 240 m above sea levels. Kumba lies in the Humid Forest Agro-ecological zone IV with a mono-modal rainfall regime (IRAD, 2013). The equatorial climate of Kumba has two seasons: the dry season, which lasts from November to March, and the rainy season, which lasts from April to October. The average annual rainfall in Kumba is between 3000 and 4000 mm. The mean annual relative humidity and temperature are between 70 % to 84 % and 24° C to 35° C, respectively, characterized by hot days with high intensity of sunlight. Kumba has sandy clay soil, brownish-yellow coloration, with high organic matter content (Giresse et al., 1994).

### Tomato nursery establishment

Three ridges of 2.2 m by 1.2 m each were raised to 20 cm height with a hoe, and 15 kg of poultry manure was mixed on the ridges 5 kg per ridge, two weeks before seeding. The ridges were watered and disinfection was done using 80 g/15L Mancozep (Fungicide) and 30 ml/15 parastal (insecticide), all mixed in a 15L knapsack and sprayed on the bed to get rid of insect pests and diseases. Ten grams of each variety (Cobra $F_1$, Rio grande and Kiara) was bought from an agro-shop in Kumba, Cameroon, these varieties were selected for this research based on the fact that they are commonly grown in the Sahelian and Tropical areas as seen in Mahbou et al. (2022) and Ngosong et al. (2018). Each variety was seeded on the respective ridge by broadcasting method, followed by watering of the ridges. Plantain leaves were used to cover the ridges to create a microclimate for rapid germination of tomato varieties and were removed three days after germination.

### Experimental design and treatments

The experimental field of 208 $m^2$ was cleared with a cutlass and raked. The design was a 3 by 4 factorial design. Factor one was variety with three levels; Cobra $F_1$, Rio Grande, and Kiara tomato varieties. While factor two had fertilizer types of four levels; control, NPK 20:10:10 granules at rate of 300 $kgha^{-1}$ (Ilupeju et al., 2015), Foliar NPK 20:10:10 fertilizer 50 g per 15 L knapsack , and Poultry manure applied at the rate of 10 $tha^{-1}$ (Ilodibia and Chukwuma, 2015).. This gave a total of 12 variety and fertilization combination treatments. The treatments were replicated three times giving 36 plots. Thirty six ridges of 4.30 m by 1.7 m each were raised 25 cm above the ground with the aid of a hoe. Treatments within a replicate were separated with a 0.5 m distance, while replicates were separated with a 1 m distance. Planting spots were dug and pegged at distances of 75 cm by 50 cm (Mahbou et al., 2022) giving 6 intra-row and 3 inter-rows, equaling 18 stands per plot.

Table 1. Treatments

| Cultivar / Fertilizer levels | Tomato Cultivars | | |
|---|---|---|---|
| | Cobra $F_1$ (CF1) | Rio Grande (RG) | Kiara (K) |
| Control (C) | CCF1 | CRG | CK |
| NPK 20:10:10 granules (NPK) | NPKCF1 | NPKRG | NPKK |
| Foliar fertilizer (FF) | FFCF1 | FFRG | FFK |
| Poultry manure (PM) | PMCF1 | PMRG | PMK |

| | | | | |
|---|---|---|---|---|
| | CCF1 | NPKCF1 | FFCF1 | PMCF1 |
| Replicate 1 | CRG | NPKRG | FFRG | PMRG |
| | CK | NPKK | FFK | PMK |
| | NPKCF1 | FFCF1 | PMCF1 | CCF1 |
| Replicate 2 | NPKRG | FFRG | PMRG | CRG |
| | NPKK | FFK | PMK | CK |
| | FFCF1 | PMCF1 | CCF1 | NPKCF1 |
| Replicate 3 | FFRG | PMRG | CRG | NPKRG |
| | FFK | PMK | CK | NPKK |

Figure 1. Factorial design experimental layout

**Seedling transplant:** Seedlings of the three varieties were transplanted to their respective experimental plots at a planting distance of 75 cm by 50 cm at a 3 cm depth following the spots (Table 1, Figure 1). Per stand, two seedlings were initially transplanted before being culled to one (Ngosong et al., 2018), one week after transplanting. Prior to and after the transplanting, the plots were irrigated using watering can.

**Field management**

**Weed management and irrigation:** Weeding was done by hand, and the use of hoe weekly based on the need. Watering was done twice a day, in the morning and evening, during periods of no rain.

**Management of diseases and pests:** 80 g/15L Mancozep and 30 mL/15L parastar, all mixed in a 15L knapsack and sprayed on the bed to get rid of insect pests and diseases weekly.

**Staking of tomato plants:** Staking was done in the fourth week after transplanting by drilling 60 cm sticks, 10 cm into the soil about 10 cm away from the root zone of the plant. Staking was done to support tomato plants to grow upright, preventing branches from lying on the soil, improving fruit quality and quantity, and preventing soil-borne diseases.

**Data collection:** Five randomly selected plants were tagged for data collection per plot.

**Growth parameters:** Vegetative data was collected from 3 weeks after transplanting and continued at 2 week intervals. Plant height was measured using a meter rule, the number of leaves, the number of flowers and the number of branches were counted and the area of the leaf was measured according to Blanco and Folegatti (2003), all recorded as aspects of plant growth.

**Yield data:** The yield of tomato plants was collected based on the weight of fruits in tons per hectare.

**Soil and organic manure analysis :** At the experimental site, augers were used to randomly collect pre- and post-soil samples from a depth of 0 to 15 cm. For the pre-soil analysis, four samples were taken and bulked into a single sample. A 2 mm sieve was used to filter the soil sample after it had been air dried. For the post-soil analysis, soils were collected per replicate per treatment from the field and air-dried. Soil samples were sent for analysis at the Soil Science Laboratory of the University of Dschang. The soil texture was sandy clay.

Utilizing the pipette method and sodium hexametaphosphate as the dispersing agent, the soil's particle size was assessed (Kalra and Maynard, 1991). After 24 hours of suspension (solid/liquid = 1/2.5 w/v), the soil pH was measured using the potentiometric method in both water ($H_2O$) and 1M potassium chloride (KCl) solutions. Using a neutral ammonium acetate solution, exchangeable bases were extracted. Atomic absorption spectrophotometry was used to determine the amounts of calcium (Ca) and magnesium (Mg), whereas flame photometry was used to determine potassium (K) and sodium (Na) (Jones, 2001). By using the KCL extraction procedure, exchangeable acidity was produced (Jones, 2001). The macrokjeldahl digestion process yields the total nitrogen (N) (Bremner and Mulvaney, 1982), and the Bray II method is used to determine the availability of phosphorus (P) (Jones, 2001). The Walkey-Black method is used to determine the soil's organic carbon content (Walkey and Black, 1934).

### Statistical analysis

With P ≤.05, two-way analysis of variance was performed using SPSS version 25 on the physical and chemical characteristics of post-soil, growth, and yield parameters to test the aftermath of treatments as categorical predictors. Duncan Multiple Range Test (DMRT) was used to distinguish means that were significantly different at P ≤ 0.05.

## Results

### Soil chemical properties as affected by sole and interaction of factors

The soil chemical properties were not significantly affected by the variety factor, whereas the fertilization types significantly affected the soil's physicochemical properties.

Poultry manure raised the soil pH ($H_2O$) to 5.50 while NPK 20:10:10 reduced it to 4.97 without significant differences same with soil pH (KCl). Poultry manure had a higher OC content (5.22 %) and the best C/N ratio (49), while $N_{tot}$ content was highest in NPK 20:10:10 (1.73 g/kg). There were fluctuations among fertilizer types for exchangeable cations, with poultry manure producing arguably the best results while NPK 20:10:10 had the highest CEC (18.05 %). $P_{avail}$ was highest in poultry manure fertilization type.

Apart from soil pH, the soil's chemical properties were significantly affected by interaction of factors. While treatment combinations with poultry manure had the best OC content (Cobra $F_1$ and poultry manure 5.24 %, Rio grande and poultry manure 5.14% and Kiara $F_1$ and poultry manure 5.27%) and C/N ratio, treatment combinations with NPK 20:10:10 had the highest $N_{tot}$. Treatment combinations with poultry manure were the best in exchangeable cations as treatment combinations with NPK 20:10:10 dominate CEC. $P_{avail}$ was highest in poultry manure treatment combination.

Table 2. Soil chemical properties as affected by sole variety and fertilization in sandy clay soil

| Soil properties | Pre-soil analysis | Post soil analysis | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Variety | | | | Fertilization types | | | | |
| | | Cobra $F_1$ | Rio grande | Kiara | *P*=.05 | Control | NPK 20:10:10 | Foliar NPK 20:10:10 | Poultry Manure | *P*=.05 |
| pH ($H_2O$) | 5.10 | 5.28$^{a}$ | 5.27$^{a}$ | 5.28$^{a}$ | 0.999 | 5.12$^{b}$ | 4.97$^{a}$ | 5.02$^{a}$ | 5.50$^{a}$ | 0.100 |
| pH (KCl) | 4.70 | 4.56$^{a}$ | 4.56$^{a}$ | 4.56$^{a}$ | 1.000 | 4.70$^{a}$ | 4.41$^{a}$ | 4.72$^{a}$ | 4.77$^{a}$ | 0.137 |
| OC, % | 4.60 | 4.73$^{a}$ | 4.65$^{a}$ | 4.76$^{a}$ | 0.493 | 4.50$^{a}$ | 4.54$^{a}$ | 4.60$^{a}$ | 5.22$^{a}$ | 0.000 |
| $N_{tot}$, g/kg | 0.82 | 1.11$^{a}$ | 1.08$^{a}$ | 1.11$^{a}$ | 0.283 | 0.74$^{d}$ | 1.73$^{a}$ | 0.90$^{c}$ | 1.02$^{b}$ | 0.000 |
| C/N | 56.00 | 53.00$^{ab}$ | 53.00$^{a}$ | 52.00$^{b}$ | 0.021 | 57.00$^{a}$ | 53.00$^{b}$ | 51.00$^{c}$ | 49.00$^{a}$ | 0.000 |
| $P_{avail}$, mg/kg | 9.21 | 11.97$^{a}$ | 11.63$^{b}$ | 12.17$^{a}$ | 0.001 | 8.95$^{d}$ | 11.48$^{c}$ | 12.62$^{b}$ | 14.63$^{a}$ | 0.000 |
| Exchangeable cations, meq/100g | | | | | | | | | | |
| Ca | 1.44 | 1.46$^{a}$ | 1.45$^{a}$ | 1.49$^{a}$ | 0.087 | 1.35$^{a}$ | 1.47$^{b}$ | 1.50$^{ab}$ | 1.53$^{a}$ | 0.000 |
| Mg | 1.08 | 1.10$^{b}$ | 1.09$^{b}$ | 1.13$^{a}$ | 0.003 | 1.04$^{c}$ | 1.11$^{b}$ | 1.14$^{a}$ | 1.13$^{ab}$ | 0.000 |
| K | 2.61 | 2.69$^{ab}$ | 2.66$^{b}$ | 2.71$^{a}$ | 0.013 | 2.55$^{a}$ | 2.93$^{a}$ | 2.64$^{b}$ | 2.62$^{b}$ | 0.000 |
| CEC | 16.02 | 16.76$^{a}$ | 16.68$^{a}$ | 16.80$^{a}$ | 0.564 | 15.65$^{d}$ | 18.05$^{a}$ | 17.20$^{b}$ | 16.09$^{c}$ | 0.000 |

OC : Organic Carbon; $N_{tot}$ : Total Nitrogen; $P_{avail}$: Available Phosphorus; CEC: Cation exchange capacity

Table 3. Soil chemical properties as affected by interaction of variety and fertilization in sandy clay soil

| | pH ($H_2O$) | pH (KCl) | OC | $N_{tot}$ | C/N | Ca | Mg | K | CEC | $P_{avail}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Cobra $F_1$ Control | 5.13$^{a}$ | 4.41$^{a}$ | 4.54$^{b}$ | 0.78$^{e}$ | 57$^{a}$ | 1.35$^{d}$ | 1.04$^{e}$ | 2.55$^{de}$ | 15.66$^{de}$ | 8.96$^{f}$ |
| Cobra $F_1$ NPK 20:10:10 | 4.96$^{a}$ | 4.70$^{a}$ | 4.53$^{b}$ | 1.73$^{a}$ | 53$^{bcd}$ | 1.47$^{ab}$ | 1.11$^{bcd}$ | 2.93$^{a}$ | 18.06$^{a}$ | 11.50$^{e}$ |
| Cobra $F_1$ Foliar NPK 20:10:10 | 5.01$^{a}$ | 4.72$^{a}$ | 4.60$^{b}$ | 0.90$^{d}$ | 51$^{def}$ | 1.50$^{ab}$ | 1.14$^{abc}$ | 2.64$^{bc}$ | 17.22$^{b}$ | 12.70$^{cd}$ |
| Cobra $F_1$ Poultry Manure | 5.50$^{a}$ | 4.77$^{a}$ | 5.24$^{a}$ | 1.02$^{bc}$ | 49$^{fg}$ | 1.53$^{ab}$ | 1.13$^{abc}$ | 2.62$^{bc}$ | 16.10$^{cd}$ | 14.70$^{ab}$ |
| Rio grande control | 5.10$^{a}$ | 4.41$^{a}$ | 4.50$^{b}$ | 0.73$^{e}$ | 58$^{a}$ | 1.32$^{d}$ | 1.02$^{e}$ | 2.52$^{e}$ | 15.58$^{e}$ | 8.77$^{f}$ |
| Rio grande NPK 20:10:10 | 4.97$^{a}$ | 4.70$^{a}$ | 4.50$^{b}$ | 1.70$^{a}$ | 54$^{bc}$ | 1.46$^{bc}$ | 1.09$^{cd}$ | 2.90$^{a}$ | 17.99$^{a}$ | 11.20$^{e}$ |
| Rio grande Foliar NPK 20:10:10 | 5.02$^{a}$ | 4.72$^{a}$ | 4.47$^{b}$ | 0.87$^{d}$ | 52$^{cde}$ | 1.49$^{ab}$ | 1.12$^{abc}$ | 2.62$^{bc}$ | 17.11$^{b}$ | 12.27$^{d}$ |
| Rio grande Poultry Manure | 5.50$^{a}$ | 4.77$^{a}$ | 5.14$^{a}$ | 1.00$^{bc}$ | 50$^{efg}$ | 1.51$^{ab}$ | 1.11$^{abc}$ | 2.60$^{bcd}$ | 16.03$^{cd}$ | 14.27$^{b}$ |
| Kiara Control | 5.13$^{a}$ | 4.41$^{a}$ | 4.47$^{b}$ | 0.71$^{e}$ | 56$^{ab}$ | 1.39$^{cd}$ | 1.06$^{de}$ | 2.58$^{cd}$ | 15.72$^{cd}$ | 9.11$^{f}$ |
| Kiara NPK 20:10:10 | 4.97$^{a}$ | 4.70$^{a}$ | 4.57$^{b}$ | 1.75$^{a}$ | 52$^{cde}$ | 1.49$^{ab}$ | 1.13$^{abc}$ | 2.96$^{a}$ | 18.10$^{a}$ | 11.73$^{e}$ |
| Kiara Foliar NPK 20:10:10 | 5.02$^{a}$ | 4.72$^{a}$ | 4.73$^{b}$ | 0.94$^{cd}$ | 50$^{efg}$ | 1.52$^{ab}$ | 1.16$^{a}$ | 2.66$^{b}$ | 17.26$^{b}$ | 12.90$^{c}$ |
| Kiara Poultry Manure | 5.50$^{a}$ | 4.77a | 5.27$^{a}$ | 1.04$^{b}$ | 48$^{g}$ | 1.55$^{a}$ | 1.15$^{ab}$ | 2.63$^{bc}$ | 16.14$^{c}$ | 14.93$^{a}$ |
| | 0.100 | 0.847 | 0.000 | 0.000 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

### Effect of variety and fertilization on tomato growth performance

### Effect of variety and fertilization and their interaction on tomato growth

Variety significantly affected the growth of tomatoes (Table 4). Rio grande had the highest vegetative performance of all the varieties cultivated in the sandy clay soils of Kumba. Plant height was highest in Rio grande (71.2 cm), so was the number of leaves (180), leaf area (37.8 cm$^2$), number of branches (15), and the number of flowers (109), all significantly different from Cobra $F_1$ and Kiara varieties.

Table 4. Effect of variety and fertilization on tomato vegetative parameters

| | Plant height (cm) | Number of leaves | Leaf area (cm$^2$) | Number of branches | Number of flowers |
|---|---|---|---|---|---|
| Variety | | | | | |
| Cobra F1 | 67.5$^b$ | 170$^b$ | 34.5$^b$ | 14$^b$ | 95$^b$ |
| Rio grande | 71.2$^a$ | 180$^a$ | 37.8$^a$ | 15$^a$ | 109$^a$ |
| Kiara | 63.8$^c$ | 161$^c$ | 30.4$^c$ | 12$^c$ | 92$^b$ |
| Significance level | 0.01 | 0.000 | 0.000 | 0.000 | 0.000 |
| Fertilization | | | | | |
| Control | 58.9$^c$ | 142$^d$ | 24.2$^d$ | 9$^c$ | 71$^b$ |
| NPK 20:10:10 | 66.8$^b$ | 171$^c$ | 31.0$^c$ | 14$^b$ | 109$^a$ |
| Foliar NPK 20:10:10 | 70.5$^{ab}$ | 180$^b$ | 37.3$^b$ | 15$^{ab}$ | 105$^a$ |
| Poultry manure | 73.9$^a$ | 198$^a$ | 44.3$^a$ | 16$^a$ | 110$^a$ |
| Significance level | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Applied fertilization significantly affected Tomato growth parameters (Table 4). Poultry manure had the highest plant height (73.9 cm), number of leaves (198), leaf area (44.3 cm$^2$), number of branches (16), and number of flowers (110), which was significantly different from the other treatments.

Factors interaction showed significantly different effects on tomato growth parameters across treatment combinations (Table 5). Rio grande poultry manure treatment had the highest plant height (77.3 cm), with the lowest in Kiara control treatment (55.7 cm). Most leaves (197) were counted in Rio grande poultry manure treatment, with the fewest leaves seen in the Kiara control treatment (131). Rio grande poultry manure treatment produced the largest leaf area (47.1 cm$^2$), while the Kiara control treatment produced the smallest leaf area. A similar trend was observed for the number of branches and flowers recorded.

Table 5. Interaction effect of variety and fertilization on tomato vegetative parameters

| Treatment | Plant height (cm) | Number of leaves | Leaf area (cm$^2$) | Number of branches | Number of flowers |
|---|---|---|---|---|---|
| Cobra $F_1$ Control | 59.0$^{de}$ | 140$^f$ | 24.6$^{fg}$ | 9$^f$ | 68$^f$ |
| Cobra $F_1$ NPK 20:10:10 | 66.1$^{cd}$ | 171$^{cd}$ | 30.3$^{de}$ | 15$^{bcd}$ | 108$^{bcd}$ |
| Cobra $F_1$ Foliar NPK 20:10:10 | 70.7$^{abc}$ | 180$^{bc}$ | 37.5$^{bc}$ | 15$^{bcd}$ | 100$^d$ |
| Cobra $F_1$ Poultry Manure | 74.3$^{ab}$ | 190$^{ab}$ | 45.9$^a$ | 16$^{abc}$ | 104$^{cd}$ |
| Rio grande Control | 62.1$^{de}$ | 155$^e$ | 27.3$^{ef}$ | 11$^e$ | 80$^e$ |
| Rio grande NPK 20:10:10 | 71.0$^{abc}$ | 179$^{bc}$ | 36.6$^{bc}$ | 16$^{abc}$ | 114$^{abc}$ |
| Rio grande Foliar NPK 20:10:10 | 74.3$^{ab}$ | 190$^{ab}$ | 40.2$^b$ | 17$^{ab}$ | 119$^{ab}$ |
| Rio grande Poultry Manure | 77.3$^a$ | 197$^a$ | 47.1$^a$ | 18$^a$ | 123$^a$ |
| Kiara Control | 55.7$^e$ | 131$^f$ | 20.7$^g$ | 7$^f$ | 64$^f$ |
| Kiara NPK 20:10:10 | 63.3$^{cde}$ | 163$^{de}$ | 26.2$^{ef}$ | 11$^e$ | 105$^{cd}$ |
| Kiara Foliar NPK 20:10:10 | 66.4$^{bcd}$ | 170$^{cd}$ | 34.2$^{cd}$ | 13$^{de}$ | 97$^d$ |
| Kiara Poultry Manure | 70.1$^{abc}$ | 180$^{bc}$ | 40.3$^b$ | 14$^{cd}$ | 102$^d$ |
| Significance level | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

### Effect of variety and fertilization on tomato fruit yield

Tomato fruit varied significantly ($P$ = 0.01) across the varieties. The Cobra $F_1$ variety had the highest fruit yield with 12.34 tha$^{-1}$, followed by Rio Grande with 11.82 tha$^{-1}$ and Kiara with 11.18 tha$^{-1}$ (Figure 2)

Fertilization treatments showed significant differences ($P$ = 0.001) in tomato fruit yield. The Poultry manure treatment produced the highest fruit yield with 13.13 tha$^{-1}$, followed by the foliar NPK 20:10:10 treatment with 12.85 tha$^{-1}$, and NPK 20:10:10 treatment with 12.29 tha$^{-1}$. The Control treatment had the lowest fruit yield with 8.72 tha$^{-1}$ (Figure 3)

Tomato fruit yield experienced a significant ($P$ =0.01) effect of the interaction between variety and fertilization (Figure 4). Cobra $F_1$ poultry manure treatment yielded the highest (13.56 tha$^{-1}$), followed by Cobra $F_1$ foliar NPK 20:10:10 treatment (13.42 tha$^{-1}$) with the least yield from the Kiara Control treatment (8.36 tha$^{-1}$).

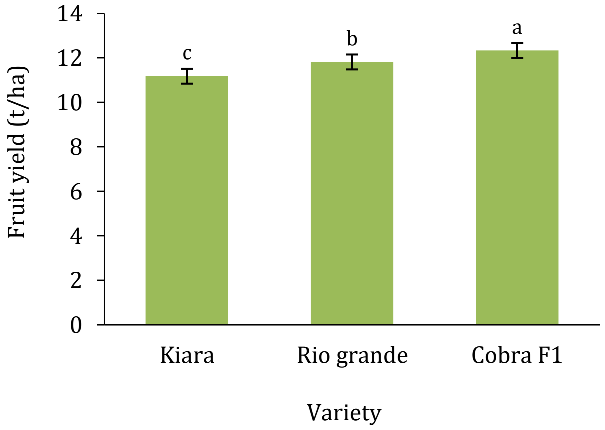


Figure 2. Effect of variety on fruit yield

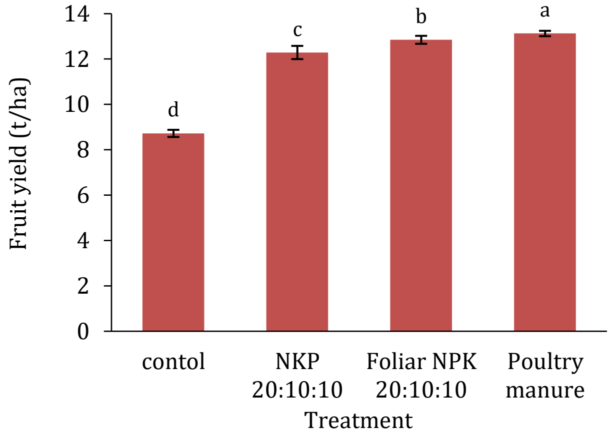


Figure 3. Effect of fertilization on fruit yield

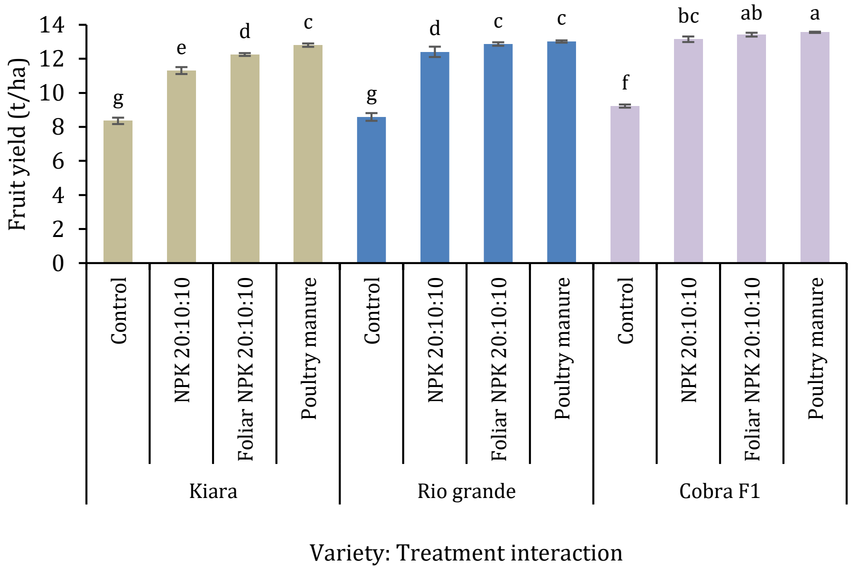


Figure 4. Interaction effect of variety and fertilization on number of tomato fruits

# Discussion

### Response of tomato varieties and fertilization on soil chemical properties

Generally, there was little effect on soil chemical properties by tomato varieties, as shown by the results. This is because the performance of varieties is a function of phenotypic and environmental factors combined with agronomic practices. Thus under the experimental setting, the agronomic and phenotypic factors enhance variety growth while the environmental factor was favored by better management (Healy et al., 2017; Ketema and Beyene, 2021). On the other hand, fertilization significantly affects the soil's chemical properties, with poultry manure showcasing prowess in enhancing soil chemical properties (Hasnain et al., 2020; Alaboz et al., 2022). The poultry manure buffered the soil pH positively, which makes more nutrients available, whereas NPK 20:10:10 further dampens the acidic pH under which nutrients like phosphorus are fixed to the metallic ions and become less available (Brunetti et al., 2019).

Interaction of varieties and fertilizer types showed that poultry manure in combination with variety achieved better results, which falls in line with other studies (Hassnain et al., 2020). This is not only emanating from the rich nature of the poultry manure as the best livestock manure but also because it supplies more energy, carbon source, and suitable pH to the soil, which enables beneficial microorganisms to thrive, leading to the solubilization and fixation of nutrients (Lin et al., 2019). Granular NPK 20:10:10 unveiled the second best result after poultry manure. This is because synthetic fertilizer makes the nutrients available momentarily and may lead to leaching. Also, it negatively affects pH, as disclosed by this study which translates to less nutrient availability due to fixation to metallic ions. Foliar NPK 20:10:10 leads to more nutrient-used efficiency as demonstrated by other studies which is reflected in this research results (Schütz et al., 2018). Control in combination with variety, least affected soil chemical properties, the values obtained were less than those of pre-soil as the was an output of nutrients by varieties without any input (Farjana et al., 2019).

**Performance of tomato in response to variety, fertilization, and their interaction**

The growth parameters were positively affected by the variety and fertilizer factors. Rio grande tomato variety had the best growth, showing that vegetatively, it is more adapted to the Kumba area of Cameroon. Perhaps, due to its ability to better use the nutrient in the sandy clay soils, its genetic makeup may also align with the area's environmental component, leading to more growth performance (Shushay et al., 2013). Cobra $F_1$ variety is known for its outstanding growth performance in the volcanic soils of Buea; thus, being second best in Kumba is not surprising as the two areas are neighbors with some similarities (Ngosong et al., 2018). Kiara variety was the least adaptive and thus is not a good variety to adopt for this area as revealed by this study (Saleem et al., 2013; Healy et al., 2017). Like the varieties, fertilization enhanced tomato performance by supplying adequate nutrients. Control had the least performance as no input means less growth. Poultry manure resulted in the best growth result, followed by foliar NPK 20:10:10, due to the high nutrient content in poultry manure and efficiency of nutrients utilization in foliar NPK 20:10:10 (Mesallam et al., 2017; Fan et al., 2023). Granular NPK 20:10:10 came third, which may have been affected by nutrient volatilization due to high solarisation, leaching due to high rainfall, and other factors (Bilalis et al. ,2018; Naz et al., 2018).

Cobra $F_1$ variety had the best fruit yield compared to the other varieties as a variety and in interaction with fertilization. This is due to low flower abortion compared to the other varieties. Also, different tomato varieties possess genetic variations that influence their fruiting characteristics, such as fruit size and yield potential (Lippman et al., 2007). Thus Cobra $F_1$ variety possessed genetic traits that were more adapted to the environment than the other varieties, this result is supported by Ngosong et al. (2018) who stated Cobra $F_1$ variety as adapted variety in Sahelian and Tropical areas. Poultry manure yielded the best fruit yield compared to the other fertilizations as fertilization and in interaction with the varieties as reveal by this study, which is in line with Shehata (2018). This is due to the nutrient slow release nature of poultry manure, ensuring sufficient nutrients for plant uptake at all stages of growth, unlike synthetic fertilizers, which are fast in nutrient releasing, and the plants can be lacking in nutrients at some stages (Naz et al., 2018; Chatzistathis et al., 2020). Despite the high flower production of the Rio grande variety, less fruit yield was recorded due to the high rate of flower abortion, maybe due to little pollination and shrinking of immature fruits (Agbor et al., 2022b). Kiara had the least fruit yield, which is in line with less growth performance (Healy et al., 2017).

## Conclusion

The result of this study shows that Cobra $F_1$ is the most performing variety given the best yield shown. All the fertilization except control successfully increased the yield of tomato varieties, but poultry manures produced the most desired outcome, considering that it is eco-friendly. Although the inorganic fertilizers increase fruit yield, their adverse effect on the soil, like decreasing soil pH, makes them not sustainable options for crop production, especially for the sandy clay acidic soils of Kumba. Thus for optimal and eco-friendly tomato production in Kumba, the farmers should adopt organic fertilization in combination with the Cobra $F_1$ variety. Rio grande variety has good vegetative growth but experiences a lot of flower abortion, and fruits shrink before maturity, while the Kiara variety is not well adapted to the environment.

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## References

Agbor, D.T., Oben, T.T., Afoh, T.L., Eboh, S.K., Kum, F.Y., Fon, T.C., Dohnji, D.J., 2022a. Comparative study of botanicals and synthetic insecticide on the control of insect pests and diseases of cowpea. *International Journal of Agriculture and Environmental Research* 8(2): 368-387.

Agbor, D.T., Acha, D.A., Eboh, K.S, Morara, C.N., Dohnji, J.D., Teche, L.M., Nkongho, R.N., 2022b. Impact of natural and hand-assisted pollination on cucumber fruit and seed yield. *International Journal of Sustainable Agricultural Research* 9(2): 76-86.

Alaboz, P., Dengiz, O., Pacci, S., Demir, S., Türkay, C., 2022. Determination of the effect of different organic fertilizers applications on soil quality using the SMAF model. *Yuzuncu Yıl University Journal of Agricultural Sciences* 32(1): 21-32.

BCA, 2019. Business in Cameroon Agriculture: Mainstay of Cameroon's Economy. Available at [Access date: 20.01.2019]: https://www.businessincameroon.com/agriculture/0111-3675-agriculture-mainstay-of-cameroon-s-economy

Bilalis, D., Krokida, M., Roussis, I., Papastylianou, P., Travlos, I., Cheimona, N., Dede, A., 2018. Effects of organic and inorganic fertilization on yield and quality of processing tomato (Lycopersicon esculentum Mill.). *Folia Horticulturae* 30(2): 321-332.

Blanco, F.F., Folegatti, M.V., 2003. A new method for estimating the leaf area index of cucumber and tomato plants. *Horticultura Brasileira* 21(4): 666-669.

Bremner, J.M., Mulvaney, C.S., 1982. Nitrogen-total. In: Methods of Soil Analysis, 2nd edition. Page, A.L., Miller, R.H., Keeney, D.R. (Eds.). American Society of Agronomy Inc., Madison, Wisconsin, USA. pp. 595-624.

Brunetti, G., Traversa, A., De Mastro, F., Cocozza, C., 2019. Short term effects of synergistic inorganic and organic fertilization on soil properties and yield and quality of plum tomato. *Scientia Horticulturae* 252: 342-347.

Chatzistathis, T., Papadakis, I.E., Papaioannou, A., Chatzissavvidis, C., Giannakoula, A., 2020. Comparative study effects between manure application and a controlled-release fertilizer on the growth, nutrient uptake, photosystem II activity and photosynthetic rate of Olea europaea L.(cv.'Koroneiki'). *Scientia Horticulturae* 264: 109176.

ED, 2016. Around the world: Tomatoes. Eurofresh Distribution. Available at [Access date: 26.06.2017]: https://www.eurofresh-distribution.com/news/around-the-world-tomatoes

Fan, H., Zhang, Y., Li, J., Jiang, J., Waheed, A., Wang, S., Rasheed, S.M., Zhang, L., Zhang, R., 2023. Effects of organic fertilizer supply on soil properties, tomato yield, and fruit quality: A global meta-analysis. *Sustainability* 15(3): 2556.

FAOSTAT, 2018. Statistics Division of the Food and Agriculture Organization of the United Nations. Available at [Access date: 26.06.2017]: https://www.fao.org/faostat/en/#home

Farjana, S., Islam, M.A. and Haque, T., 2019. Effects of organic and inorganic fertilizers, and mulching on growth and yield of cabbage (Brassica oleracea var. capitata L.). *Journal of Horticulture and Postharvest Research* 2(2): 95-104.

Giresse, P., Maley, J., Brenac, P., 1994. Late Quaternary palaeoenvironments in the Lake Barombi Mbo (West Cameroon) deduced from pollen and carbon isotopes of organic matter. *Palaeogeography, Palaeoclimatology, Palaeoecology* 107(1-2): 65-78.

Hasnain, M., Chen, J., Ahmed, N., Memon, S., Wang, L., Wang, Y., Wang, P., 2020. The effects of fertilizer type and application time on soil properties, plant traits, yield and quality of tomato. *Sustainability* 12(21): 9065.

Healy, G.K., Emerson, B.J., Dawson, J.C., 2017. Tomato variety trials for productivity and quality in organic hoop house versus open field management. *Renewable Agriculture and Food Systems* 32(6): 562-572.

Ilodibia, C.V., Chukwuma, M.U., 2015. Effects of application of different rates of poultry manure on the growth and yield of tomato (Lycopersicum esculentum Mill.). *Journal of Agronomy 14*(4): 251-253.

Ilupeju, E.A.O., Akanbi, W.B., Olaniyi, J.O., Lawal, B.A., Ojo, M.A., Akintokun, P.O., 2015. Impact of organic and inorganic fertilizers on growth, fruit yield, nutritional and lycopene contents of three varieties of tomato (Lycopersicon esculentum (L.) Mill) in Ogbomoso, Nigeria. *African Journal of Biotechnology 14*(31): 2424-2433.

Ingenbleek, L., Jazet, E., Dzossa, A.D., Adebayo, S.B., Ogungbangbe, J., Dansou, S., Diallo, Z.J., Kouebou, C., Adegboye, A., Hossou, E., Coulibaly, S., Eyangoh, S., Bizec, B.L., Verger, P., Kamanzi, J., Merten, C., Leblanc, J.C., 2017. Methodology design of the regional sub-saharan Africa total diet study in Benin, Cameroon, Mali and Nigeria. *Food and Chemical Toxicology* 109: 155-169.

IRAD, 2013. Institute of Research for Agricultural Development. Meteological data of Meme Division, Kumba.

Jones, J.B., 2001. Laboratory guide for conducting soil tests and plant analyses. CRC Press, New York, USA. 363p.

Kalra, Y.P., Maynard, D.G., 1991. Methods Manual for Forest Soil And Plant Analysis. Information Report Nor-X-319. Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta. 116p. Available at [Access date: 06.02.2023]: https://d1ied5g1xfgpx8.cloudfront.net/pdfs/11845.pdf

Ketema, W., Beyene, D., 2021. Adaptability study and evaluation of improved varieties of tomato (Lycopersicon esculentum L.) under irrigation for their yield and yield components in east Wollega, western Ethiopia. *International Journal of Advanced Research in Biological Sciences* 8(7): 118-125.

Kimengsi, J.N., Tosam, J.N., 2013. Climate variability and cocoa production in Meme Division of Cameroon: Agricultural development policy options. *Greener Journal of Agricultural Sciences* 3(8): 606-617.

Kirui, O.K., Abiodun, F.O., 2017. Innovation for sustainable agricultural growth in Cameroon. Forum to Agricultural Research to Africa (FARA), Centre for Development Research University of Bonn (ZEF) and Program of Accompaying Research for Agricultural Innovation (PARI). 46p. Available at [Access date: 06.02.2023]: https://research4agrinnovation.org/app/uploads/2017/11/CameroonDossier2017.pdf

Lin, Y., Ye, G., Kuzyakov, Y., Liu, D., Fan, J., Ding, W., 2019. Long-term manure application increases soil organic matter and aggregation, and alters microbial community structure and keystone taxa. *Soil Biology and Biochemistry* 134: 187-196.

Lippman, S.A., Pulerwitz, J., Chinaglia, M., Hubbard, A., Reingold, A., Díaz, J., 2007. Mobility and Its Liminal Context: Exploring Sexual Partnering among Truck Drivers Crossing the Southern Brazilian Border. *Social Science & Medicine* 65(12): 2464-2473.

Mahbou, S.T.G., Ntsomboh-Ntsefong, G., Aminatou, M.F., Lessa, F.T., Onana, G.E., Youmbi, E., 2022. Effect of grafting on growth and shelf life of tomatoes (Solanum lycopersicum L.) grafted on two local Solanum species. *Advances in Bioscience and Biotechnology* 13(9): 401-418.

Mengui, K.C., Oh, S., Lee, S.H., 2019. The technical efficiency of smallholder Irish potato producers in Santa subdivision, Cameroon. *Agriculture* 9(12): 259.

Mesallam, M.G., Shafshak, N.S., Abo-Sedera, F.A., Abou Elmagd, M.M., 2017. Effect of bio fertilizers, organic and mineral nitrogen fertilizer on growth and yield of tomato plants grown under sandy soil conditions. *Annals of Agricultural Science, Moshtohor 55*(2), 343-354.

Naz, M., Khan, Q.U., Khan, M.J., Sayal, O.U., Afridi, A., Sayal, A.U., 2018. Impact of foliar NPK and NAA blended with organic material on tomato yield attributes and properties of soil. *Pakistan Journal of Agricultural Research* 31(4): 323.

Ngosong, C., Tanyi, C.B., Njume, C.A., Mfombep, P.M., Okolle, J.N., Njock, T.E., Nkongho, R.N., Tening, A.S., 2018. Importance of NPK foliar fertilization for ımproving performance of tomato (Solanum lycopersicum L.), managing diseases and leafminer (Tuta absoluta). *Journal of Experimental Agriculture International* 20(2): 1-14.

Nkongho, R.N., Efouba-Mbong, J.T., Ndam, L.M., Ketchem, G.A., Etchu-Takang, E.G., Agbor, D.T., 2022. Seed production system and adaptability of okra (Abelmoschus esculentus L.) cultivars in Buea, Cameroon. *PLoS ONE* 17(12): e0278771.

Norbert, N.F., Aaron, S.T., Kenneth, M., 2017. Physicochemical properties of soils and some water sources on the Eastern Flank of Mount Cameroon. *African Journal of Environmental Science and Technology* 11(5): 219-236.

Okolle, J.N., 2019. Research Notes on Current Issues in Cameroon Agriculture. FARA Research Results 169p. Available at [Access date: 06.02.2023]: https://research4agrinnovation.org/app/uploads/2019/12/FRR-Vol-4-No-14_2019-Thumbnail.pdf

Okolle, N.J., Ijiang, T.P., Ngome, A.F., 2014. Evaluation of farmer's knowledge on pests and diseases of vegetables and their management practices in three different Agroecological zones in Cameroon. AgroVital Services & Consulting – AgroViSc Cameroon, 62p. Available at [Access date: 06.02.2023]: https://humidtropics.cgiar.org/wp-content/report2013docs/Cameroon%20Crop%20protect%20study%20Report.pdf

Ravindran, B., Lee, S.R., Chang, S.W., Nguyen, D.D., Chung, W.J., Balasubramanian, B., Mupambwa, H.A., Arasu, M.V., Al-Dhabi, N.A., Sekaran, G., 2019. Positive effects of compost and vermicompost produced from tannery waste-animal fleshing on the growth and yield of commercial crop-tomato (Lycopersicon esculentum L.) plant. *Journal of Environmental Management* 234: 154-158.

Saleem, M.Y., Asghar, M., Iqbal, Q., 2013. Augmented analysis for yield and some yield components in tomato (*Lycopersicon esculentum* Mill.). *Pakistan Journal of Bot*any 45(1): 215-218.

Schütz, L., Gattinger, A., Meier, M., Müller, A., Boller, T., Mäder, P., Natarajan, M., 2018. Improving crop yield and nutrient use efficiency via biofertilization, A global meta-analysis. *Frontiers of Plant Science* 8: 2204.

Shehata, M.N., 2018. The Infuence of organic manures and foliar spray of moringa extract on growth, quality and yield of tomato. *Journal of Plant Production* 9(12): 1167-1173.

Shushay, C., Derbew, B., Fetien, A., 2013. Genetic variability and association of characters in tomato (Solanum lcopersicon L.) genotypes in northern Ethiopia. *International Journal of Agricultural Research* 8(2): 67-76.

Tolly, L.D.E., Kamtchouing, P., 2016. Dynamics of losses in tomato commodity chain (Estimates based on experimental design in Cameroon ICAS VII Seventh International Conference on Agricultural Statistics, 24-26 October 2016, Rome, Italy. Available at [Access date: 06.02.2023]: https://doi.org/10.1481/icasVII.2016.b15e

van Reeuwijk, L.P., 2012. Procedures for Soil Analysis. International Soil Reference and Information Centre (ISRIC)/ Food and Agriculture Organization of The United Nations (FAO). 6th Edition. Wageningen. The Netherlands.

Walkley, A., Black, C.A., 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29–38.

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# Assessment of soil properties and trace element accumulation in arid regions: A case study of Kalmykia's central dry steppe zone, Russia

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## Abstract

Soil plays a pivotal role in ecosystem health and agricultural productivity. This study focuses on a critical region for soil research, Kalmykia's central dry steppe zone in southern Russia, characterized by arid conditions and unique challenges. Our investigation aimed to evaluate the current state of soil properties and assess trace element accumulation within this environment. The region's distinctive characteristics, including being home to Europe's first desert, present a complex scenario for soil conservation and management. A thorough analysis of key physicochemical properties, including organic matter content, soil texture, pH levels, and the concentrations of trace elements (V, Cr, Co, Ni, Cu, Zn, Sr, and Pb) using established methodologies, was conducted. Our findings revealed several crucial insights into the soil conditions of this arid region. Soil samples predominantly consisted of Haplic Kastanozems Sodic, characterized by low organic carbon content (0.3-1.9%). Soil texture analysis indicated a predominantly light and medium loamy granulometric composition with a prevalence of sandy fractions. Soil pH values ranged from neutral (pH = 7.6-7.9) to slightly alkaline (pH = 8.0-8.4). Furthermore, the study provided the first assessment of soil conditions in residential areas of the Caspian Lowland's arid region. Notably, trace element analysis showed elevated concentrations of several metals, with Sr having the highest levels. Co, Cr, and Zn concentrations did not significantly increase compared to the background values. The results of this soil fertility evaluation hold significance for soil restoration and conservation efforts in this unique and fragile ecosystem. In conclusion, this study underscores the urgent need for soil monitoring and management practices to address soil degradation and desertification driven by overgrazing and erosion. Understanding the physicochemical properties and trace element dynamics in arid regions is essential for developing strategies to restore and conserve these valuable soils.

**Keywords:** Haplic Kastanozems Sodic, humus, soil texture, soil pH, trace elements, X-ray fluorescent.



## Introduction

Being the only region of Europe with desert, the Republic of Kalmykia is one of the most important territories for research in the south of Russia (Sangadzhiev et al., 2018; Dedova et al., 2020). Kalmykia is vastly distinguished, even from neighboring federal subjects, not only by its soil, but also by a more continental climate (Degtyarev, 2019). Nowadays, the region is facing the problems of soil degradation and desertification, largely resulting from overgrazing practices (Tashninova, 2015; Lazareva et al., 2018; Bakinova et al., 2019; Shumova, 2021). Huge desert areas, limited plant cover, and strong winds give rise to such meteorological phenomena as dust and sandstorms (Sangadzhiev et al., 2021). Physical and chemical properties of soils,

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including content of organic matter, which serves as a main soil fertility factor, tend to deteriorate (Danchenko et al., 2022; Gurkova et al., 2022). In this context, soil monitoring plays an important role in soil fertility regulation, with the former consisting of observations of changes in agrochemical parameters of topsoil across rural Kalmykia (Okonov et al., 2021).

The territory of the south of Russia is characterized by efficient agricultural activities, resulting in increased anthropogenic impacts on farmlands. The key negative processes are unorganized grazing and overgrazing, degradation of natural forage lands, and water and wind erosions that give rise to multiple desert pockets and, consequently, lead to soil fertility reduction.

The soil fertility of the arid region of the Caspian Lowland was investigated and provided comprehensive insights into soil qualitative parameters in rural areas.

## Material and Methods

The northwestern part of the studied area is geomorphologically located in the Ergeni upland (190-210 m above sea level) (Muev et al., 2013; Sangadzhiev et al., 2021), whereas its eastern part is in the Caspian Depression, which is a flat plain sloping towards the sea as shown in Figure 1. The numerous arroyos in the eastern parts fill up in the spring and completely dry out in the summer (Semenkov et al., 2022). The topsoil comprises Kastanozems (chestnut soils), essentially associated with solonetzes and covering arroyo watersheds and their sides. Haplic Kastanozems are dominant soils in the Ergeni upland soil cover (Klimanov et al., 2014) and can be found as associated soils along mesorelief depressions. Endosalic calcisols sodic co-dominate in flat areas of the Caspian Depression. The studied area was in the central steppe zone of Kalmykia and characterized as an arid and very arid climate with hot and moderately hot summers and moderately cold winters (Nemkeeva et al., 2019). The dry steppe zone's relatively flat landform conditions have determined an original and structurally complete plant cover dominated by perennial xerophytic plants: *Festuca valesiaca, Stipa capilláta, Stipa lessingiana, Agropyron desertorum*, *Poa bulbosa*; and xerophilous plants: *Artemisia absnthium, Artemisia pauciflora*, etc. (Fedorova, 2015; Semenkov et al., 2020; Novikova et al., 2020). The soil was sampled at the 16 settlements at 2 districts of Kalmykia: Tcelinnyy and Ketchenerovsky (Figure 1). There are 129 soil samples. The soil samples were collected during seasonal expeditions. The monitoring sites included central parts of a settlement or school yard, settlement boundaries, and at the 500 m away from the settlement boundaries (background areas) (Figure 1). At the monitoring sites (5 × 5 m), sampling was done according to ISO 18400-104:2018 guidelines. All soil samples were taken in triplicate. The weight of the sample from each monitoring site was 1500 g.

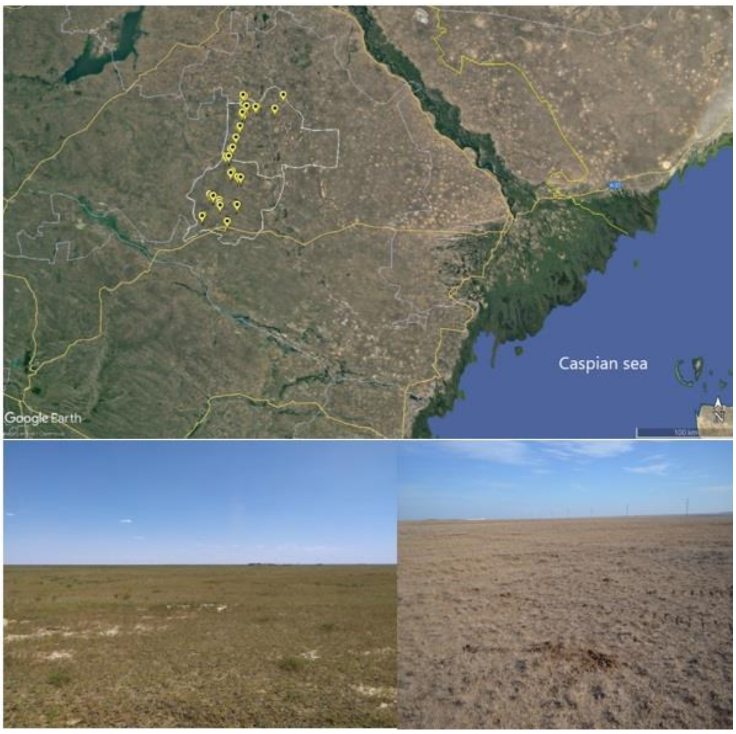


Figure 1. The monitoring sites of soil sampling.

The soil samples were air-dried in the laboratory, cleaned from root remains, grinded and sieved to 1.0 mm. The physicochemical properties of collected soil samples were determined by the following methods: pH in $H_2O$ using a glass electrode in a 1:5 (volume fraction) suspension of soil in water (ISO 10390:2005); organic matter content by the sulfochromic oxidation, ISO 14235:1998 and carbonate content by the volumetric method, ISO 10693:1995. The pipette method with the pyrophosphate procedure preparation was used to determine the soil particle size distribution (ISO 13317-2:2001; Shein, 2009). The total elemental composition (Si, Al, Fe, Ca, Mg, S, and Na) in the soils was determined by an X-ray fluorescent scanning spectrometer “Spectroscan Makc-GV" (Spectron, Saint-Petersburg, Russia).

The statistical processing of the obtained results was carried out using the Microsoft Excel computer software package. The standard error was determined for each arithmetic mean. To assess the accumulation processes of each element, the following indicators were calculated: the concentration coefficient (Kk), the coefficient of relative accumulation of trace elements in the soil (Kkr), and the background concentration coefficient (Kkf). The calculation of the indicators was carried out according to the method of Glazovskaya (1999).

## Results and Discussion

The soil in the studied area is represented by Haplic Kastanozems Sodic. The average pH was showed the values of 7.6–8.7. The pH values of the monitoring sites were close and vary slightly (V=3%) from 7.7-8.7 (Ketchenerovsky district) and 7.6-8.4 (Tcelinnyy district), i.e., they have an alkaline and highly alkaline reaction (up to 8.7 units). The soil organic carbon ($C_{org}$) contents ranged between 0.67 and 1.89%, and the average $C_{org}$ was noted at 1.39% (Table 1). The average value with $C_{org}$ in the Ketchenerovsky district was 0.94%, in the territory of the Tselinsky district - 1.40%. The maximum values of $C_{org}$ (1.89%) coincide both on the territory of the Ketchenerovsky district (Kegult village, background) and on the territory of the Tcelinsky district (Verkhny Yashkul, background) (Table 1). Carbonates are almost equally represented by calcium and magnesium salts. The Ca content of the topsoil in Haplic Kastanozems Sodic was 0.60-0.98%, and the Mg content was 0.53-0.79% (Table 1). Their content in the soil fine-grained soil on the territory of the Ketchenerovsky district ranged from 0.55%-0.90%, the content of $CaCO_3$ was in the range (V=7%) from 1.60% to 2.30% (Ketchenery village, school), $MgCO_3$ (V=7%) - from 1.93% to 2.52% (Kegult village, edge locality). In the Tcelinsky district, the content of carbonates in soils varies (V=12%) from 1.6 to 2.7% ($CaCO_3$) and 1.9 to 2.7% ($MgCO_3$).

Table 1. Statistical parameters of physico-chemical properties of soils

| Parameter | M (average) | SD (standard deviation) | Med | Min | Max | SE (standard error) | CV |
|---|---|---|---|---|---|---|---|
| Ketchenerovsky district | | | | | | | |
| $C_{org}$, % | 0.94 | 0.44 | 0.90 | 0.31 | 1.89 | 0.10 | 47 |
| pH in water | 8.21 | 0.27 | 8.20 | 7.70 | 8.70 | 0.06 | 3 |
| Ca, % | 0.80 | 0.11 | 0.86 | 0.60 | 0.90 | 0.02 | 14 |
| Mg, % | 0.61 | 0.04 | 0.60 | 0.55 | 0.72 | 0.01 | 7 |
| $CaCO_3$, % | 2.10 | 0.15 | 2.12 | 1.60 | 2.30 | 0.03 | 7 |
| $MgCO_3$, % | 2.14 | 0.14 | 2.10 | 1.93 | 2.52 | 0.03 | 7 |
| Tcelinnyy district | | | | | | | |
| $C_{org}$, % | 1.40 | 0.40 | 1.37 | 0.67 | 1.89 | 0.08 | 29 |
| pH in water | 8.10 | 0.21 | 8.20 | 7.60 | 8.40 | 0.04 | 3 |
| Ca, % | 0.82 | 0.08 | 0.80 | 0.64 | 0.98 | 0.02 | 10 |
| Mg, % | 0.66 | 0.06 | 0.67 | 0.53 | 0.79 | 0.01 | 9 |
| $CaCO_3$, % | 2.07 | 0.24 | 2.10 | 1.60 | 2.70 | 0.05 | 12 |
| $MgCO_3$, % | 2.35 | 0.23 | 2.35 | 1.85 | 2.77 | 0.04 | 10 |

The contents of clay vary in a wide range from 6.84 to 64.88, with minimum values observed in the schoolyards of Ovata, Arshan-Bulg, Baga-Chonos, and Voznesenovka (Figures 2, 3, Table S2). Low content of P was noted, i.e., 0.09–0.18%, while P exchange content is medium - 1.37–2.98% (Table 3). In Ovata, the former's medium value is 0.14%, and that of exchange potassium is 2.98%. A determination of metals was performed, and the high content of these toxic metals was observed. According to Table 2, the total content of the accumulated metals is categorized as follows:

Arshan-Bulg : Sr > V > Cr > Zn > Cu > Pb > Ni > Co
Baga-Chonos : Sr > Cr > Cu > Zn > V > Co > Ni > Pb
Voznesenovka : Sr > Cr > V > Zn > Ni > Cu > Pb > Co
Verkhny Yashkul : Sr > Cr > V > Zn > Ni > Cu > Pb > Co
Iki-Chonos : Sr > Cr > V > Zn > Ni > Cu > Pb > Co
Ovata : Sr > Cr > V > Zn > Ni > Cu > Pb > Co
Troitskoye : Sr > Cr > Zn > V > Ni > Cu > Pb > Co
Khar-Buluk : Sr > Zn > Cr > V > Ni > Cu > Pb > Co

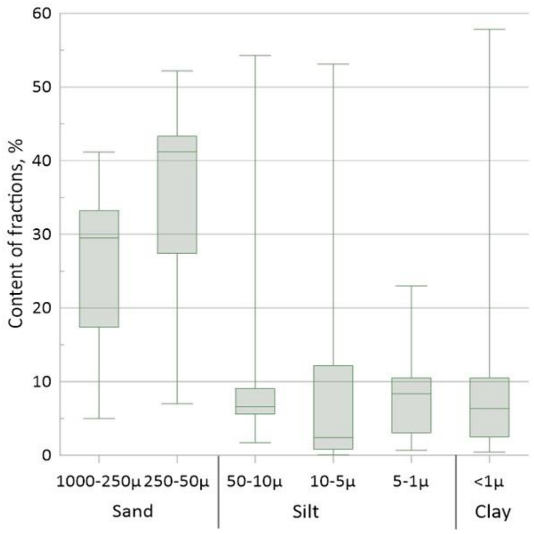


Figure 2. Variation of granulometric fractions. The central line is the median, the borders of the box are quartiles, the ends of the whiskers are the minimum and maximum

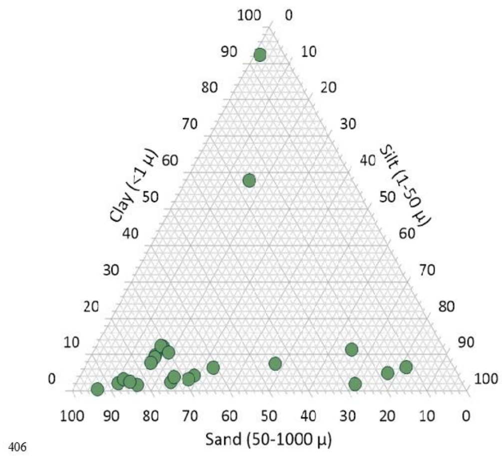


Figure 3. The ratio of granulometric fractions

Table 2. Average total content of macro- and microelements in soil samples

| Soil Sampling Site | $P_2O_5$, % | $K_2O$, % | V, mg/kg | Cr, mg/kg | Co, mg/kg | Ni, mg/kg | Cu, mg/kg | Zn, mg/kg | Sr, mg/kg | Pb, mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|
| Arshan-Bulg | 0.18±0.02 | 2.24±0.16 | 91.22±0.52 | 86.85±0.41 | 11.37±0.23 | 48.01±1.75 | 32.29±1.25 | 70.60± 1.35 | 213.27±1.75 | 24.44±0,95 |
| Baga-Chonos | 0.17±0.02 | 1.37±0.17 | 22.90±0.85 | 75.43±0.85 | 14.76±2.06 | 10.07±0.46 | 15.17±1.46 | 45.04±1.46 | 83.13±1.95 | 6.42±0.42 |
| Voznesenovka | 0.10±0.02 | 2.43±0.17 | 88.31±0.19 | 138.25±0.70 | 14.27±2.01 | 54.73±1.75 | 35.94±2.06 | 66.72±1.61 | 180.91±1.50 | 17.35±0.86 |
| Verkhny Yashkul | 0.09±0.01 | 2.42±0.16 | 82.56±1.07 | 117.59±5.42 | 13.31±1.80 | 43.14±2.21 | 29.06±1.95 | 54.95±1.40 | 181.28±1.00 | 15.27±0.75 |
| Iki-Chonos | 0.17±0.03 | 2.44±0.16 | 83.47±1.70 | 96.90±0.70 | 9.99±2.48 | 61.34±2.21 | 40.72±2.26 | 75.38±1.25 | 235.15±1.00 | 26.75±0.75 |
| Ovata | 0.14±0.01 | 2.98±0.16 | 88.97±0.35 | 117.33±0.64 | 10.14±1.96 | 76.37±1.61 | 48.83±1.95 | 83.95±1.06 | 185.58±1.00 | 15.94±0.75 |
| Troitskoye | 0.17±0.01 | 2.15±0.16 | 74.33±0.27 | 99.92±2.65 | 8.30±0.06 | 36.22±2.05 | 30.91±1.20 | 83.94±1.07 | 196.88±1.25 | 16.30±0.70 |
| Khar-Buluk | 0.15±0.01 | 2.43±0.16 | 89.46±2.00 | 94.86±3.22 | 14.84±0.58 | 55.45±1.95 | 38.13±1.20 | 102.33±1.61 | 190.20±1.15 | 22.58±0.75 |
| Maximum allowable concentration (SanPiN, 2021) | - | - | 150 | 100 | 5.0 | 85.0 | 55.0 | 100.0 | 600 | 30.0 |
| Substance hazard category | - | - | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 2 |
| Clarke according to Vinogradov (Semenkov and Konyushkova, 2022) | - | - | 100.0 | 200.0 | 18.0 | 58.0 | 14.7 | 83.0 | 340 | 16.0 |
| Haplic Kastanozems of the Ergeni Upland | - | - | 125.0 | 60.0 | 7.7 | 28.0 | 17.0 | 38.0 | 116.0 | - |
| Background matter content in soils worldwide | - | - | - | 200.0 | 10.0 | 40.0 | 20.0 | 50.0 | - | 10.0 |

In soil samples, the highest levels are registered for Sr, the lowest ones for Co and Pb. In order to assess the distribution and accumulation of trace elements in soils, an analysis of variance (ANOVA) was carried out (Table 3). The results obtained were compared with the lithosphere Clark according to Vinogradov (Kk), with the coefficient of relative accumulation of trace elements (Kkr), and with the regional background concentration (Kkf).

Table 3. Analysis of variance of the results of the determination of metals

| Element | Kk | Kkr | Kkf | Shares of MPC |
|---|---|---|---|---|
| V | 0.77 | 0.62 | - | 0.55 |
| Cr | 0.52 | 1.73 | 0.51 | 1.03 |
| Co | 0.67 | 1.58 | 1.21 | 2.42 |
| Ni | 0.83 | 1.72 | 1.20 | 0.57 |
| Cu | 0.72 | 1.99 | 1.69 | 0.62 |
| Zn | 0.88 | 1.92 | 1.46 | 0.72 |
| Sr | 0.54 | 1.58 | - | 0.31 |
| Pb | 1.13 | - | 1.81 | 0.60 |

All elements Kk < 1, except Pb, had an increased value of -1.13 in comparison with the lithosphere Clark (Table 3). The lowest concentrations Clarks relative to the litho-sphere were obtained for Cr (Kk = 0.52) and Sr (Kk = 0.54). A comprehensive evaluation of soil indicators showed damage to the central dry steppe zone of Kalmykia. The physiochemical characteristics of soils play a major role in restricting fertility, while high metal contents restrict growth and impose a risk on the food chain. The pH of the soil solution is an essential parameter to characterize soil conditions and formation processes. Soil acidity influences plant nutrition, and even soils rich in organic matter may be barren. Soil acidity analyses of samples from the settlements of Tcelinnyy District reveal faintly alkaline reactions of soil solutions, with pH equal to 8.0–8.4, while samples from Arshan-Bulg, Iki-Chonos, and Voznesenovka show neutral values of 7.6–7.8, which are environmentally optimal for the growth and development of agricultural plants (Figure 4; Table S1).

The soil of the Ketchenerovskiy district was characterized by more alkaline reaction (pH > 8) of the soil solution than in soil of the Tcelinnyy district (Figure 4). On the territory of the school and the boundary of the Ketchenery settlement, areas with a highly alkaline reaction of the medium (pH 8.5-8.7) were observed (Table 1). Most likely, the highly alkaline environment the school grounds are associated with the use of carbonate crushed stone layed on road surfaces, building materials, as well as due to the sprinkling of anti-icing agents in the winter season in the school yard. Dordzhiev et al. (2018) mentioned that it was the decent Ca content in soils that pro-vided the most favorable conditions for the majority of plants and aerobic microorganisms. The highest levels of cation exchange are inherent in soils with clay granulometric composition and increased organic matter (Ovata), while low ones are observed in sandy soils (Arshan-Bulg). Studies of the content of exchangeable cations of the Ketchenerovsky district had shown that the content of exchangeable Mg didn't exceed 0.67%, Ca - 0.90% (Table 1).

Soil organic matter (humus) is a regulator of the most important physiological and biological properties of the soil, which determine the water-air and nutrient regimes of soils. One of the key soil-forming processes is humus accumulation, which occurs during the humification and mineralization of incoming plant residues (Semenov et al., 2008). The content of soil organic carbon is the main indicator for assessing the soil's tolerance toward degradation and for predicting the possibility of restoring the fertility of degraded soil. Wind erosion is the main factor in the degradation of soil in the Caspian lowlands. It promotes the removal of fine particles and humus, lowering the soil fertility. As a result, there are sharp fluctuations in the total humus content of the soil, which affects the soil fertility (Gurkova, 2022). An increase in this parameter results in better physical and physicochemical properties and higher biological activity (Post et al., 1990; Davidson et al., 2000; Gurkova, 2022). Soil monitoring results attest to the fact that the prevailing share of Russia's soils is characterized by organic matter contents of 3% to 6% and 41 million ha, i.e., 48.6% of soils. Analysis of soil samples from Tselinny District shows humus levels are evaluated as low (less than 3%). So, organic carbon contents in settlement territories range between 0.67 and 1.89%, with the highest (1.89%) recorded in Verkhny Yashkul and Ovata background areas and the lowest (0.67% and 0.79%) in Baga-Chonos and Voznesenovka schoolyards in Haplic Kastanozems Sodic (Figure 5). In Ovata, carbon contents in topsoil (1.81–1.89%) slightly exceed those from other settlements. Low humus content losses in analyzed soil samples can be explained by the destruction of the humus horizon resulting from agricultural activities.

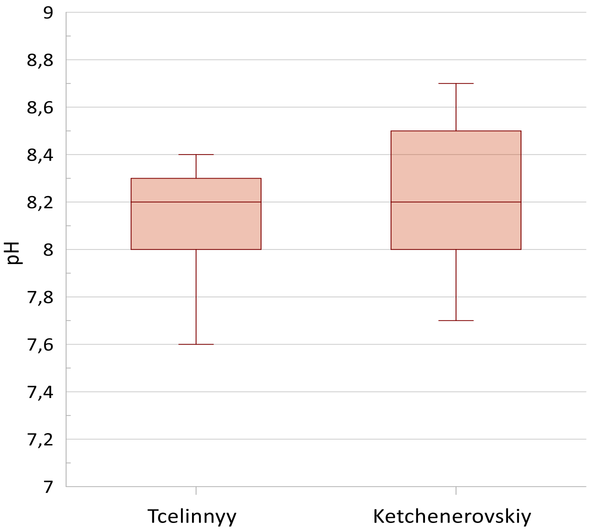


Figure 4. Variation of pH in soil samples. The central line is the median, the borders of the box are quartiles, the ends of the whiskers are the minimum and maximum.

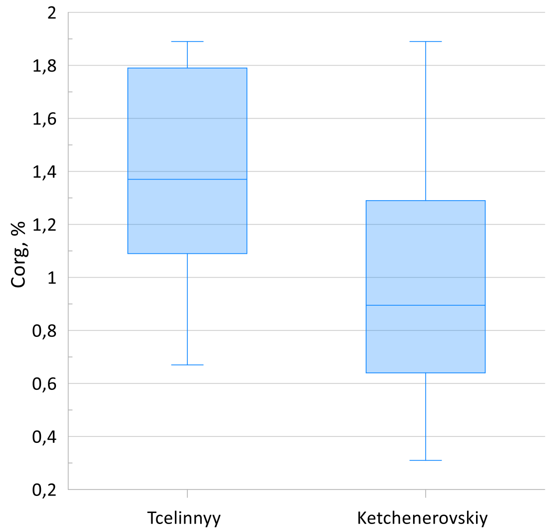


Figure 5. Variation of Corg content in soil samples. The central line is the median, the borders of the box are quartiles, the ends of the whiskers are the minimum and maximum.

According to the humus content, the soils of the Ketchenerovsky district differ slightly from the soils of the Tcelinnyy district, they belong to weak and low humus. The $C_{org}$ content varies in the range from 0.31 to 1.89% (Table 1). Its lowest content was noted on the territory of the settlement of Gojur (0.31-0.34%). In the vicinity of the settlements of Gashun-Burgusta (center) and Kegult (background), the maximum values of 1.87 and 1.89%, were noted respectively (Table 1). Soil texture is another important parameter affecting soil fertility. Granulometric analysis concludes the dominant soils of the studied district are loamy ones. The contents of physical clay vary in a wide range from 6.84 to 64.88, with minimum values observed in the schoolyards of Ovata, Arshan-Bulg, Baga-Chonos, and Voznesenovka (Figure 2; Table 2). The investigated soils cluster with medium and light silty sandy loams since the prevailing fractions are those of medium sand (up to 41.18) and fine sand (up to 51.18). Such soils are characterized by a strong clod structure and the air and water holding capacities of their topsoil. As a result, the soil in Ovata is Haplic Kastanozems Sodic, medium loamy, cloddy silty, and loose. The schoolyard topsoil sample contains less silt (1.44) than the background and boundary ones. Values of physical clay vary from 23.84 to 29.84.

Phosphorus (P) and potassium (K) are of utmost importance for plant mineral nutrition. So, labile P and exchangeable K levels are also essential to soil fertility. In our study, labile P values in topsoil samples from examined localities are basically very low, between 0.09 and 0.18%, while K exchange content is medium, at 1.37 to 2.98% (Table 2). In Ovata, the former's medium value is 0.14%, while that of the exchange potassium was noted at 2.98%. Organic matter content is related not only to clay minerals but also to total microelements. For example, an increase in humus content facilitates a decreased migration of zinc and copper, resulting in a slight reduction in the values of these metals.

One of the main indicators of the anthropogenic load on the soil is the content of trace elements. They are accumulating in the upper fertile layer of the soil, where they have a negative impact on agricultural crops and can also enter animal and human bodies through food chains. In this regard, there is a need to conduct monitoring studies of soils to control the level of trace elements. Metal accumulation in soil can significantly alter the soil ecosystem by lowering soil quality and fertility due to their non-biodegradable properties. In the present study, the maximum value of V was registered in Arshan-Bulg, while the minimum was in Baga-Chonos (Table 2 and 3). These values are below the current maximum allowable concentration and background element content in soils worldwide, as well as the corresponding Clarke number according to Vinogradov (Korte et al., 1975; Dordzhiev et al., 2018). High levels of Cr were traced in Voznesenovka (138.25 mg/kg) and low ones in Baga-Chonos (75.43 mg/kg). These exceed the established maximum allowable concentration but not the background element content in soils worldwide or the Clarke number, according to Vinogradov (1962).

Total content of Co exceeds maximum allowable concentrations in all investigated settlements, with average values for this element traced in the district being 1.5-2 times higher than regionally established background levels, though they remain below the Clarke number, according to Vinogradov (1962). Ni and Cu contents from analyzed samples lie in a wide range, and maximum values for these elements were registered in Ovata (Ni: 76.37 mg/kg, Cu: 48.83 mg/kg). The concentration values did not exceed maximum allowable concentration ones but tended to increase as compared to background parameters and Clarke numbers, according to Vinogradov (1962). Zn content was below maximum allowable concentrations, the only and slight exception being that of 102.33 mg/kg in Khar-Buluk. The maximum (235.15 mg/kg) and minimum (83.13 mg/kg) Sr contents were found in Iki-Chonos and Baga-Chonos, respectively. Average content levels of the element are below the maximum allowable concentration. Pb concentration analysis of soil samples from the studied district attests to the fact that values vary from 6.42 mg/kg to 26.75 mg/kg, with the maximum in Iki-Chonos (26.75 mg/kg) and the minimum in Baga-Chonos (6.42 mg/kg). Pb content is below the maximum allowable concentration but exceeds background content levels in soils worldwide and the Clarke value. The Pb concentration in the sample from Baga-Chonos is below the regionally established background value. In soil samples, the highest levels are registered for Sr, the lowest ones for Co and Pb. High levels of these elements not only reduce soil fertility and plant growth, but they may also pose a threat to humans through the food chain.

## Conclusion

For the first time, an assessment of the soils condition in residential areas of the arid region of the Caspian Lowland was carried out. The average levels of organic carbon in Haplic Kastanozems Sodic were low. A stable decrease in humus reserves (less than 3%) suggested deterioration in soil nutritional content. It was established that the soil acidity was neutral to faintly alkaline. The variable contents of P and K in studied soil were shown. The soil texture was mainly loamy in nature and belonged to dusty-sandy medium and light loams. Since the fractions of medium sand (up to 41.18%) and fine sand (up to 51.18%) dominate, heavy loam is less common. In the soil of studied area Co, Cr, and Zn contents exceed maximum allowable concentrations. The Co values in all settlements were higher than maximum allowable concentrations up to 2–3 times. The varia-tions of soil quality parameters in the different areas of the Caspian lowland were re-vealed. The results are important evidence for necessity of protecting or restoring the soil fertility at the central dry steppe zone of Kalmykia by reasonably utilizing soil resources.

Table S1. Chemical and Physical Properties of Arid Region Soils (0–20)

| Settlements | pH | $C_{org}$, % | Calcium: Ca (meq/100 g in the numerator, in the denominator –%) | Calcium: $CaCO_3$ (%) | Magnesium: Mg (meq/100 g in the numerator, in the denominator – %) | Magnesium: $MgCO_3$ (%) |
|---|---|---|---|---|---|---|
| Arshan-Bulg, background | 8.3 ± 0.03 | 1.24 ± 0.17 | 0.054 ± 0.005<br>0.980 ± 0.080 | 2.70 ± 0.28 | 0.056 ± 0.001<br>0.672 ± 0.016 | 2.35 ± 0.06 |
| Arshan-Bulg, schoolyard | 8.2 ± 0.03 | 1.09 ± 0.17 | 0.038 ± 0.005<br>0.760 ± 0.080 | 1.90 ± 0.28 | 0.060 ± 0.001<br>0.720 ± 0.016 | 2.52 ± 0.06 |
| Arshan-Bulg, boundary | 8.3 ± 0.03 | 1.66 ± 0.17 | 0.036 ± 0.005<br>0.720 ± 0.080 | 1.80 ± 0.28 | 0.060 ± 0.001<br>0.720 ± 0.016 | 2.52 ± 0.06 |
| Baga-Chonos, schoolyard | 8.2 ± 0.12 | 0.67 ± 0.22 | 0.044 ± 0.002<br>0.880 ± 0.048 | 2.20 ± 0.12 | 0.056 ± 0.001<br>0.672 ± 0.016 | 2.35 ± 0.06 |
| Baga-Chonos, boundary | 7.8 ± 0.12 | 1.25 ± 0.22 | 0.042 ± 0.002<br>0.840 ± 0.048 | 2.10 ± 0.12 | 0.056 ± 0.001<br>0.672 ± 0.016 | 2.35 ± 0.06 |
| Baga-Chonos, background | 7.9 ± 0.12 | 1.37 ± 0.22 | 0.036 ± 0.002<br>0.720 ± 0.048 | 1.80 ± 0.12 | 0.060 ± 0.001<br>0.720 ± 0.016 | 2.52 ± 0.06 |
| Voznesenovka, boundary | 7.8 ± 0.17 | 0.79 ± 0.28 | 0.048 ± 0.001<br>0.960 ± 0.013 | 2.40 ± 0.03 | 0.052 ± 0.001<br>0.624 ± 0.001 | 2.18 ± 0.00 |
| Voznesenovka, background | 8.4 ± 0.17 | 1.45 ± 0.28 | 0.046 ± 0.001<br>0.920 ± 0.013 | 2.31 ± 0.03 | 0.052 ± 0.001<br>0.624 ± 0.001 | 2.18 ± 0.00 |
| Voznesenovka, schoolyard | 8.0 ± 0.17 | 1.75 ± 0.28 | 0.046 ± 0.001<br>0.920 ± 0.013 | 2.30 ± 0.03 | 0.052 ± 0.001<br>0.624 ± 0.001 | 2.18 ± 0.00 |
| Verkhny Yashkul, boundary | 8.2 ± 0.20 | 0.83 ± 0.32 | 0.040 ± 0.001<br>0.800 ± 0.013 | 2.00 ± 0.03 | 0.054 ± 0.002<br>0.648 ± 0.034 | 2.27 ± 0.12 |
| Verkhny Yashkul, boundary | 8.2 ± 0.20 | 0.83 ± 0.32 | 0.040 ± 0.001<br>0.800 ± 0.013 | 2.00 ± 0.03 | 0.054 ± 0.002<br>0.648 ± 0.034 | 2.27 ± 0.12 |
| Verkhny Yashkul, schoolyard | 8.2 ± 0.20 | 1.62 ± 0.32 | 0.038 ± 0.001<br>0.760 ± 0.013 | 1.90 ± 0.03 | 0.050 ± 0.002<br>0.600 ± 0.034 | 2.10 ± 0.12 |
| Background area between Verkhny Yashkul and Tarata | 7.6 ± 0.20 | 1.89 ± 0.32 | 0.040 ± 0.001<br>0.800 ± 0.013 | 2.10 ± 0.03 | 0.060 ± 0.002<br>0.720 ± 0.034 | 2.52 ± 0.12 |
| Iki-Chonos, schoolyard | 8.3 ± 0.08 | 0.83 ± 0.12 | 0.038 ± 0.002<br>0.760 ± 0.046 | 1.90 ± 0.12 | 0.050 ± 0.003<br>0.600 ± 0.041 | 2.10 ± 0.27 |
| Iki-Chonos, boundary | 8.2 ± 0.08 | 1.14 ± 0.12 | 0.046 ± 0.002<br>0.920 ± 0.046 | 2.30 ± 0.12 | 0.056 ± 0.003<br>0.672 ± 0.041 | 2.77 ± 0.27 |
| Iki-Chonos, background | 8.0 ± 0.08 | 1.21 ± 0.12 | 0.042 ± 0.002<br>0.840 ± 0.046 | 2.11 ± 0.12 | 0.044 ± 0.003<br>0.528 ± 0.041 | 1.85 ± 0.27 |
| Ovata, schoolyard | 8.3 ± 0.10 | 1.85 ± 0.02 | 0.040 ± 0.002<br>0.800 ± 0.048 | 2.00 ± 0.12 | 0.062 ± 0.001<br>0.744 ± 0.013 | 2.60 ± 0.05 |
| Ovata, background | 8.0 ± 0.10 | 1.81 ± 0.02 | 0.032 ± 0.002<br>0.640 ± 0.048 | 1.60 ± 0.12 | 0.060 ± 0.001<br>0.720 ± 0.013 | 2.52 ± 0.05 |
| Ovata, boundary | 8.0 ± 0.10 | 1.89 ± 0.02 | 0.038 ± 0.002<br>0.760 ± 0.048 | 1.90 ± 0.12 | 0.064 ± 0.001<br>0.768 ± 0.013 | 2.69 ± 0.05 |
| Troitskoye, schoolyard | 8.0 ± 0.08 | 1.79 ± 0.24 | 0.040 ± 0.001<br>0.800 ± 0.013 | 2.00 ± 0.03 | 0.066 ± 0.005<br>0.648 ± 0.057 | 2.60 ± 0.16 |
| Troitskoye, boundary | 8.1 ± 0.08 | 1.80 ± 0.24 | 0.042 ± 0.001<br>0.840 ± 0.013 | 2.10 ± 0.03 | 0.066 ± 0.005<br>0.792 ± 0.057 | 2.52 ± 0.16 |
| Troitskoye, background | 8.3 ± 0.08 | 1.08 ± 0.24 | 0.042 ± 0.001<br>0.840 ± 0.013 | 2.10 ± 0.03 | 0.050 ± 0.005<br>0.600 ± 0.057 | 2.10 ± 0.16 |
| Khar-Buluk, background | 8.3 ± 0.10 | 1.79 ± 0.25 | 0.042 ± 0.002<br>0.840 ± 0.040 | 2.11 ± 0.05 | 0.052 ± 0.012<br>0.624 ± 0.012 | 2.18 ± 0.04 |
| Khar-Buluk, schoolyard | 7.8 ± 0.10 | 1.29 ± 0.25 | 0.038 ± 0.002<br>0.760 ± 0.040 | 1.90 ± 0.05 | 0.050 ± 0.012<br>0.600 ± 0.012 | 2.10 ± 0.04 |
| Burgsun, center | 7.7 ± 0.25 | 0.85 ± 0.20 | 0.04 ± 0.01<br>0.84 ± 0.03 | 2.10 ± 0.07 | 0.05 ± 0.01<br>0.58 ± 0.01 | 2.02 ± 0.04 |
| Burgsun, background | 8.2 ± 0.25 | 1.21 ± 0.20 | 0.04 ± 0.01<br>0.90 ± 0.03 | 2.10 ± 0.07 | 0.05 ± 0.01<br>0.60 ± 0.01 | 2.10 ± 0.04 |
| Gashun-Burgusta, schoolyard | 8.2 ± 0.06 | 1.87 ± 0.39 | 0.04 ± 0.01<br>0.90 ± 0.02 | 2.12 ± 0.01 | 0.05 ± 0.01<br>0.60 ± 0.01 | 2.10 ± 0.03 |
| Gashun-Burgusta, boundary | 8.0 ± 0.06 | 0.85 ± 0.39 | 0.04 ± 0.01<br>0.90 ± 0.02 | 2.13 ± 0.01 | 0.05 ± 0.01<br>0.60 ± 0.01 | 2.10 ± 0.03 |
| Gashun-Burgusta, background | 8.0 ± 0.06 | 0.58 ± 0.39 | 0.05 ± 0.01<br>0.85 ± 0.02 | 2.12 ± 0.01 | 0.05 ± 0.01<br>0.57 ± 0.01 | 2.02 ± 0.03 |
| Godzhur, center | 7.9 ± 0.20 | 0.31 ± 0.03 | 0.04 ± 0.01<br>0.86 ± 0.01 | 2.20 ± 0.01 | 0.05 ± 0.01<br>0.62 ± 0.01 | 2.18 ± 0.01 |

Table S1. (continued)

| Settlements | pH | $C_{org}$, % | Calcium: Ca (meq/100 g in the numerator, in the denominator –%) | Calcium: $CaCO_3$ (%) | Magnesium: Mg (meq/100 g in the numerator, in the denominator – %) | Magnesium: $MgCO_3$ (%) |
|---|---|---|---|---|---|---|
| Godzhur, background | 8.3 ± 0.20 | 0.37 ± 0.03 | 0.03 ± 0.01 / 0.88 ± 0.01 | 2.22 ± 0.01 | 0.05 ± 0.01 / 0.62 ± 0.01 | 2.17 ± 0.01 |
| Ergeninskii, schoolyard | 8.1 ± 0.12 | 0.64 ± 0.12 | 0.04 ± 0.01 / 0.89 ± 0.01 | 2.14 ± 0.01 | 0.05 ± 0.01 / 0.60 ± 0.01 | 2.10 ± 0.03 |
| Ergeninskii, background | 8.1 ± 0.12 | 1.02 ± 0.12 | 0.04 ± 0.01 / 0.88 ± 0.01 | 2.13 ± 0.01 | 0.05 ± 0.01 / 0.60 ± 0.01 | 2.10 ± 0.03 |
| Ergeninskii, background | 8.3 ± 0.12 | 0.94 ± 0.12 | 0.04 ± 0.01 / 0.90 ± 0.01 | 2.15 ± 0.01 | 0.05 ± 0.01 / 0.62 ± 0.01 | 2.18 ± 0.03 |
| Kegul'ta, schoolyard | 8.2 ± 0.12 | 1.02 ± 0.29 | 0.06 ± 0.01 / 0.67 ± 0.06 | 2.10 ± 0.03 | 0.05 ± 0.01 / 0.60 ± 0.05 | 2.10 ± 0.18 |
| Kegul'ta, boundary | 8.0 ± 0.12 | 0.96 ± 0.29 | 0.05 ± 0.01 / 0.60 ± 0.06 | 2.20 ± 0.03 | 0.06 ± 0.01 / 0.72 ± 0.05 | 2.52 ± 0.18 |
| Kegul'ta, background | 7.8 ± 0.12 | 1.89 ± 0.29 | 0.05 ± 0.01 / 0.60 ± 0.06 | 2.18 ± 0.03 | 0.05 ± 0.01 / 0.55 ± 0.05 | 1.93 ± 0.18 |
| Ketchenery, schoolyard | 8.7 ± 0.06 | 0.79 ± 0.21 | 0.04 ± 0.01 / 0.86 ± 0.03 | 2.30 ± 0.07 | 0.06 ± 0.01 / 0.67 ± 0.02 | 2.35 ± 0.07 |
| Ketchenery, boundary | 8.6 ± 0.06 | 0.58 ± 0.21 | 0.03 ± 0.01 / 0.88 ± 0.03 | 2.10 ± 0.07 | 0.05 ± 0.01 / 0.65 ± 0.02 | 2.27 ± 0.07 |
| Ketchenery, background | 8.5 ± 0.06 | 1.30 ± 0.21 | 0.04 ± 0.01 / 0.79 ± 0.03 | 1.90 ± 0.07 | 0.05 ± 0.01 / 0.60 ± 0.02 | 2.10 ± 0.07 |
| Tugtun, schoolyard | 8.2 ± 0.15 | 0.40 ± 0.15 | 0.04 ± 0.01 / 0.74 ± 0.05 | 2.11 ± 0.01 | 0.05 ± 0.01 / 0.58 ± 0.01 | 2.10 ± 0.01 |
| Tugtun, background | 8.5 ± 0.15 | 0.69 ± 0.15 | 0.05 ± 0.01 / 0.85 ± 0.05 | 2.10 ± 0.01 | 0.05 ± 0.01 / 0.60 ± 0.01 | 2.11 ± 0.01 |
| Shin-Mer, schoolyard | 8.4 ± 0.05 | 1.29 ± 0.02 | 0.03 ± 0.01 / 0.66 ± 0.01 | 1.90 ± 0.07 | 0.05 ± 0.01 / 0.55 ± 0.06 | 1.93 ± 0.21 |
| Shin- Mer, boundary | 8.5 ± 0.05 | 1.33 ± 0.02 | 0.03 ± 0.01 / 0.64 ± 0.01 | 1.60 ± 0.06 | 0.06 ± 0.01 / 0.67 ± 0.06 | 2.35 ± 0.21 |

Table S2. Characteristics of soil samples (topsoil) texture

| Soil Sampling Site | 1-0.25 | 0.25-0.05 | 0.05-0.01 | 0.01-0.005 | 0.005-0.001 | < 0.001 silt | < 0.01 physical clay | Soil type by granulometric composition |
|---|---|---|---|---|---|---|---|---|
| Arshan-Bulg, background | 31.90 | 41.90 | 7.20 | 12.40 | 4.20 | 2.40 | 19.00 | Sandy Loam |
| Arshan-Bulg, schoolyard | 37.70 | 47.70 | 7.80 | 2.40 | 1.20 | 3.20 | 6.84 | Loamy Sand |
| Arshan-Bulg, boundary | 31.10 | 41.20 | 7.70 | 4.00 | 12.20 | 3.80 | 20.0 | Sandy Loam |
| Baga-Chonos, schoolyard | 29.50 | 39.40 | 6.50 | 12.20 | 9.20 | 3.20 | 24.60 | Light Loamy |
| Baga-Chonos, boundary | 25.50 | 35.50 | 8.84 | 18.20 | 5.60 | 6.40 | 30.20 | Medium Loamy |
| Baga-Chonos, background | 28.50 | 38.46 | 7.64 | 12.40 | 8.80 | 4.20 | 25.40 | Light Loamy |
| Voznesenovka, boundary | 31.90 | 42.06 | 6.28 | 0.08 | 9.88 | 9.80 | 19.76 | Light Loamy |
| Voznesenovka, background | 39.36 | 43.32 | 6.40 | 0.76 | 8.52 | 5.60 | 18.88 | Light Loamy |
| Voznesenovka, schoolyard | 37.03 | 47.03 | 9.04 | 1.40 | 3.00 | 2.50 | 16.90 | Light Loamy |
| Verkhny Yashkul, boundary | 37.62 | 49.62 | 5.60 | 1.96 | 3.08 | 2.12 | 17.16 | Light Loamy |
| Verkhny Yashkul, schoolyard | 33.20 | 43.06 | 6.36 | 2.28 | 7.40 | 7.70 | 17.38 | Light Loamy |
| Background area between Verkhny Yashkul and Tarata | 30.50 | 40.42 | 5.92 | 0.16 | 10.84 | 12.16 | 23.16 | Light Loamy |
| Iki-Chonos, schoolyard | 5.00 | 7.00 | 23.12 | 53.10 | 5.28 | 6.48 | 64.88 | Heavy Loamy |
| Iki-Chonos, boundary | 10.70 | 12.78 | 53.76 | 10.76 | 0.68 | 11.32 | 22.76 | Light Loamy |
| Iki-Chonos, background | 17.36 | 27.36 | 42.32 | 2.56 | 2.96 | 7.44 | 12.96 | Light Loamy |
| Ovata, schoolyard | 41.18 | 51.18 | 3.80 | 0.32 | 2.08 | 1.44 | 23.84 | Medium Loamy |
| Ovata, background | 8.10 | 18.02 | 5.04 | 2.64 | 8.36 | 7.84 | 29.84 | Medium Loamy |
| Ovata, boundary | 32.20 | 42.20 | 1.72 | 3.48 | 11.20 | 9.20 | 28.88 | Medium Loamy |
| Troitskoye, schoolyard | 29.14 | 41.14 | 6.60 | 0.80 | 11.80 | 10.52 | 23.10 | Light Loamy |
| Troitskoye, boundary | 29.17 | 42.20 | 5.20 | 0.91 | 10.20 | 10.69 | 23.12 | Light Loamy |
| Troitskoye, background | 29.32 | 43.32 | 4.96 | 0.96 | 10.52 | 10.92 | 22.40 | Light Loamy |
| Khar-Buluk, background | 9.68 | 17.68 | 52.96 | 13.52 | 4.28 | 1.88 | 19.68 | Light Loamy |
| Khar-Buluk, schoolyard | 5.78 | 11.78 | 54.28 | 0.28 | 23.00 | 4.88 | 29.16 | Medium Loamy |

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## References


Bakinova, T.I., Darbakova, N.E., Kazakova, G.Y., Sangadzhieva, S.A., Darbakova, I.E., 2019. Information support of monitoring as a tool of ecological optimization of agricultural land use. *Journal of Environmental Management and Tourism* 10(1): 195-201.

Danchenko, N.N., Artemyeva, Z.S., Kolyagin, Y.G., Kogut, B.M., 2022. A comparative study of the humic substances and organic matter in physical fractions of haplic chernozem under contrasting land uses. *Eurasian Soil Science* 55(10): 1371-1383.

Davidson, E.A., Trumbore, S.E., Amundson, R., 2000. Biochemistry: Soil warming and organic carbon content. *Nature* 408: 789-790.

Dedova, E.B., Goldvarg, B.A., Tsagan-Mandzhiev, N.L., 2020. Land degradation of the Republic of Kalmykia: Problems and reclamation methods. *Arid Ecosystems* 10(2): 140-147.

Degtyarev, K.S., 2019. Potential of renewable energy sources in the republic of Kalmykia. Vestnik Moskovskogo Universiteta, Seriya 5: Geografiya (1): 75-82.

Dordzhiev, A.A., Dordzhiev, A.G., Sangadzhiev, M.M., Rubeko, L.M., Onkaev, V.A., 2018. Salt composition of clay soils and its variation with long-term water filtration in republic of Kalmykia. *Journal of Environmental Management and Tourism* 9(1): 130-135.

Fedorova, N.L., Muchkaeva I.A., 2015. Vegetation dynamics of steppe ecosystems on the example of the Naintakhinsky CFR Tselinny district of the Republic of Kalmykia. *Bulletin of the Institute of Complex Studies of Arid Territories* 1(30): 25-33.

Glazovskaya, M.A., 1999. Problems and methods of assessment of the ecogeochemical resilience of soils and the soil cover towards technogenic impacts. *Eurasian Soil Science* 32 (1): 99-108.

Gurkova, E.A., Sokolov, D.A., 2022. Influence of texture on humus accumulation in soils of dry steppes of Tuva. *Eurasian Soil Science* 55(1): 90-101.

ISO 10390:2005. Soil Quality – Determination of pH. Available at [Access date: 28.05.2022]: https://www.iso.org/standard/40879.html

ISO 10693:1995. Soil Quality – Determination of carbonate content-Volumetric method. Available at [Access date: 28.05.2022]: https://www.iso.org/standard/18781.html

ISO 13317–2:2001. Determination of particle size distribution by gravitational liquid sedimentation methods – Part 2: Fixed pipette method. Available at [Access date: 28.05.2022]: https://www.iso.org/standard/30663.html

ISO 14235:1998. Soil Quality – Determination of organic carbon by sulfochromic oxidation. Available at [Access date: 28.05.2022]: https://www.iso.org/standard/23140.html

ISO 18400-104:2018. Soil Quality — Sampling. Part 104: Strategies. Available at [Access date: 28.05.2022]: https://www.iso.org/ru/standard/65223.html

Klimanov, A.V., Vorobyova, L.A., Novikova, A.F., Konyushkova, M.V., 2014. The nature of alkalinity in virgin and anthropogenically modified solonetzes of northern Kalmykia. *Eurasian Soil Science* 47(4): 266-275.

Korte, N.E., Skopp, J., Niebla, E.E., Fuller, W.H., 1975. A baseline study on trace metal elution from diverse soil types. *Water, Air, Soil Pollution* 5(2):149-156.

Lazareva, V.G., Bananova, V.A., 2018. Dynamics of anthropogenic desertification of the European desert on the example of Russian Precaspian region. *International Journal of Engineering & Technology* 7(4): 309-313.

Muev, B., Evieva, B., 2013. Production growth reserves in the livestock industry (on the example of JSC Sarpa of the Republic of Kalmykia). *Oriental Studies* 6(1): 126-130. [In Russian].

Nemkeeva, V.V., Tertyshnaya, A.G., 2019. Arable lands of Kalmykia's central southern zone: Soil-fertility conditions. In: Soil Fertility in Russia: Conditions, Trends, Prognosis. Sychev, V.G. (Ed.). Conference Proceedings. Russian Agrochemistry Research Institute, Moscow, Russia. pp. 225-232.

Novikova, N.M., Volkova, N.A., Ulanova, S.S., Chemidov, M.M., 2020. Change in vegetation on meliorated solonetcic soils of the Peri-Yergenian plain over 10 Years (Republic of Kalmykia). *Arid Ecosystems* 10(3): 194-202.

Okonov, M.M., Bakinova, T.I., Batyrov, V.A., Orosov, S.A., Shabanov, R.M., Dzhirgalova, E.A., Ubushaeva, S.V., Mandzhieva, A.N., 2021. Supply of nutrients of zonal soil subtypes and macronutrients balance in fodder crop rotation links on irrigation. IOP Conference Series: Earth and Environmental Science 868: 012082.

Post, W.M., Peng, T.H., Emanuel, W.R., King, A.W., Dale, V.H., Angelis, D.L., 1990. The Global Carbon Cycle. American Scientist 78: 310–326.

Sangadzhiev, M.M., Nastinova, G.E., Sadykova, A.Zh., Nikolaeva, G.V., Fazlyeva, G.A., 2021. Dust storms in Kalmykia. *Moscow Economic Journal* 10: 169-180.

Sangadzhiev, M.M., Onkaev, V.A., Germasheva, Y.S., 2021. Analysis of palaeoecological factors in shaping modern landscape of Republic of Kalmykia. IOP Conference Series: Earth and Environmental Science 666: 052013.

Sangadzhiev, M.M., Tsathlangova, E.A., Sangadzhieva, S.A., Nuraeva, V.E., Sangadzhieva, A.A. 2018. Modern anthropogenic impact on desertification processes in the Republic of Kalmykia: an economic factor. *Innovations and Investments, Scientific and Analytical Journal* 2: 144-148.

Sangadzhieva L.Kh., 2001. Trace elements in landscapes of Kalmykia and biogeochemical zoning of its territory. Ecological and Geographical Bulletion of the South of Russia 3(4): 54-63.

SanPiN 1.2.3685-21. Hygienic Norms and Safety Requirements. 2021. Available at: [Access date: 28.05.2022]: http://publication.pravo.gov.ru/Document/View/0001202102030022

Semenkov, I.N., Konyushkova, M.V., 2022. Geochemical partition of chemical elements in Kastanozems and Solonetz in a local catchment within a semiarid landscape of SW Russia. *Catena* 210: 105869.

Semenkov, I.N., Konyushkova, M.V., Klink, G.V., Krupskaya, V.V., Enchilik, P.R., Novikova, N.M., 2020. Data on the soil and vegetation properties at the small gully catchment area: Steppe region of Kalmykia Republic (South Russia). *Data in Brief* 40: 107746.

Semenov, V.M., Ivannikova, L.A., Kuznetsova, T.V., Semenova, N.A, Tulina, A.S., 2008. Mineralization of organic matter and the carbon sequestration capacity of zonal soils. *Eurasian Soil Science* 41: 717–730.

Shein, E.V., 2009. The particle-size distribution in soils: Problems of the methods of study, interpretation of the results, and classification*. Eurasian Soil Science* 42(3): 284-291.

Shumova N.A., 2021. Quantitative climate indicators applied to the assessment of hydrothermal conditions in the Republic of Kalmykia. *Arid Ecosystems* 11(4): 327–336.

Tashninova, L., 2015. The soil of the federal reserves of the Republic of Kalmykia in the new classification. *Oriental Studies* 8(2): 201-207. [in Russian].

Vinogradov, A.P., 1962. Average values for chemical elements in main types of igneous rocks. Geokhimiya (Geochemistry) 7: 555-571. [in Russian].

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# Early seedling features and mineral content of maize seeds grown under salinity stress

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## Abstract

High seedling performance is crucial for the growth and development of plants, as it directly affects the potential for crop yield. Therefore, robust early seedling characteristics can lead to higher yields and better crop productivity. This work evaluated the early seedling characteristics of maize seeds grown under four irrigation water salinities (0.30, 1.5, 3.5, and 7 dS $m^{-1}$). For this purpose, maize plants were grown to maturity in pots under rain shelter conditions, and then maize seeds were harvested. Subsequently, the maize seeds germinated to determine the early seedling characteristics, the leaf's $Na^+$, $Ca^{+2}$, $K^+$ content, and the $K^+$/ $Na^+$, $Ca^{+2}$/ $Na^+$. The results showed that irrigation of maize crops at 7.0 dS $m^{-1}$ reduced seedling fresh weight, root fresh weight, and SPAD parameters by 46.9%, 78.1%, and 38.7%, respectively, compared to 0.30 dS $m^{-1}$. Irrigation of maize plants with 8.0 dS $m^{-1}$ significantly hampered the reusability of maize seeds and decreased seedling height (7.81 cm), root dry weight (0.13 g), and root length (5.5 cm). Moreover, the highest ratios of $K^+/Na^+$ (12.58) and $Ca^{+2}/Na^+$ (3.46) ratios and the lowest leaf $Na^+$ content (0.24%) of maize seedlings were found in 0.30 dS $m^{-1}$ treatment. Based on the results, it could be suggested that the reusability of maize seeds, which irrigation maize crops with ≥ 3.5 dS $m^{-1}$ saline water, is not recommended for sustainable maize production due to low seedling growth performance. Finally, the current study has the potential to provide important insights into identifying robust and healthy maize seeds grown in high-salinity environments.

**Keywords:** Salinity stress, maize germination, seed quality, seedling growth.



## Introduction

Maize is an essential crop in many cultures worldwide due to its versatility and importance as a staple food (Erenstein et al., 2022). Maize is the third most cultivated cereal globally, after wheat and rice, with a worldwide production of 1.13 billion tonnes in 2021, as stated by FAO (2021). In addition to its role as the primary food source for millions of people, maize is also used to produce animal feed, biofuels, and industrial products (Chaudhary et al., 2013; Rouf Shah et al., 2016). Up to now, maize production has faced numerous environmental problems (Ahmad et al., 2020). Climate change, erratic rainfall patterns, salinity, and water stress have become critical areas of concern for researchers because they seriously affect grain-filling processes and quality, ultimately leading to lower crop productivity (Vaughan et al., 2018; Salika and Riffat, 2021).

Climate change significantly impacts resources worldwide, including increasing water scarcity in many regions (Lu et al., 2019) due to higher temperatures, changing precipitation patterns, and more frequent extreme weather events (Hopmans et al., 2021). As a result, many farmers are turning to alternative water sources, such as saline water, for irrigated agriculture (Singh, 2022). Although using salt water can be a viable solution to freshwater scarcity, it also presents new challenges. Sustainable management practices and

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technologies must be developed to ensure that using high water salinity in irrigated agriculture is practical and environmentally responsible.

Using saline water for irrigation can affect crop yield, physiology, morphology, and grain quality (Kiremit and Arslan, 2016; Arif et al., 2020). High soil salinity can reduce the availability of essential nutrients and water to plants, resulting in lower yields (Arif et al., 2020). In addition, saline water can adversely influence plant physiology by interfering with water uptake, photosynthesis, and other physiological processes (Alkharabsheh et al., 2021; Mukhopadhyay et al., 2021). Moreover, the high salt concentration in saline water can affect plant morphology, including changes in root and shoot development (Bistgani et al., 2019). The seed quality of plants irrigated with saline water may also be affected, with lower protein content, starch content, and altered mineral composition (Koyro and Eisa, 2008).

Seed quality is a vital component in the growth of plants and yield. It can increase seed resistance to environmental factors by providing a high germination rate and seedling growth characteristics (Sehgal et al., 2018). The germination process depends on efficiently mobilizing stored reserves to promote successful emergence (Bewley et al., 2013). The seed's high growth capacity significantly improved the productivity of the crops. Therefore, examining early seedling growth attributes of seeds grown under unfavorable conditions is necessary to facilitate the selection of strong and healthy seeds.

In literature, generally, the researchers have been focused on how saline water affects the germination and seedling growth ability of maize seeds (Khodarahmpour et al., 2014; Li et al., 2019; Öztürk et al., 2021). However, no study has been investigated to determine the seedling growth performance of maize seeds grown under saline water conditions. Therefore, to fill this gap in the literature, this study aimed to find out how saline irrigation water affected seedling development and leaf macronutrient content in maize seeds.

## Material and Methods

### Growing environment and seed sources

The study was established under a rain shelter in the Experimental Area of the University of Ondokuz Mayıs (Samsun, Türkiye) during the summer of 2021. The mean daily temperature and relative humidity under the rain shelter fluctuated between 19-36 °C and 44-72% during growth. The study soil was classified as clay loam, consisting of 36.5% clay, 22.8% silt, and 40.7% sand, collected at a depth of 30 cm at the Ondokuz Mayıs University Experimental Farm. The collected soil was air-dried under a rain shelter, grounded, and passed through a 4 mm sieve. After that, each plastic pot (0.30 m high × 0.28 m top × 0.26 m bottom) was filled with 2 kg of gravel at the bottom and then with 12 kg of sieved soil. Chemical analysis showed that the contents of $Ca^{+2}$, $Mg^{+2}$, $Na^{+,}$ and $K^{+}$ were 1.20, 2.30, 2.80, and 0.8 mg/100 g of soil, respectively. The field capacity, permanent wilting point, electrical conductivity (EC), and soil pH were 25.7%, 15.7%, 0.15 dS $m^{-1}$, and 6.85, respectively. Cin mısır (Zea mays everta Sturt) seed, one of the most widely grown cereal varieties in Turkey, was used in the study. Maize seeds were sown on June 17, 2021, and harvested on October 10, 2021 respectively.

### Experimental setup and agronomic practices

The study was set up as a factorial experiment in a completely randomized design consisting of four saline waters ($S_1$ = 0.30 dS $m^{-1}$, $S_2$ = 1.5 dS $m^{-1}$, $S_3$ = 3.5 dS $m^{-1}$, $S_4$ = 7.0 dS $m^{-1}$) with three replicates per treatment (4 salinity levels × 3 replicates = 12 pots). Five seeds were sown in each pot and thinned to one uniform healthy seedling per pot 20 days after sowing. All pots were irrigated with the same amount of tap water during the germination period. After thinning, irrigation with saline water was started according to the treatments. To achieve this, $S_1$ was tap water, while salinity levels of $S_2$, $S_3$, and $S_4$ were prepared by adding NaCI and $CaCI_2$ to the water of $S_1$ in a 1:1 ratio. Before sowing, all pots were saturated with tap water to determine the field capacity weight of each pot. The surface of the pots was wrapped with a plastic cover to prevent water loss by evaporation. After stopping the drainage and establishing the balance between air and water in the soil, each pot was weighed, and this was taken as the field capacity of each pot. Irrigation practices were realized when 0.40% of the available water in the soil was consumed by evapotranspiration throughout the growing cycle. Each pot was weighed daily to determine soil moisture loss due to evapotranspiration. Also, to minimize high salt buildup in the root zone, 15% leachate was given at each irrigation.

The maize plant was fertilized with 250 kg N $ha^{-1}$, 100 kg $P_2O_5$ $ha^{-1}$, and 180 kg $K_2O$ $ha^{-1}$. Phosphorus and potassium were employed as base fertilizers in the form of triple superphosphate (1.41 g $pot^{-1}$) and potassium sulfate (0.88 g $pot^{-1}$), respectively, before sowing. Nitrogen was applied in two doses: 50% nitrogen at the time of the grand growth stage and a second dose of 50% nitrogen at the tessling stage.

**Germination experiment**

The surface of the harvested maize seeds was sterilized in a 5% NaOCl solution for 10 min prior to germination. The germination study was set up as a factorial experiment in a completely randomized design with three replicates per treatment (ten seedlings per replicate). A total of 12 petri dishes (4 irrigation water salinity × 3 replicates = 12 petri dishes) were used to achieve this purpose. Twenty seeds were sown with tweezers in glass petri dishes (9×9×4cm) with double-layer blotting paper for each treatment. The seeds were irrigated daily with 10 ml of 0.22 $dSm^{-1}$ irrigation water. Petri dishes were kept in an incubator at a temperature of 25 ± $1^{0}$C and a relative humidity of 50%. During each day of the experiment, the dishes were exposed to a light intensity of 1200 l x for 12 hours.

After 14 days, ten seedlings were randomly selected from each replicate to measure the shoots' fresh and dry weights as well as shoots and root lengths. The SPAD readings were taken from the leaves of 5 different seedlings from each petri dish using the SPAD 502 Meters [Spectrum Technologies, Inc., USA]. The fresh weights of the shoots and roots were obtained by weighing 10 seedlings chosen at random from each petri plate. The dry weights of the shoot and roots were determined by keeping the seedling at 70 °C in the oven-dried up to reaching consistent weight, and then weights were determined with an electronic balance. The lengths of the shoots and roots were measured with a ruler.

**Statistical Analysis**

One-way analysis of variance was performed on the data, and statistical analysis was made using SPSS 25.0 (SPSS, Chicago, IL, USA). Significant differences between means were separated using the Duncan test at the 0.05 probability level. Bar graphs for leaf macronutrient content were created using Microsoft Office 365 software. The vertical lines on the bar graphs show the standard error of the three replicates for each treatment.

## Results and Discussion

The stem fresh and dry weights, root fresh and dry weights, and chlorophyll content were considerably affected by irrigation water salinity ($p<0.001$); moreover, irrigation water salinity showed a significant effect on seedling height and root length ($p< 0.01$).

Table 1. Effects of irrigation water salinity on early seedling traits of maize seeds

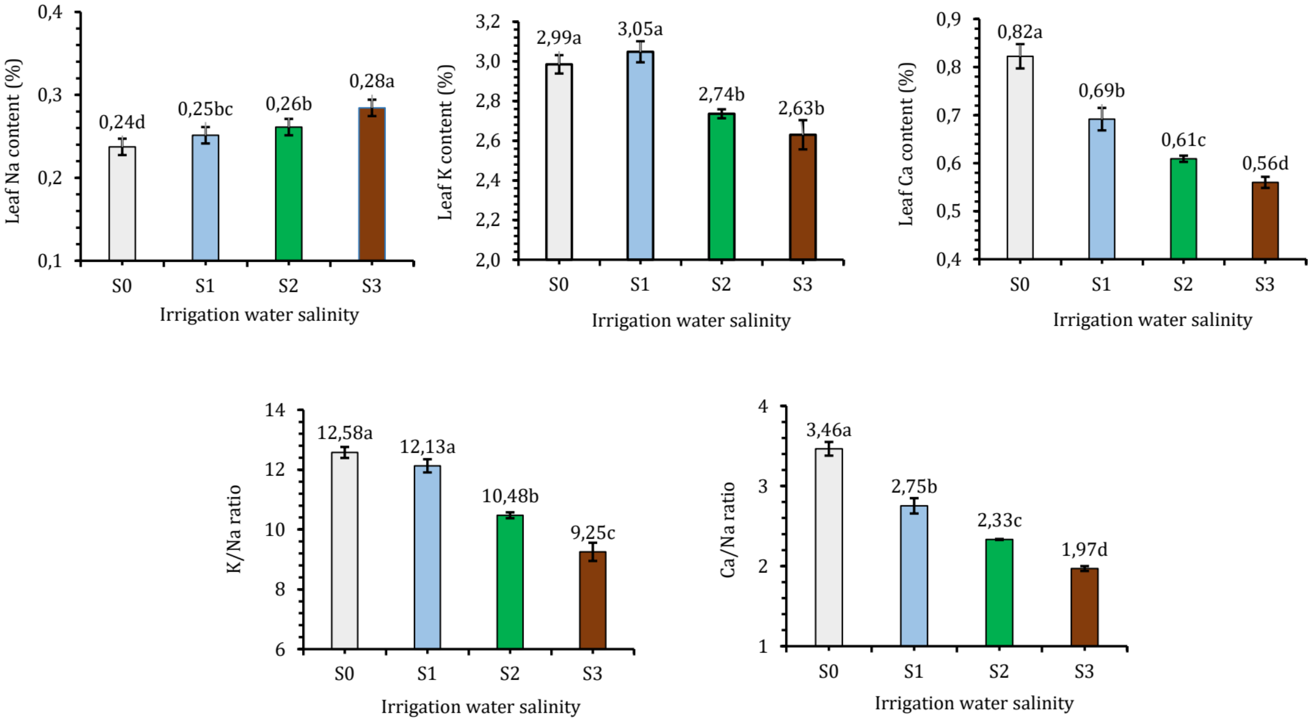
| Irrigation water salinity ($dS\ m^{-1}$) | Seedling Parameters | | |
|---|---|---|---|
| | Seedling height (cm) | Stem fresh weight (g) | Stem dry weight (g) |
| S1 | 10.34 ± 0.38a | 4.9 ± 0.2a | 0.45 ± 0.04a |
| S2 | 10.02 ± 0.57a | 4.8 ± 0.2a | 0.44 ± 0.02a |
| S3 | 10.19 ± 0.19a | 4.0 ± 0.2b | 0.34 ± 0.01b |
| S4 | 7.81 ± 0.19b | 2.6 ± 0.2c | 0.27 ± 0.01c |
| ANOVA | | | |
| *P>F* | ** | *** | ** |
| | Root fresh weight (g) | Root dry weight (g) | Root length (cm) |
| S1 | 3.20 ± 0.06a | 0.28 ± 0.01a | 8.8 ± 0.6a |
| S2 | 2.94 ± 0.24a | 0.22 ± 0.001b | 7.7 ± 0.2b |
| S3 | 1.72 ± 0.35b | 0.17 ± 0.02c | 6.1 ± 0.3c |
| S4 | 0.70 ± 0.02c | 0.13 ± 0.003d | 5.5 ± 0.2c |
| ANOVA | | | |
| *P>F* | *** | *** | ** |
| | SPAD | SDW/SFW ratio | RDW/RFW ratio |
| S1 | 26.6 ± 0.3a | 9.18 ± 0.35b | 8.83 ± 0.48b |
| S2 | 25.3 ± 0.6b | 9.33 ± 0.81b | 8.35 ± 0.23b |
| S3 | 21.7 ± 0.8c | 9.15 ± 0.06b | 9.52 ± 1.02b |
| S4 | 16.3 ± 0.4d | 11.34 ± 0.35a | 17.99 ± 0.17a |
| ANOVA | | | |
| *P>F* | *** | *** | ** |

$S_1$, $S_2$, $S_3$, and $S_4$ show 0.30, 1.5, 3.5, and 7.0 $dSm^{-1}$, respectively. According to Duncan's Test, different letters in each feature significantly differ at a 0.05% probability level. ***: $p≤0.001$ **: $p≤0.01$.

The $S_1$ treatment produced the greatest seedling height (10.34 cm), whereas the $S_4$ treatment obtained the lowest (7.81 cm). Seedling lengths decreased by 3%, 1.5%, and 24.46% in $S_2$, $S_3$, and $S_4$, respectively, when compared to the $S_1$. In addition, the seedling heights for $S_1$, $S_2$, and $S_3$ treatments were not statistically different (Table 1). Stem fresh and dry weights of the highest saline irrigation treatment ($S_4$) were reduced by 46.8% and 40%, respectively, relative to the $S_1$ treatment. However, there was no statistical difference between $S_1$ and $S_2$ treatments in both stem fresh and dry weights. The highest root wet weight value (3.20 g) was found in $S_1$, while the lowest (0.70 g) was observed in the $S_4$ treatment. Root dry weight values were reduced with an increment in irrigation water salinity. Root dry weight decreased by 21.4%, 39.28%, and 57.53% in $S_2$, $S_3$, and $S_4$, respectively, compared to $S_1$ treatment. The greatest root length was measured in $S_1$ (8.8 cm) and the lowest in $S_4$ (5.5 cm). SPAD values for maize seedlings changed between 16.3-26.6, and the highest value (26.6) was observed in the $S_1$ treatment, whereas the lowest was in the $S_4$ treatment. However, the SPAD value between the $S_1$ and $S_2$ treatments statistically differed, but no high differences were found between the two treatments. SDW/SFW and RDW/RFW ratios were increased with increments in saline water. For the two parameters, the highest values (11.34 and 17.99) were observed in the $S_4$ treatment, while no significant differences were observed between the $S_1$, $S_2$, and $S_3$ treatments. Considering all the early growth attributes of the maize seeds, irrigation of the maize plants with 3.5 and 7 $dSm^{-1}$ caused a greater reduction in the growth capacity of the seeds compared to water salinity of 1.5 and 0.30 $dSm^{-1}$. This reduction in the early seedling growth ability of the seed could be related to seed reserve content. For this, carbohydrate accumulation decreased at 3.5 and 7.0 $dSm^{-1}$ water salinity, caused by the toxic salinity concentration in the root zone. Similar results to our study, Meena and Yadav (2018) reported that assimilated reserves in the embryo of the seeds might reduce with increasing salinity stress. Soriano et al. (2014) explained that seed reserve content is closely related to the germination percentage. In a study conducted by Begcy and Walia (2015), it was found that seed reserve proteins play a crucial role as a reservoir of amino acids and nitrogen, which are essential for the growth and development of new seedlings. The study also suggested that any disturbance in the quantity or quality of these proteins could inhibit seedling establishment and vigor. The findings of the current investigation suggested that the water salinity should not exceed 3.5 $dSm^{-1}$ to avoid any adverse effects on the quality and serve of the seeds due to the buildup of salt minerals in the root zone during the seed filling period.

Figure 1 illustrates the differences in leaf $Na^+$, $Ca^{+2}$, $K^+$ contents, $K^+/Na^+$, and $Ca^{2+}/Na^+$ ratios in maize seed grown under different irrigation water salinity conditions. The salinity of irrigation water had significant effects on the contents of leaf nutrients of the maize seedlings, and the leaf $Na^+$ content increased with the increment in water salinity level. Compared with the highest saline water ($S_4$), $S_1$, $S_2$, and $S_3$ decreased leaf $Na^+$ by 16.5%, 11.6%, and 8.1%, respectively. Moreover, the greatest leaf $K^+$ content (3.05%) was observed in the $S_1$ (Figure 1). Furthermore, the leaf $K^+$ content of $S_1$ was slightly lower than that of $S_2$, and no significant differences were observed between the $S_1$ and $S_2$ treatments ($p>0.05$) (Figure 1). The leaf $Ca^{+2}$ contents of maize seedling were significantly differed between saline irrigation waters. Consequently, $S_1$ had the highest leaf $Ca^{+2}$ content (0.82%), which decreased by 15.9%, 25.9%, and 31.9% for the $S_1$, $S_2$, and $S_3$ treatments, respectively (Figure 1).

The $K^+/Na^+$ ratio depicted a decrease with increment in water salinity level. Compared with the $S_1$ treatment, the $K^+/Na^+$ ratio of the maize seeds grown at $S_2$, $S_3$, and $S_4$ treatments decreased by 3.6%, 16.7%, and 26.4%, respectively. Irrigation with saline water induced decreases in the $Ca^{+2}/Na^+$ ratio of maize seeds (Figure 1). The $S_1$ treatment exhibited the greatest $Ca^{+2}/Na^+$ ratio (3.46%), followed by the $S_2$ treatment (Figure 1). The reductions in the $Ca^{+2}/Na^+$ ratio were around 20.6%, 32.7, and 43.2% for $S_1$, $S_2$, and $S_3$, respectively, compared with the $S_1$ treatment (Figure 1). Considering all mineral contents of maize, it could be noted that the increment in salinity of irrigation water resulted in a significant reduction in $K^+$ and $Ca^{2+}$ content of maize seeds. The greatest decrease in these parameters was observed in the $S_4$ treatment; this could be linked with the salinity of the irrigation water causing high osmotic stress and ion toxicity in the root zone, resulting in low nutrient availability to the maize crops. Farooq et al. (2015) explained that excessive accumulation of sodium and chloride ions in the root zone of maize in saline soils causes severe nutritional imbalances. These ions interact with other vital mineral elements such as potassium, nitrogen, and calcium (Läuchli and Grattan, 2007). Hu and Schmidhalter (2005) also reported that increasing the level of salt concentration within a root zone induces an increment in the soil osmotic potential, thereby decreasing the movement of $K^+$ ions in the soil and ultimately affecting the $K^+$ uptake potential of the plants. Like ours, Sezer et al. (2021) found that the $K^+$ and $Ca^{+2}$ content in maize seedlings reduced with increasing water salinity. Regarding our research, the presence of $K^+$, $Ca^{2+}$, and $Na^+$ ions in seed reserves can be attributed to the ability of plants to withstand osmotic stress under salinity conditions. Therefore, irrigating maize plants with ≥ 3.5 dS $m^{-1}$ saline waters is not recommended due to decreasing assimilate movement from root to grain, thus causing poor seed quality.




| | ANOVA | | | | |
|---|---|---|---|---|---|
| | $Na^{+2}$ | $K^{+}$ | $Ca^{+2}$ | $K^{+}/Na^{+2}$ | $Ca^{+2}/Na^{+2}$ |
| *P>F* | ** | *** | ** | *** | *** |

Figure 1. Changes in leaf $Na^{+2}$, $Ca^{+2}$, $K^{+}$ levels, $K^{+}/Na^{2+}$, and $Ca^{2+}/Na^{2+}$ ratios in maize seeds grown at different salinities of irrigation water. ***: p≤0.001 **: p≤0.01.

## Conclusion

This study aimed to test a practical method for indicating the reuse potential and the early seedling capacity of maize seeds grown under irrigation water salinities. The findings showed that the saline irrigation water significantly affected the growth parameters, with the highest growth observed at the lowest salinity (0.30 $dSm^{-1}$). Additionally, the research indicated that using saline water for irrigation led to a noteworthy variation in the nutrient levels of maize seedlings' leaves, whereby the amount of $Na^{+}$ in the leaves rose proportionally to the salinity level of the irrigation water. In contrast, leaf $K^{+}$ and $Ca^{2+}$ ions reduced markedly with increasing water salinity. According to our study, it is recommended that the water salinity level should be kept below 3.5 dS $m^{-1}$ to prevent salt buildup in the root zone during the seed-filling period, which can adversely impact seed quality and yield. Overall, the results of this study provide new insights for farmers and researchers in reusing and selecting maize seeds harvested from saline soils.

## References

Ahmad, I., Ahmad, B., Boote, K., Hoogenboom, G., 2020. Adaptation strategies for maize production under climate change for semi-arid environments. *European Journal of Agronomy* 115: 126040.

Alkharabsheh, H.M., Seleiman, M.F., Hewedy, O.A., Battaglia, M.L., Jalal, R.S., Alhammad, B.A., Schillaci, C., Ali, N., Al-Doss, A., 2021. Field crop responses and management strategies to mitigate soil salinity in modern agriculture. *Agronomy* 11(11): 2299.

Arif, Y., Singh, P., Siddiqui, H., Bajguz, A., Hayat, S., 2020. Salinity induced physiological and biochemical changes in plants: An omic approach towards salt stress tolerance. *Plant Physiology and Biochemistry* 156: 64-77.

Bewley, J.D., Bradford, K.J., Hilhorst, H.W.M., Nonogaki, H., 2013. Seeds: Physiology of development, germination and dormancy. Third edition. Springer, 392p.

Bistgani, Z.E., Hashemi, M., DaCosta, M., Craker, L., Maggi, F., Morshedloo, M.R., 2019. Effect of salinity stress on the physiological characteristics, phenolic compounds and antioxidant activity of Thymus vulgaris L. and Thymus daenensis Celak. *Industrial Crops and Products* 135: 311-320.

Chaudhary, D.P., Kumar, S., Langyan, S., 2013. Maize: Nutrition Dynamics and Novel. Springer, 161p.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., Prasanna, B.M., 2022. Global maize production, consumption and trade: trends and R&D implications. *Food Security* 14: 1295-1319.

FAO, 2021. Statistical yearbook 2021. Food and Agriculture Organization of the United Nations, Rome, 2021.

Farooq, M., Hussain, M., Wakeel, A., Siddique, K.H.M., 2015. Salt stress in maize: effects, resistance mechanisms, and management. A review. *Agronomy for Sustainable Development* 35: 461-481.

Hopmans, J.W., Qureshi, A.S., Kisekka, I., Munns, R., Grattan, S.R., Rengasamy, P., Ben-Gal, A., Assouline, S., Javaux, M., Minhas, P.S., Raats, P.A.C., Skaggs, T.H., Wang, G., De Jong van Lier, Q., Jiao, H., Lavado, R.S., Lazarovitch, N., Li, B., Taleisnik, E., 2021. Critical knowledge gaps and research priorities in global soil salinity, *Advances in Agronomy* 169: 1-191.

Hu, Y., Schmidhalter, U., 2005. Drought and salinity: A comparison of their effects on mineral nutrition of plants. *Journal of Plant Nutrition and Soil Science* 168: 541-549.

Khodarahmpour, Z., Ifar, M., Motamedi, M., 2014. Effects of NaCl salinity on maize (Zea mays L.) at germination and early seedling stage. *Journal of Agriculture and Food Sciences* 11: 298-304.

Kiremit, M.S., Arslan, H., 2016. Effects of irrigation water salinity on drainage water salinity, evapotranspiration and other leek (Allium porrum L.) plant parameters. *Scientia Horticulturae* 201: 211-217.

Koyro, H.W., Eisa, S.S., 2008. Effect of salinity on composition, viability and germination of seeds of Chenopodium quinoa. *Plant and Soil* 302: 79-90.

Läuchli, A., Grattan, S.R., 2007. Plant growth and development under salinity stress, In: Advances in Molecular Breeding Toward Drought and Salt Tolerant Crops. Jenks, M.A., Hasegawa, P.M., Jain, S.M. (Eds.). Springer, pp. 1-32.

Li, J., Chen, J., Jin, J., Wang, S., Du, B., 2019. Effects of ırrigation water salinity on maize (zea may l.) emergence, growth, yield, quality, and soil salt. Water 11(10): 2095.

Lu, S., Bai, X., Li, W., Wang, N., 2019. Impacts of climate change on water resources and grain production. *Technological Forecasting and Social Change* 143: 76-84.

Meena, H.N., Yadav, R.S., 2018. Effects of reusing peanut seeds grown in saline ırrigation water on yield attributes and quality traits. *Journal of Irrigation and Drainage Engineering* 144: 04018002.

Mukhopadhyay, R., Sarkar, B., Jat, H.S., Sharma, P.C., Bolan, N.S., 2021. Soil salinity under climate change: Challenges for sustainable agriculture and food security. *Journal of Environmental Management* 280: 111736.

Öztürk, E., Akay, H., Sezer, İ., 2021. Şeker mısırda çimlenme ve erken fide gelişimi döneminde tuz stresine karşı salisilik asit ön uygulamasının etkisi. *Journal of the Institute of Science and Technology* 11: 3213-3221. [in Turkish].

Rouf Shah, T., Prasad, K., Kumar, P., 2016. Maize-A potential source of human nutrition and health: A review. *Cogent Food & Agriculture* 2: 1166995.

Salika, R., Riffat, J., 2021. Abiotic stress responses in maize: a review. *Acta Physiologiae Plantarum* 43: 130.

Sehgal, A., Sita, K., Siddique, K.H.M., Kumar, R., Bhogireddy, S., Varshney, R.K., HanumanthaRao, B., Nair, R.M., Prasad, P.V.V., Nayyar, H., 2018. Drought or/and heat-stress effects on seed filling in food crops: Impacts on functional biochemistry, seed yields, and nutritional quality. *Frontiers in Plant Science* 871: 1705.

Singh, A., 2022. Soil salinity: A global threat to sustainable development. *Soil Use and Management* 38(1): 39-67.

Soriano, D., Huante, P., Gamboa-deBuen, A., Orozco-Segovia, A., 2014. Effects of burial and storage on germination and seed reserves of 18 tree species in a tropical deciduous forest in Mexico. *Oecologia* 174: 33-44.

Vaughan, M.M., Block, A., Christensen, S.A., Allen, L.H., Schmelz, E.A., 2018. The effects of climate change associated abiotic stresses on maize phytochemical defenses. *Phytochemistry Reviews* 17: 37-49.

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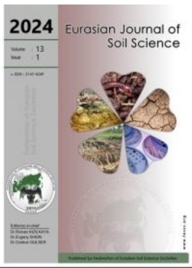

# Optimal timing of satellite data acquisition for estimating and modeling soil salinity in cotton fields of the Mingbulak District, Uzbekistan

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## Abstract
Agriculture is frequently hampered by soil salinity, which has a negative impact on crop growth and yield. This study aims to identify the optimal timing of satellite data acquisition to predict soil salinity levels indirectly using satellite images in cotton growth fields as a basis. Data was collected in the Mingbulak district of Uzbekistan, where soil electrical conductivity (EC) was measured in a laboratory using soil samples collected from various fields with similar management practices. In this research, we present a linear regression model that uses satellite data and the Normalized Difference Salinity Index (NDSI) to forecast soil salinity levels indirectly. The results of the linear regression analysis showed a positive correlation between the soil electrical conductivity values and the NDSI values for each month, with August having the highest correlation ($R^2$ = 0.70). The study found that the cotton growth stages and the process of soil salinity formation in the study area were the main factors affecting the correlation between electrical conductivity and NDSI. The model developed in this study has $R^2$ value of 0.70. This suggests a moderate to strong relationship between the two variables, which is promising for the indirect assessment of soil salinity using the NDSI index. The study discovered a positive relationship between soil electrical conductivity and NDSI values, which were highest in pre-flowering and flowering stages of cotton. Our findings show that satellite-based estimation and modeling with NDSI can be used to indirectly assess cotton field soil salinity, especially during the pre-flowering and flowering stages. This study contributes to the development of optimal satellite data acquisition timing, which can improve soil salinity predictions and agricultural productivity.

**Keywords:** Cotton, index, soil, salinity, satellite image.



## Introduction

Salinity is a pervasive issue in many arid and semi-arid regions worldwide, including Uzbekistan, where it significantly impacts crop productivity and agricultural yields (Hamad, 2016; Asfaw et al., 2018; Zörb et al., 2019). In Uzbekistan alone, saline soils affect half of the 4.2 million-hectare irrigated agricultural area (Kholdorov et al., 2022). Several factors contribute to soil salinization, such as mineralization, groundwater depth, and the imbalance between precipitation and evaporation (Stavi et al., 2021; Zhang et al., 2022). It is crucial to map and monitor soil salinity for national food security purposes. While conventional techniques for mapping and monitoring geographical and temporal changes in soil salinity exist, they may prove to be slower, more costly, and more intensive than remote sensing technologies (Tan et al., 2023). Given the substantial variability in soil salinity across large regions and timeframes, the effective mapping and monitoring of soil salinity in irrigated lands is crucial (Kholdorov et al., 2023a).

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Remote sensing has recently become an effective approach for soil salinization mapping because of its rapid updates, large coverage, and significant spectrum information. Nevertheless, remote sensing applications are severely constrained when the soil surface is partially vegetated, since vegetation may affect the overall spectral features of saline soil, resulting in poor forecast accuracy (Liu et al., 2019). However, plant cover may be utilized as the primary indication of agricultural land salinity. Vegetation indices were utilized as indirect indicators in various investigations to demonstrate a relationship between remote sensing spectral reflectance and soil salinity (Khajehzadeh et al., 2022; Li et al., 2022). Some research has utilized salinity indices, which are strongly connected to vegetative cover, to assess cropland salinity (Aslanov et al., 2021; Kholdorov et al., 2023b). The degree of soil salinisation is intimately connected to vegetation characteristics. For example, plants may generate less chlorophyll when stressed by high soil salt levels, resulting in alterations in the reflectance spectra of leaves (Zhu et al., 2021). As plants are subjected to biotic and abiotic stress (such as salt), their photosynthetic activity diminishes, resulting in increased visible reflectance and decreased near-infrared reflectance (NIR) from the vegetation (Scudiero et al., 2015). Soil salinity has been determined in areas with different types of vegetation, including cotton vegetation (Pankova and Mazikov, 1985; Zhang et al., 2021). Cotton is considered an ideal indicator for assessing soil salinity in irrigated drylands because of its strong correlation with electrical conductivity (Metternicht and Zinck, 2003). Aerial imaging techniques are effectively employed to map and quantify soil salinity levels in cotton fields by integrating image analysis, spectral observations, and ground-truth data (Wiegand et al., 1994). Accurate estimation of salinity from satellite imagery is contingent on the temporal dimension of image data acquisition. Pankova and Mazikov (1976) established the most favorable timing for detecting salinization in cotton fields using aerial photographs as their principal data source. In Turkey, the evaluation of soil salinity relies on hyperspectral remote sensing and the spectral characteristics of crops, such as cotton and wheat, confirming their suitability for detecting soil salinity (Allbed and Kumar, 2013). Ivushkin et al. (2017) conducted a study in Uzbekistan's salt-affected semi-arid Syrdarya Province, utilizing MODIS satellite data to monitor canopy temperature. Their research revealed significant correlations between soil salinity and canopy temperature, with the most pronounced associations observed in cotton fields, particularly in September. Advancements in remote sensing technology have resulted in improved accuracy and precision for measuring soil salinity. Advanced satellite sensors can provide a precise assessment of salinity levels in cotton fields, thereby enabling efficient crop management and yield optimization. The indirect estimation of soil salinity using satellite image is relatively straightforward when studies are conducted on a variety of plant species. This is because the large variation in soil salinity that results from the diversity of the environment makes the estimation of soil salinity relatively straightforward. However, when only cotton fields are considered, the variation in soil salinity may be quite minimal. The existence of salt-tolerant weeds in cultivated fields has the potential to decrease the accuracy of indirect salinity determination as these plants are able to flourish in saline environments. Nevertheless, in the cotton fields of the study region, salt-tolerant weeds are rarely observed due to the implementation of regular weed control measures. Additionally, the study was conducted in these cotton fields because they represent over half of the agricultural land in Mingbulak district. This makes it possible to produce a district-level salinity map utilizing the developed model. Because of this, the applicability of existing methods for estimating soil salinity from remote sensing data is called into question. It is necessary to conduct additional research in order to determine whether or not such methods can be applied successfully in this context. Furthermore, the time of year when the image data used for this purpose is captured is also considered to be important in accurately estimating salinity from satellites. However, to the best of our knowledge, there are no studies that have investigated the optimal timing in Mingbulak disrtrict of Uzbekistan.

We used satellite-based estimation and modelling to fill the knowledge gap in indirect soil salinity analysis in cotton fields in Mingbulak, Uzbekistan. Our novel method uses satellite images to determine the best time to estimate soil salinity levels, improving our understanding of indirect soil salinity and plant growth. We used five months of Landsat 8 Operational Land Imager images and linear regression analysis of NDSI values from the satellite images because of based on our previous study where we compared 17 indices obtained from Landsat 8 and Sentinel-2A satellite data and found that Landsat 8 NDSI index provided highly accurate estimates of soil salinity (Kholdorov et al., 2023b). In total, we used five months of satellite imagery and collected soil samples from 40 points in the study field to verify EC values. Research questions: How well do satellite-based estimation and modeling indirectly assess soil salinity in cotton fields in Mingbulak district? When should satellite images be used to estimate indirect soil salinity in study cotton fields? We aimed to create a high-resolution remote sensing and statistical model for indirectly analyzing soil salinity. Our results will help policymakers and farmers manage indirect soil salinity in Mingbulak. This study will bridge satellite-based estimation and soil salinity analysis, improving our understanding of cotton field soil salinity dynamics.

## Material and Methods

### Study area

The research was carried out in Uzbekistan's Mingbulak district. The Mingbulak district is critical to the agricultural local economy (Figure 1). Irrigated cropland accounted for 37779 hectares of the total land area of 52580 ha. The majority of irrigated soil groups are represented by Gleysols or Solanchaks. The Mingbulak district is critical to the agricultural local economy. Irrigated cropland accounted for 37779 hectares of the total land area of 52580 ha. Cotton is the most important industrial crop farmed in the region.

Two soil types that are frequently found in the Minbulak district of Namangan, Uzbekistan, are gleysols and solonchaks. Poor drainage and the presence of gley and rust stains in the deeper soil layers are two characteristics of gleysols. In contrast, solonchaks are saline soils that have a high concentration of soluble salts and are typically found in arid and semiarid areas with shallow groundwater. Due to their physical and chemical characteristics, both soil groups have a restricted potential for agriculture. In the Minbulak district, where they make up the majority of irrigated soil groups, Gleysols and Solonchaks are still frequently used for irrigation. In the Minbulak district, the predominant soil types for Gleysols and Solonchaks are sandy loam, sandy clay loam, and sandy clay, with a homogeneous structure made up of layers with a light mechanical composition.

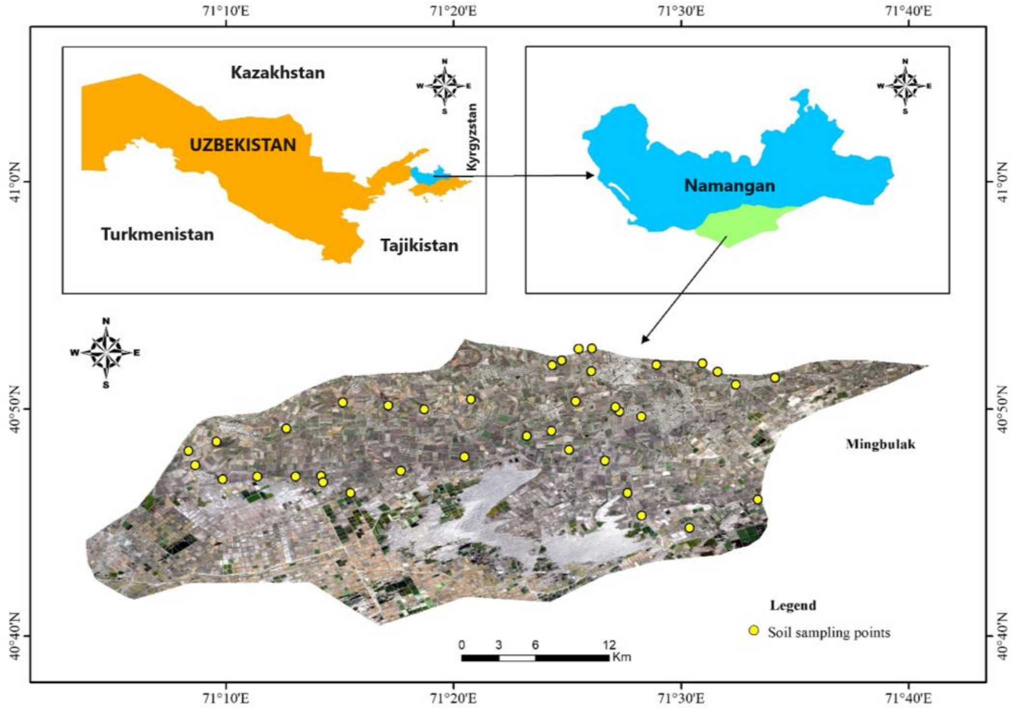


Figure 1. Study location and soil sampling points

### Soil sample collection and laboratory analysis

Soil samples were collected at a depth of 0-20 cm from 40 randomly selected points in various fields with similar management practices to cotton planting in the study area from September 18 to September 25, 2022 (Figure 1). The exact coordinates of each sampling point were determined using a global positioning system (GPS).

Soil samples' EC values were determined using a soil-and-water suspension with a concentration of one-fifth (1:5). Twenty grams of air-dried soil was placed in a 250 ml polyethylene Erlenmeyer flask, 100 ml of distilled water was added (1:5, weight/volume), the flask was sealed with glass caps, and it was inverted and shaken in a horizontal position using a piston shaker. Shaken for 60 minutes at 180 osc $min^{-1}$. After 30 minutes of shaking, the mixture was taken out of the shaker and left to rest. The EC value (in dS $m^{-1}$) was determined to be optimal at a temperature of 25 degrees Celsius (FAO, 2021). The electrical conductivity values of the 1:5 soil extracts obtained in the laboratory were converted to ECe using a conversion factor specific to the soil texture of the study area to ensure consistency with the USDA classification (Richards, 1954). The conversion was carried out using the following formula, which takes into account the soil texture-specific conversion factor CF (CF = 10)

$$ECe = EC_{1:5} \times CF$$

### Satellite data

As a satellite image, Landsat 8-9 Operational Land Imager (OLI) Thermal Infrared Sensor (TIRS) Collection 2 Level 2 images were used to develop a model for estimating soil salinity. The Landsat-8 image was obtained from the website (www. earth explorer.gov) of the United States Geological Survey (USGS). The Landsat 8-9 Operational Land Imager (OLI) Thermal Infrared Sensor (TIRS) Collection 2 Level images have a spatial resolution of 30 m for most bands, with a higher resolution available in the panchromatic band (15 m) and a lower resolution for thermal bands (100 m). Landsat 8-9 OLI/TRIS 2 Level data encompass visible, near-infrared, shortwave infrared, cirrus, and thermal infrared bands. They are characterized by a repeat cycle of approximately 16 days and a radiometric resolution of 12 bits per pixel. These images were preprocessed, including atmospheric correction and geometric rectification, making them ready for analysis. Landsat 8-9 OLI/TRIS 2 Level data are freely accessible and widely used for diverse applications in environmental monitoring, land cover classification, and more (Vaughn, 2019). Between May and September 2022, satellite images were obtained on five occasions at various times. On the following dates, the data was downloaded: May 24, 2022, June 25, 2022, July 27, 2022, August 20, 2022, and September 21, 2022. Band 4 (red) and band 5 (near-infrared) of Landsat 8-9 OLI/TRIS were used indirect estimating soil salinity as Normalized Difference Salinity Index (NDSI) with following equation (Khan et al., 2001).

$$\text{NDSI} = (\text{Red} - \text{NIR})/(\text{Red} + \text{NIR})$$

For all five downloads, the NDSI index was calculated using the same equation and index source, with no variations or modifications. The primary reason for using the Normalized Difference Salinity Index (NDSI) as mentioned above, index determination of soil salinity in the study area is that in previous studies, the NDSI index demonstrated the highest accuracy among salinity indices (Aslanov et al., 2021; Kholdorov et al., 2023b). Using satellite images of the study area, NDSI index values were calculated using ArcGIS 10.8 software. Each soil sampling point's NDSI values were obtained separately from 5 months of satellite images.

### Statistical analysis and model development

Regression analysis was carried out utilizing EC laboratory data which soil samples were taken from depths of 0-20cm. Models explaining soil EC from the NDSI salinity index obtained from the satellite were developed by a single regression analysis using the least squares method with modelling datasets. The model with the best fit was adopted by linear regression. Microsoft Excel was used for tabulation and statistical analyses. Regression analysis was performed on a cross-section of all downloaded satellite images corresponding to the cotton growing season.

## Results and Discussion

### Laboratory and image analysis results

Laboratory analysis and ArcGIS software were used to collect data for the study. Table 1 presents the EC values obtained by laboratory analysis of soil samples from the study area and the results obtained by processing satellite images. The soils of the study area are nonsaline (0-2 dS $m^{-1}$), slightly saline (2-4 dS $m^{-1}$), and moderately saline (4-8 dS $m^{-1}$) based on EC values

obtained in the laboratory and calcification suggested by USDA (Richards, 1954). The main reason for the absence of highly saline and very highly saline levels in the study area is that salt leaching measures are done every year before cotton planting. Furthermore, cotton cultivation takes place primarily in non-saline areas. Despite the fact that cotton is a relatively salt-tolerant crop, increased soil salinization would compromise its ability to cope with salt stress (Zafar et al., 2022). Cotton grown on non-saline soil has significantly higher productivity and vegetative development than cotton grown under the influence of salinization (Guo et al., 2012).

The NDSI values obtained from analyzing satellite images downloaded at five different times for the study vary considerably. NDSI values changed significantly according to the cotton growing season (Figure 2). The NDSI value was high in the first month of cotton development (May), but it dropped dramatically when cotton reached its peak of development (August). The main trend line in Figure 2 is the 36 ID soil sampled field, where the NDSI value did not change consistently due to the abundance of salt-tolerant weeds. The reasons for the change in NDSI values are discussed in detail in the statistical analysis and modeling results section.

Table 1. EC values and monthly NDSI values for each soil sampling point

| ID | EC, dSm-1 | NDSI values | | | | | |
|---|---|---|---|---|---|---|---|
| | | May | June | July | August | September | Average |
| 1 | 3.25 | -0.143 | -0.317 | -0.312 | -0.303 | -0.200 | -0.255 |
| 2 | 1.22 | -0.124 | -0.297 | -0.334 | -0.387 | -0.179 | -0.264 |
| 3 | 2.23 | -0.112 | -0.314 | -0.344 | -0.337 | -0.279 | -0.277 |
| 4 | 1.2 | -0.147 | -0.308 | -0.410 | -0.419 | -0.201 | -0.297 |
| 5 | 1.82 | -0.057 | -0.190 | -0.352 | -0.328 | -0.146 | -0.215 |
| 6 | 1.38 | -0.088 | -0.297 | -0.407 | -0.408 | -0.229 | -0.286 |
| 7 | 2.3 | -0.069 | -0.212 | -0.346 | -0.360 | -0.169 | -0.231 |
| 8 | 1.27 | -0.124 | -0.380 | -0.386 | -0.394 | -0.204 | -0.297 |
| 9 | 0.86 | -0.074 | -0.284 | -0.331 | -0.372 | -0.198 | -0.252 |
| 10 | 2.29 | -0.143 | -0.239 | -0.313 | -0.335 | -0.186 | -0.243 |
| 11 | 1.75 | -0.092 | -0.291 | -0.381 | -0.400 | -0.192 | -0.271 |
| 12 | 2.07 | -0.118 | -0.343 | -0.398 | -0.425 | -0.204 | -0.298 |
| 13 | 1.6 | -0.149 | -0.281 | -0.337 | -0.356 | -0.216 | -0.268 |
| 14 | 3.05 | -0.096 | -0.204 | -0.291 | -0.340 | -0.183 | -0.223 |
| 15 | 1.64 | -0.093 | -0.317 | -0.364 | -0.368 | -0.224 | -0.273 |
| 16 | 2.18 | -0.080 | -0.197 | -0.334 | -0.310 | -0.175 | -0.219 |
| 17 | 2.38 | -0.116 | -0.249 | -0.331 | -0.360 | -0.159 | -0.243 |
| 18 | 1.58 | -0.116 | -0.249 | -0.331 | -0.360 | -0.159 | -0.243 |
| 19 | 0.42 | -0.120 | -0.363 | -0.406 | -0.429 | -0.226 | -0.309 |
| 20 | 1.29 | -0.126 | -0.351 | -0.375 | -0.390 | -0.208 | -0.290 |
| 21 | 0.49 | -0.119 | -0.364 | -0.462 | -0.460 | -0.234 | -0.328 |
| 22 | 3.3 | -0.123 | -0.185 | -0.326 | -0.311 | -0.217 | -0.232 |
| 23 | 2.01 | -0.101 | -0.337 | -0.409 | -0.420 | -0.275 | -0.308 |
| 24 | 2.36 | -0.101 | -0.215 | -0.342 | -0.343 | -0.220 | -0.244 |
| 25 | 2.25 | -0.163 | -0.276 | -0.314 | -0.338 | -0.224 | -0.263 |
| 26 | 2.04 | -0.161 | -0.363 | -0.403 | -0.414 | -0.221 | -0.312 |
| 27 | 0.75 | -0.072 | -0.226 | -0.361 | -0.392 | -0.178 | -0.246 |
| 28 | 1.16 | -0.124 | -0.317 | -0.391 | -0.410 | -0.244 | -0.297 |
| 29 | 2.36 | -0.113 | -0.280 | -0.334 | -0.346 | -0.179 | -0.250 |
| 30 | 2.24 | -0.079 | -0.272 | -0.335 | -0.348 | -0.179 | -0.242 |
| 31 | 1.9 | -0.066 | -0.150 | -0.344 | -0.332 | -0.153 | -0.209 |
| 32 | 1.43 | -0.092 | -0.261 | -0.365 | -0.384 | -0.163 | -0.253 |
| 33 | 2.21 | -0.080 | -0.296 | -0.350 | -0.384 | -0.211 | -0.264 |
| 34 | 0.5 | -0.083 | -0.306 | -0.418 | -0.433 | -0.242 | -0.297 |
| 35 | 3.26 | -0.156 | -0.180 | -0.263 | -0.296 | -0.198 | -0.219 |
| 36 | 4.5 | -0.161 | -0.170 | -0.150 | -0.160 | -0.160 | -0.160 |
| 37 | 0.42 | -0.139 | -0.289 | -0.417 | -0.422 | -0.247 | -0.303 |
| 38 | 0.46 | -0.083 | -0.251 | -0.400 | -0.425 | -0.224 | -0.277 |
| 39 | 3.18 | -0.106 | -0.229 | -0.296 | -0.332 | -0.234 | -0.240 |
| 40 | 2.19 | -0.109 | -0.292 | -0.308 | -0.358 | -0.231 | -0.260 |

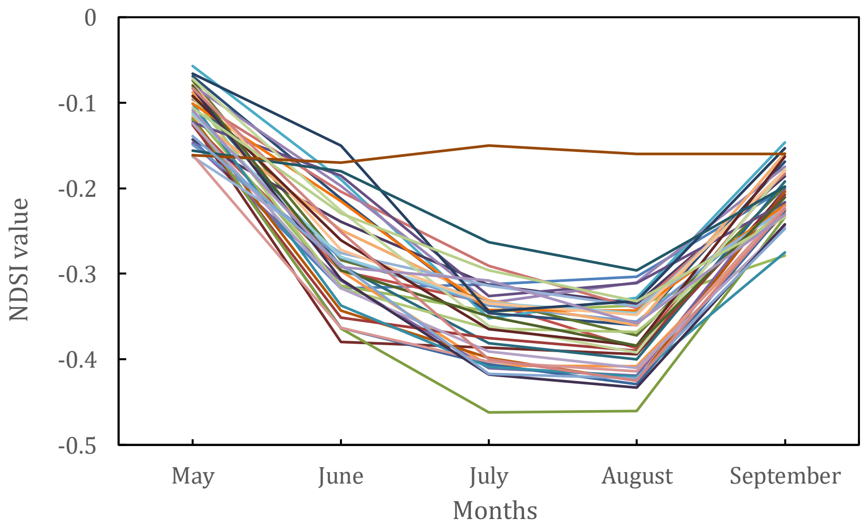

Figure 2. Seasonal variation in NDSI by soil sampling site

**Results of statistical analysis and modelling**

The results of our linear regression analysis showed a positive relationship between the EC values of the soil samples and the NDSI values derived from satellite images for each month (Figure 3). The $R^2$ values show a significant and precise relationship ($R^2 = 0.70$) between the soil EC value and the NDSI value obtained from the August satellite image. Based on previous studies by Pankova and Mazikov (1976), it was determined that the optimal shooting time for cotton, particularly in Uzbekistan, is during late summer and early autumn. Pankova and Mazikov (1985) used aerial photographs to determine this, and later published a detailed methodology in 1985 recommending flight dates during this period.

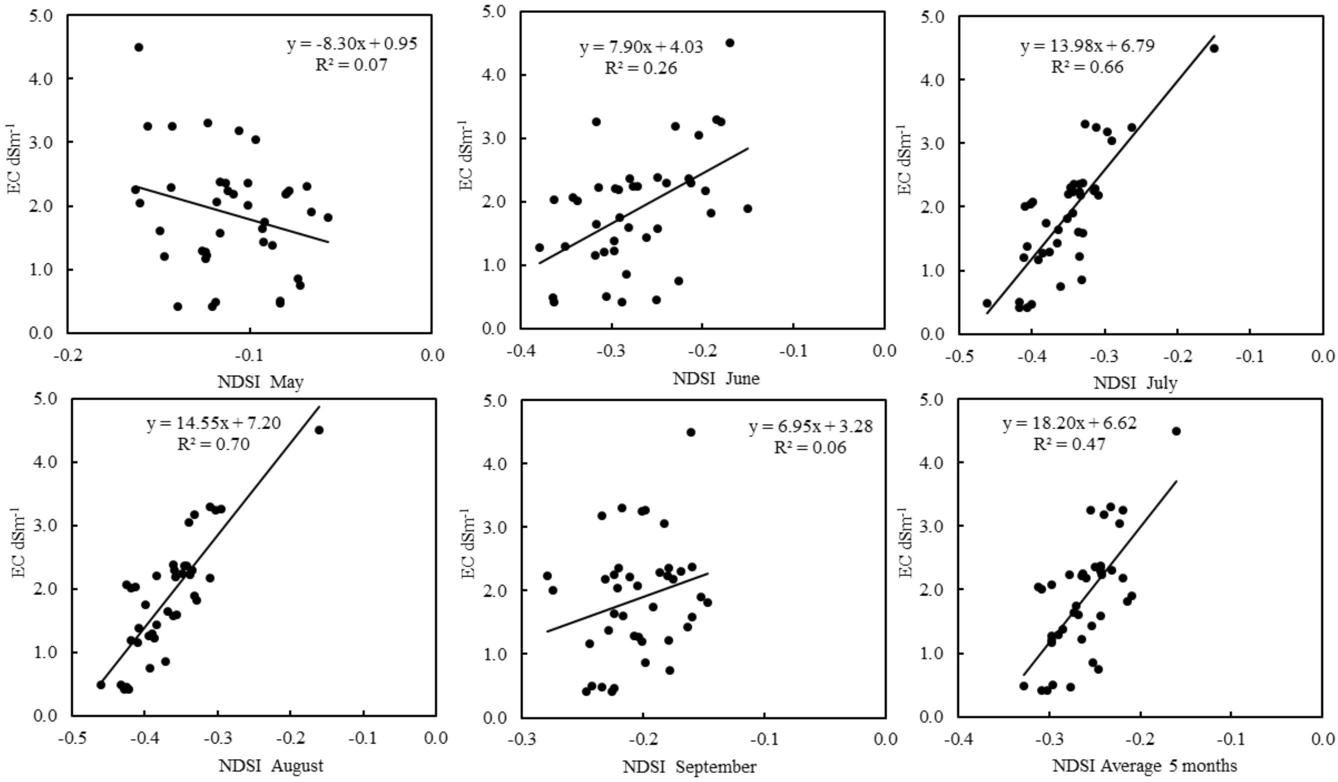


Figure 3. Relationships between EC value and monthly NDSI value

Based on the $R^2$ values, the order of highest to lowest correlation is as follows: July ($R^2 = 0.66$), the 5-month average ($R^2 = 0.47$), June ($R^2 = 0.26$), May ($R^2 = 0.07$), and September ($R^2 = 0.06$). There are several reasons for the high correlation between August and July. The NDSI index used in the study can be used to detect soil salinity directly. It detects salinity through the visible white salt crusts on the bare soil surface (Ijaz et al., 2020). However, in the remote sensing process, the cotton plant's covering of the soil surface significantly reduces the possibility of detecting salt particles directly on the soil surface using the NDSI index. Nevertheless, NDSI can be used in conjunction with plant reflectance measurements to better understand the spatial distribution and severity of soil salinity (Elhag and Bahrawi, 2017). Salinity-induced stress in cotton plants was determined indirectly in this study using changes in visible and near-infrared reflectors. Based on this, the linear regression analysis results can be divided into binary main factors. The main two factors are the cotton growth stages and the process of soil salinity formation in the study area depending on the period of cotton growth (Figure 4). August has the highest correlation between EC and NDSI, and the first reason for this is the cotton plant's growing season. The cotton plant is planted in the Mingbulak district, which is the research area, in the middle of April, and the vegetation period lasts until the beginning of November (Figure 4).

As a result, cotton's initial development occurs during the months of April, May, and June, when the plant is small and has few leaves. This had an effect on the NDSI values, limiting the plant's ability to separate visible and infrared reflectance. This reduces the possibility of indirect determination of salinity. If we look at the period of cotton growth, the peak of vegetative development corresponds to the end of July and August. During this period, the plant canopy covers a large portion of the pixel surface, appearing as the object with the greatest influence on spectral emissivity, so leaves become the transmitter of soil salinity effects (Salcedo et al., 2022). This indicates that it is the optimal period for determining indirect salinity. Cotton harvest aids involve the use of chemical defoliants to disrupt cotton's physiological and biochemical processes (Chen et al., 2022). Cotton grows and matures faster, and its leaves fall off earlier. Cotton cultivation defoliation activities are carried out in the study region in September. Green leaves begin to dry and fall off as a result. This significantly reduces remote sensing's ability to indirectly determine soil salinity using the example of a cotton plant, as well as the correlation between EC and NDSI for September in this study.

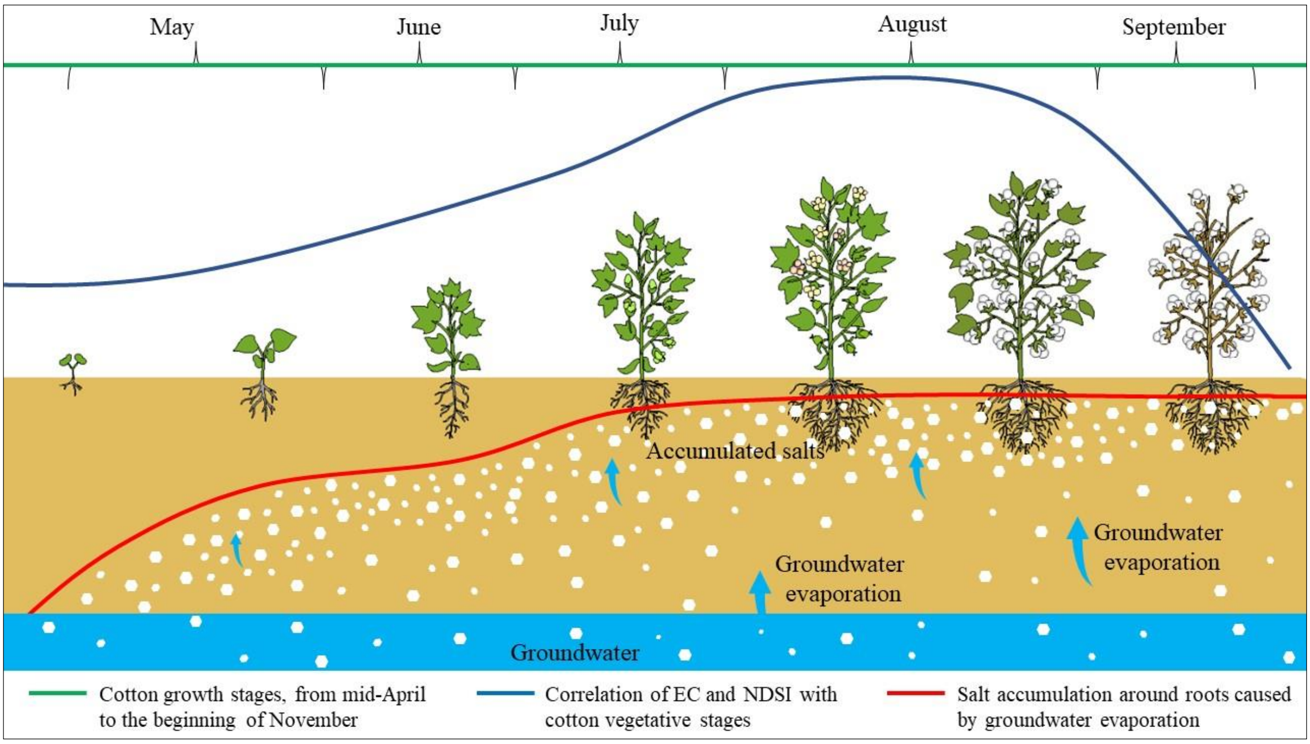


Figure 4. Diagram of seasonal variation in the growth of cotton mulberry and the degree of salt accumulation

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Although soil samples collected in September were theoretically predicted to have the highest correlation. Another significant aspect is that the mineralogical composition of groundwater is one of the primary causes of salinity in the study area. Cotton fields in the study area are primarily irrigated through furrows, causing groundwater levels to rise. The evaporation of underground water is caused by high temperatures during the summer months (Corwin, 2021; Jahanbazi et al., 2023; Zhang et al., 2023). The maximum temperature in May was 36 °C, 40 °C in June, 41 °C in July, 36 °C in August, and 38 °C in September, according to data from the meteorological station installed in the study area. The evaporation of underground water reached its maximum in July, and as a result, this effect was hidden in August, resulting in the greatest amount of salt accumulating around the plant's roots (Figure 4). Because of the salt accumulation around the roots, the plant's ability to absorb nutrients and water through the roots is limited, resulting in a stress situation in the plant (Kholliyev et al., 2020). As a consequence, it is reasonable to infer that a high accuracy correlation between EC and NDSI was observed in August.

After investigating the relationship between soil salinity and the NDSI index, we used the NDSI to model obtained in August for indirect soil salinity assessment (EC). As a result, the relationship between EC and NDSI was established, as shown in the equations below, with $R^2 = 0.70$:

$$EC = 14.55 \times NDSI + 7.20$$

Using this model, it is possible to deduce the EC level of soils indirectly by remotely analyzing cotton field satellite imagery acquired in the Mingbulak region during August. Although previous studies have used aerial photographs to determine soil salinity, this study utilized more advanced satellite sensors that were not available at the time of those studies. These newer sensors provide more accurate and up-to-date information on soil salinity. Therefore, the findings of this study can be considered an update and improvement on previous research. It is critical to recognize that the outcomes produced by salinity index models are heavily dependent on the various environmental factors present in the study area. As a result, it is plausible to assert that the salinity index and its corresponding models may produce divergent results in different environments.

## Conclusion

The relationship between soil salinity and the normalized difference salinity index (NDSI) derived from satellite images was investigated in this study for the Mingbulak region of Uzbekistan. According to the research findings, there is a positive correlation between soil EC values and NDSI values for each month, with pre-flowering and flowering stages August having the highest correlation ($R^2$ = 0.70), as determined by the linear regression analysis.

Furthermore, when analyzing the correlation between EC and NDSI, the study emphasized the importance of accounting for cotton growth stages and the process of soil salinity formation in the study area. The authors determined that August is the best time to use the NDSI index to indirectly determine soil salinity because it corresponds to the peak of vegetative development in the cotton plant, which maximizes the plant's ability to reflect the effects of soil salinity. Additionally, the study proposed a model for indirect soil salinity assessment based on the NDSI index obtained in August, which can be used for remote analysis of cotton field satellite imagery to determine soil EC levels. However, when applying this model in different regions, it is critical to consider environmental factors. Accurately identifying the source of stress, whether salinity, lack of water, or nutrients, is critical for obtaining reliable results in plant stress assessment. The timing of the survey with respect to watering was not specifically addressed in our study which may impact on the interpretation of remote sensing data, and we recognize this as a limitation that will be considered in future studies. It is recommended that irrigation tables be used in conjunction with soil nutrient analysis to achieve greater accuracy. Besides that, the authors intend to improve the precision of their models in future research by collecting soil samples throughout the yearand tracking soil salinity and nutrient levels. This will allow them to create more precise models for assessing soil salinity in agricultural areas. Overall, we found a positive correlation between soil EC values and NDSI values, with the highest correlation found in pre-flowering and flowering stages of cotton. Our results suggest that satellite-based estimation and modeling using NDSI can provide a reliable means of indirectly assessing soil salinity levels in cotton fields. This enables the creation of salinity maps for indirect soil salinity assessment via remote sensing in countries with extensive cotton cultivation, such as Uzbekistan. This approach can potentially save significant time and economic resources compared to traditional soil salinity determination methods.

## References

Allbed, A., Kumar, L., 2013. Soil salinity mapping and monitoring in arid and semi-arid regions using remote sensing technology: A Review. *Advances in Remote Sensing* 2(4): 373–385.

Asfaw, E., Suryabhagavan, K.V., Argaw, M., 2018. Soil salinity modeling and mapping using remote sensing and GIS: The case of Wonji sugar cane irrigation farm, Ethiopia. *Journal of the Saudi Society of Agricultural Sciences* 17: 250–258.

Aslanov, I., Kholdorov, S., Ochilov, S., Jumanov, A., Jabbarov, Z., Jumaniyazov, I., Namozov, N., 2021. Evaluation of soil salinity level through using Landsat-8 OLI in Central Fergana valley, Uzbekistan. E3S Web of Conferences 258, 03012.

Chen, P., Xu, W., Zhan, Y., Yang, W., Wang, J., Lan, Y., 2022. Evaluation of cotton defoliation rate and establishment of spray prescription map using remote sensing imagery. *Remote Sensing* 14(17): 4206.

Corwin, D.L., 2021. Climate change impacts on soil salinity in agricultural areas. *European Journal of Soil Science* 72(2): 842-862.

Elhag, M., Bahrawi, J.A., 2017. Soil salinity mapping and hydrological drought indices assessment in arid environments based on remote sensing techniques. *Geoscientific Instrumentation Methods and Data Systems* 6: 149–158.

FAO, 2021. Standard operating procedure for soil electrical conductivity, soil/water, 1:5. FAO, Rome, Italy. 15p. Available at [Access date: 18.05.2023]: https://www.fao.org/3/cb3354en/cb3354en.pdf

Guo, W., Maas, S.J., Bronson, K.F., 2012. Relationship between cotton yield and soil electrical conductivity, topography, and Landsat imagery. *Precision Agriculture* 13: 678–692.

Hamad, I.A., 2016. The use of ınverse distance weighted and fuzzy logic to estimate land suitability by geographic ınformation system in South of Iraq. *Alexandria Science Exchange Journal* 37: 26-35.

Ijaz, M., Ahmad, H.R., Bibi, S., Ayub, M.A., Khalid, S., 2020. Soil salinity detection and monitoring using Landsat data: a case study from Kot Addu, Pakistan. *Arabian Journal of Geosciences* 13: 510.

Ivushkin, K., Bartholomeus, H., Bregt, A.K., Pulatov, A., 2017. Satellite thermography for soil salinity assessment of cropped areas in Uzbekistan. *Land Degradation and Development* 28(3): 870–877.

Jahanbazi, L., Heidari, A., Mohammadi, M.H., Kuniushkova, M., 2023. Salt accumulation in soils under furrow and drip irrigation using modified waters in Central Iran. *Eurasian Journal of Soil Science* 12(1): 63–78.

Khajehzadeh, M., Afzali, S.F., Honarbakhsh, A., Ingram, B., 2022. Remote sensing and GIS-based modeling for predicting soil salinity at the watershed scale in a semi-arid region of southern Iran. *Arabian Journal of Geosciences* 15, 423.

Khan, N.M., Rastoskuev, V. V, Shalina, E. V, Sato, Y., 2001. Mapping Salt-affected Soils Using Remote Sensing Indicators-A Simple Approach With the Use of GIS IDRISI. Proceedings of the 22nd Asian Conference on Remote Sensing, 5-9 November 2001, Singapore. Center for Remote Imaging, Sensing and Processing (CRISP), National University of Singapore; Singapore Institute of Surveyors and Valuers; Asian Association on Remote Sensing, 5 p.

Kholdorov, Sh., Gopakumar, L., Katsura, K., Jabbarov, Z., Jobborov, O., Shamsiddinov, T., Khakimov, A., 2022. Soil salinity assessment research using remote sensing techniques: a special focus on recent research. IOP Conference Series: Earth and Environmental Science 1068: 012037.

Kholdorov, S., Jabbarov, Z., Shamsiddinov, T., 2023a. Soil governance: A review of the current legislative framework for managing soil resources in Uzbekistan. *Soil Security* 13: 100105.

Kholdorov, Sh, Lakshmi, G., Jabbarov, Z., Yamaguchi, T., Yamashita, M., Samatov, N., Katsura, K., 2023b. Analysis of irrigated salt-affected soils in the central Fergana Valley, Uzbekistan, Using Landsat 8 and Sentinel-2 Satellite Images, Laboratory Studies, and Spectral Index-Based Approaches. *Eurasian Soil Science* 56, 1178–1189.

Kholliyev, A., Norboyeva, U., Kholov, Y., Boltayeva, Z., 2020. Productivity of cotton varieties ın soil salinity and water deficiency. *The American Journal of Applied Sciences* 2(10): 7–13.

Li, Y., Chang, C., Wang, Z., Zhao, G., 2022. Remote sensing prediction and characteristic analysis of cultivated land salinization in different seasons and multiple soil layers in the coastal area. *International Journal of Applied Earth Observation and Geoinformation* 111: 102838.

Liu, Y., Zhang, F., Wang, C., Wu, S., Liu, J., Xu, A., Pan, K., Pan, X., 2019. Estimating the soil salinity over partially vegetated surfaces from multispectral remote sensing image using non-negative matrix factorization. *Geoderma* 354: 113887.

Metternicht, G.I., Zinck, J.A., 2003. Remote sensing of soil salinity: Potentials and constraints. *Remote Sensing of Environment* 85(1): 1-20.

Pankova E.I., Mazikov V.M., 1985. Guidelines for the use of aerial photography materials for assessing soil salinity and conducting salt surveys of irrigated areas of the cotton-growing zone on a large and medium scale. Moscow, Russia. 73p. [in Russian].

Pankova E.I., Mazikov V.M., 1976. Estimation of salinity of irrigated soils of cotton fields from aerial photographs (on the example of the Golodnoy Steppe). Pochvvedenie 5: 55–65. [in Russian].

Salcedo, F.P., Cutillas, P.P., Cabañero, J.J.A., Vivaldi, A.G., 2022. Use of remote sensing to evaluate the effects of environmental factors on soil salinity in a semi-arid area. *Science of The Total Environment* 815: 152524.

Scudiero, E., Skaggs, T.H., Corwin, D.L., 2015. Regional-scale soil salinity assessment using Landsat ETM+ canopy reflectance. Remote Sensing of Environment 169: 335–343.

Stavi, I., Thevs, N., Priori, S., 2021. Soil salinity and sodicity in drylands: A review of causes, effects, monitoring, and restoration measures. *Frontiers in Environmental Science* 9: 712831.

Tan, J., Ding, J., Han, L., Ge, X., Wang, X., Wang, J., Wang, R., Qin, S., Zhang, Z., Li, Y., 2023. Exploring planetscope satellite capabilities for soil salinity estimation and mapping in arid regions oases. *Remote Sensing* 15(4): 1066.

Richards, L.A., 1954. Diagnosis and improvement of saline and alkaline soils. Agriculture Handbook, Vol. 60, USDA, Washington DC, 160 p.

Vaughn, I., 2019. Landsat 8 (L8) Data Users Handbook. USGS Science for a Changing World. EROS, Sioux Falls, South Dakota. 106p.

Wiegand, C.L., Rhoades, J.D., Escobar, D.E., Everitt, J.H., 1994. Photographic and videographic observations for determining and mapping the response of cotton to soil salinity. *Remote Sensing of Environment* 49(3): 212-223.

Zafar, M.M., Shakeel, A., Haroon, M., Manan, A., Sahar, A., Shoukat, A., Mo, H., Farooq, M.A., Ren, M., 2022. Effects of salinity stress on some growth, physiological, and biochemical parameters in cotton (Gossypium hirsutum L.) germplasm. *Journal of Natural Fibers* 19(14): 8854–8886.

Zhang, J., Zhang, Z., Chen, J., Chen, H., Jin, J., Han, J., Wang, X., Song, Z., Wei, G., 2021. Estimating soil salinity with different fractional vegetation cover using remote sensing. *Land Degradation and Development* 32(2): 597–612.

Zhang, X., Shu, C., Wu, Y., Ye, P., Du, D., 2023. Advances of coupled water-heat-salt theory and test techniques for soils in cold and arid regions: A review. *Geoderma* 432: 116378.

Zhang, Y., Hou, K., Qian, H., Gao, Y., Fang, Y., Xiao, S., Tang, S., Zhang, Q., Qu, W., Ren, W., 2022. Characterization of soil salinization and its driving factors in a typical irrigation area of Northwest China. Science of the Total Environment 837: 155808.

Zhu, K., Sun, Z., Zhao, F., Yang, T., Tian, Z., Lai, J., Zhu, W., Long, B., 2021. Relating hyperspectral vegetation indices with soil salinity at different depths for the diagnosis ofwinter wheat salt stress. *Remote Sensing* 13(2): 250.

Zörb, C., Geilfus, C.M., Dietz, K.J., 2019. Salinity and crop yield. *Plant Biology* 21(S1): 31-38.

Eurasian Journal of Soil Science 2024, 13(1), 35 - 42

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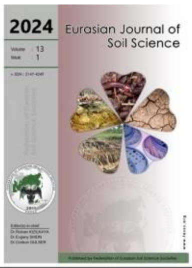

# Impact of tillage and crop rotations on soil organic matter content in Northern Kazakhstan's chernozem soils: A 10-year study (2011-2021)

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## Abstract

This extensive 10-year study conducted in Northern Kazakhstan investigates the intricate relationship between soil management techniques, crop rotations, and soil organic matter (SOM) content in Chernozem soils, an essential agricultural resource in the region. The experiments were established at the Karabalyk Agricultural Experimental Station, characterized by a arid continental climate. The study systematically examined the impact of two primary soil management techniques, conventional tillage (CT) and no-tillage (NT), in combination with various crop rotations. The crop rotations tested included grain-fallow rotations, fruit-exchange crop rotations, and an eight-field fruit-exchange crop rotation. The results provide valuable insights into the sustainable management of Chernozem soils in arid conditions, underscoring the role of crop rotation strategies in preserving SOM content. The findings reveal that among the crop rotations tested, the eight-field fruit-exchange crop rotation exhibited the most favorable outcomes for SOM preservation. This rotation helped maintain relatively stable SOM levels over the 10-year study period, contributing to soil health and fertility. In the context of the region's arid climate, the choice of soil management technique (CT or NT) had a limited impact on SOM content. The stability of SOM levels across diverse crop rotations and years highlights the dominant influence of crop management practices in this distinctive agricultural environment. This research serves as a valuable reference for tailored approaches to ensure soil health and organic matter preservation in the unique conditions of Northern Kazakhstan. It promotes the adoption of diversified crop rotations, with particular emphasis on the effectiveness of the eight-field fruit-exchange crop rotation, as a powerful strategy to mitigate organic matter loss, enhance soil quality, and optimize soil fertility in arid agricultural landscapes. The insights gained from this study are vital for sustainable land management in the region and underscore the importance of region-specific, holistic investigations to guide effective agricultural practices. The findings offer a solid foundation for the development of strategies that address soil health and safeguard the integrity of essential soil resources in these unique environments. The study conducted at the Karabalyk Agricultural Experimental Station in Northern Kazakhstan between 2011 and 2021 provides critical insights into the relationship between soil management techniques, crop rotations, and SOM content in Chernozem soils. The research suggests that diversified crop rotations, particularly the eight-field fruit-exchange crop rotation, represent a promising approach for mitigating organic matter loss and enhancing soil quality in arid regions.

**Keywords:** Chernozem soils, soil organic matter, soil management techniques, crop rotations, tillage.



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## Introduction

Soil, an indispensable natural resource, serves as the lifeblood of agricultural production, food security, and environmental equilibrium, particularly in regions characterized by arable landscapes like Kazakhstan. In such areas, the preservation of soil fertility and the sustainable management of this vital resource stand as pivotal drivers for agricultural advancement (Saparov, 2014). Central to the concept of soil fertility is the soil organic matter (SOM) content, a fundamental determinant of crop productivity and soil quality (Kızılkaya and Hepşen Türkey, 2014; Gülser et al., 2015; İslamzade et al., 2023).

Traditional agricultural practices, while undeniably essential for food production, often carry the unintended consequences of water scarcity, soil erosion, and a reduction in soil fertility (Montgomery, 2007; Quinton et al., 2010). Recognizing these challenges, there has been a significant shift towards the adoption of conservation agriculture, an approach aimed at enhancing the sustainability of agroecosystems (Farooq et al., 2011; Zhang et al., 2016). Conservation agriculture introduces diversity into the cultivation landscape, favoring crop rotation over the continuous cultivation of a single crop species. This approach contributes to the conservation of soil organic carbon (West and Post, 2002; Tiemann et al., 2015). Furthermore, conservation tillage practices, defined by the retention of at least 30% of soil surface cover through crop residues, mitigate physical disturbances to the soil structure and can aid in the restoration of soil fertility (Madejon et al., 2009; Liu et al., 2014).

Understanding the intricacies of how crop rotation and conservation tillage impact soil properties has been the subject of extensive field and incubation studies (Bünemann et al., 2004; Jacinthe and Lal, 2005; Madari et al., 2005; Salvo et al., 2010; Xu et al., 2013; Suleimenova et al., 2019; Ospanbayev et al., 2023). Collectively, these studies have presented a multifaceted view of the relationship between these practices and soil organic carbon. While some research indicates that conservation practices promote the accumulation of organic carbon in the surface layer of soil, primarily due to crop residue retention (Mazzoncini et al., 2016; VandenBygaart et al., 2010), others have reported less pronounced effects or no significant differences compared to conventional tillage and monoculture approaches (Angers et al., 1997; Barbera et al., 2012; Chatterjee et al., 2016; Sombrero and de Benito, 2010). Consequently, the dynamics of soil organic carbon content in response to crop rotation and various tillage practices remain intricate and warrant further exploration.

Ordinary chernozem soils, prevalent in regions like Kostanay, are distinguished by their naturally high SOM content, predominantly concentrated within the 60-80 cm horizon, where average SOM hovers around 7% (Saparov, 2014). Although these soils experience alterations due to anthropogenic activities, their fundamental classification generally remains intact. However, debates persist regarding whether prolonged human influence can engender substantial shifts in soil formation.

The sustained cultivation of crops over time, particularly within monoculture systems, has had a gradual and adverse effect on SOM content. Recent soil analyses conducted at the Karabalyk Agricultural Experimental Station tell a telling tale – by 2021, the SOM content had dwindled to 5.0-5.5%, marking a disconcerting loss exceeding 20% over half a century (Kabbozova-Saljnikov, 2004). These changes have driven the adoption of intensive mechanical soil treatments, aimed at controlling weeds, retaining moisture, and preserving nutrients. However, these very mechanical actions foster the mineralization of SOM in fallow fields (Kabbozova-Saljnikov, 2004). In recent years, the agricultural sector in northern Kazakhstan has witnessed the implementation of systemic measures aimed at adopting highly efficient no-tillage technology. This innovative approach to soil management, as introduced in the region, has played a pivotal role in mitigating soil erosion processes and bolstering grain crop yields (FAO, 2013; Saparov, 2014). Furthermore, various agricultural zones across the Republic of Kazakhstan have embraced the foundational principles of resource-conserving agriculture. This involves the implementation of mulch systems utilizing plant residues and, in some cases, a significant reduction or even the complete elimination of mechanical tillage. Consequently, the adoption of No-tillage technology has emerged as a linchpin in advancing the sustainability of dryland agriculture in the region. It achieves this by curbing erosion, enhancing soil quality, and augmenting the overall ecosystem services provided by the soil.

This study seeks to explore the ramifications of various tillage technologies, crop rotations, and precursors on SOM content in ordinary chernozem soils, particularly in the context of moderately arid steppe conditions. To this end, our research pursues several core objectives:

- Conduct a comprehensive comparative assessment of the influence of diverse tillage technologies on SOM content.

- Elucidate the distinctions in SOM preservation between grain fallow and fruit-exchange crop rotations, with a focus on the technological applications employed.
- Investigate the effects of continuous spring wheat cultivation on SOM content in contrast to crop rotations.
- Identify and recommend the most effective crop rotation strategies and processing technologies to mitigate SOM losses.

Furthermore, our research benefits from an extensive dataset collected at the Karabalyk Agricultural Experimental Station, spanning from 2011 to 2021 and encompassing the transition to a diversified eight-field fruit-exchange crop rotation. By comparing the long-term effects of zero technology with traditional practices, our study aims to make significant contributions to the ongoing discourse surrounding soil health and fertility preservation in Kazakhstan's agricultural landscape.

## Material and Methods

### Experimental Site

The study was conducted at the Karabalyk Agricultural Experimental Station which is situated in the Karabalyk region, Kazakhstan (53°50´N, 62°05´E). The experimental site is characterized by typical chernozem soils in a region with a high-water table, with a humus horizon thickness ranging from 40 to 60 cm. The soil is characterized by high base saturation (95-98%), primarily dominated by $Ca^{2+}$ (29.7 meq 100 $g^{-1}$) in the soil exchange complex, low $Na^{+}$ content (0.22 meq 100 $g^{-1}$), resulting in low swelling and good sediment absorption properties. The soil's pH in aqueous extract is near neutral (6.6-7.0). The nutrient content in the arable layer is as follows: total nitrogen (N) - 0.28-0.32%, total phosphorus (P) - 0.11-0.15%, and total potassium (K) - 1.8-2.8%.


Figure 1. Location of the experimental site at the Karabalyk Agricultural Experimental Station, Kazakhstan

The climate of the experimental site is continental and dry with large daily and monthly fluctuation in air temperatures. Mean annual temperature is around 2,8°C and the average yearly precipitation was 340 mm. The locations of the evaluations were characterized by the continental climate (large daily and annual fluctuations in air temperature, characterized by cold winters and long hot summers), the air temperature reaches minimum values in January (-17,5$^{0}$C), and maximum values in July (20,6$^{0}$C).

### Experimental Design:

This study was conducted at the "Karabalyk Agricultural Experimental Station". The rotations were set in a randomized complete block design in three replicates with all phases of each rotation present every year. Plot size was 55 × 6 m. The experiment followed a split-plot design with four replications, considering two main factors: tillage practices (Tillage) and crop rotations. Three tillage practices were examined: (i) Conventional Tillage (CT), which involved deep plowing followed by clod fragmentation, (ii) No-till (NT), where all mechanical treatments were excluded except for direct seeding after glyphosate application.

Crop Rotations;

- Grain-Fallow Crop Rotation (2011-2015)
- Fruit-Exchange Type Crop Rotation (2011-2015)
- Eight-Field Crop Rotation (Fruit-Exchange Type) (2016-2021)
- Eight-Field Crop Rotation (Fruit-Exchange Type) (2016-2021)

**Agronomic Activities**

Throughout the experimental period, various agronomic activities were meticulously conducted at the experimental site. These activities encompassed soil preparation, planting, cultivation, and harvesting, all performed in strict adherence to the designated tillage practices and crop rotations. The overarching objective was to establish and maintain conditions conducive to crop growth and data collection within the constraints of real-world agricultural practices. It is important to emphasize that no external organic matter inputs, aside from natural sources such as post-harvest crop residues, were introduced to the soils during the trial period. Furthermore, it should be noted that irrigation was exclusively reliant on natural precipitation and excluded any supplemental watering practices under controlled conditions. This comprehensive description ensures a clear understanding of the ecological and agronomic parameters governing the experimental setup.

**Soil Sampling and SOM analyses**

Soil samples were collected during specific time frames relevant to the study's objectives. Sampling involved collecting soil from the topsoil layer (0–20 cm depth) and was performed with three replicates. Soil organic carbon was determined using the wet oxidation method. Approximately 0.2 g of air-dried, 0.5 mm-sieved soil was oxidized with a solution of potassium dichromate ($K_2Cr_2O_7$) and sulfuric acid ($H_2SO_4$), and the soil organic carbon content was determined titrimetrically (Walkley and Black, 1934).

## Results and Discussion

Table 1 presents the SOM content based on different tillage practices in the grain-fallow crop rotation and continuous wheat monoculture for the years 2011 to 2015. Two tillage practices, Conventional Tillage (CT) and No-till (NT), were compared to evaluate their effects on SOM content. In the grain-fallow crop rotation, it is evident that both CT and NT resulted in similar SOM content across the years, with an average of around 5.0%. This indicates that the choice of tillage method had a limited impact on SOM in this specific rotation. It's important to note that there were no significant differences observed between CT and NT. In contrast, when considering continuous wheat monoculture, similar results were observed. The average SOM content remained around 5.0% for both CT and NT, indicating that neither tillage method had a substantial impact on SOM in this scenario.

Table 1. SOM content based on different tillage practices in grain-fallow crop rotation and continuous wheat monoculture (2011 - 2015, %)

| Year | Tillage | Crops of grain-fallow crop rotation | | | | Average crop rotation | Monoculture of wheat |
|---|---|---|---|---|---|---|---|
| | | Fallow | Wheat 1 after fallow | Wheat 2 after wheat | Wheat 3 after wheat | | |
| 2011 | CT | 4,8 | 5,2 | 5,2 | 5,2 | 5,1 | 5,0 |
| | NT | 5,0 | 5,2 | 5,0 | 5,0 | 5,1 | 5,0 |
| 2012 | CT | 5,0 | 5,4 | 5,4 | 5,3 | 5,3 | 5,0 |
| | NT | 5,1 | 5,4 | 5,2 | 5,2 | 5,2 | 5,0 |
| 2013 | CT | 4,7 | 5,1 | 5,1 | 5,1 | 5,0 | 4,9 |
| | NT | 4,9 | 5,1 | 4,9 | 4,9 | 5,0 | 4,9 |
| 2014 | CT | 4,8 | 5,4 | 5,2 | 5,3 | 5,2 | 4,9 |
| | NT | 5,1 | 5,4 | 5,1 | 5,1 | 5,2 | 4,9 |
| 2015 | CT | 4,7 | 5,2 | 5,1 | 5,1 | 5,1 | 5,0 |
| | NT | 5,0 | 5,2 | 5,0 | 5,0 | 5,0 | 5,0 |
| Average | CT | 4,8 | 5,3 | 5,2 | 5,2 | 5,1 | 5,0 |
| | NT | 5,0 | 5,3 | 5,0 | 5,0 | 5,1 | 5,0 |

Table 2 presents the SOM content based on different tillage practices in the fruit-exchange type crop rotation and continuous wheat monoculture for the years 2011 to 2015. The same tillage practices, CT and NT, were evaluated in this rotation. In the fruit-exchange type crop rotation, there was a slight variation in SOM content between CT and NT, with the average SOM content for CT being around 5.2% and for NT around 5.4%. These results suggest that NT may have a slightly positive effect on SOM content compared to CT in this specific rotation. For continuous wheat monoculture, the average SOM content for CT was around 5.0%, while for NT, it was also around 5.0%. These results indicate that, similar to the grain-fallow crop rotation, the choice of tillage method had minimal impact on SOM content in continuous wheat monoculture.

Table 3 presents the SOM content based on different tillage practices in the first section of the eight-field crop rotation in the fruit-exchange type and continuous wheat monoculture for the years 2016 to 2021. In this rotation, CT and NT were compared. For the first section of the eight-field crop rotation, both CT and NT resulted in similar SOM content, with an average of around 4.9%. This suggests that the choice of tillage method did not have a significant impact on SOM content in this section of the rotation. In the case of continuous wheat monoculture, the average SOM content for both CT and NT remained around 4.9%. Thus, as in previous cases, the choice of tillage method had limited effects on SOM content in continuous wheat monoculture.

Table 2. SOM content based on different tillage practices in fruit-exchange type crop rotation and continuous wheat monoculture (2011 - 2015, %)

| Year | Tillage | Crop rotation crops of the fruit-exchange type | | | | Average by crop rotation | Monoculture of wheat |
|---|---|---|---|---|---|---|---|
| | | Pea | Wheat after peas | Oilseed flax after wheat | Wheat after oilseed flax | | |
| 2011 | CT | 5,1 | 5,4 | 5,4 | 5,2 | 5,3 | 5,0 |
| | NT | 5,4 | 5,4 | 5,2 | 5,2 | 5,3 | 5,0 |
| 2012 | CT | 5,2 | 5,4 | 5,4 | 5,3 | 5,3 | 5,0 |
| | NT | 5,5 | 5,4 | 5,3 | 5,2 | 5,4 | 5,0 |
| 2013 | CT | 5,4 | 5,6 | 5,5 | 5,3 | 5,5 | 4,9 |
| | NT | 5,7 | 5,5 | 5,4 | 5,6 | 5,6 | 4,9 |
| 2014 | CT | 5,2 | 5,4 | 5,4 | 5,3 | 5,3 | 4,9 |
| | NT | 5,5 | 5,4 | 5,3 | 5,2 | 5,3 | 4,9 |
| 2015 | CT | 5,1 | 5,4 | 5,4 | 5,2 | 5,3 | 5,0 |
| | NT | 5,4 | 5,4 | 5,2 | 5,2 | 5,3 | 5,0 |
| Average | CT | 5,2 | 5,4 | 5,4 | 5,3 | 5,3 | 5,0 |
| | NT | 5,5 | 5,4 | 5,3 | 5,3 | 5,4 | 5,0 |

Table 3. SOM content based on different tillage practices in the first section of the eight-field crop rotation in fruit-exchange type and continuous wheat monoculture (2016-2021, %)

| Year | Tillage | Crops of the first section of the crop rotation of the fruit-exchange type | | | | Average by section | Monoculture of wheat |
|---|---|---|---|---|---|---|---|
| | | Fallow | Wheat after fallow | Pea after wheat | Wheat after pea | | |
| 2016 | CT | 4,9 | 5,0 | 5,4 | 5,3 | 5,2 | 5,0 |
| | NT | 4,9 | 5,4 | 5,6 | 5,4 | 5,3 | 5,0 |
| 2017 | CT | 4,8 | 4,9 | 5,3 | 5,2 | 5,1 | 4,9 |
| | NT | 4,8 | 5,3 | 5,5 | 5,3 | 5,2 | 4,9 |
| 2018 | CT | 5,0 | 5,1 | 5,5 | 5,4 | 5,3 | 4,9 |
| | NT | 5,0 | 5,5 | 5,7 | 5,5 | 5,4 | 4,9 |
| 2019 | CT | 5,1 | 5,0 | 5,4 | 5,3 | 5,2 | 4,8 |
| | NT | 5,1 | 5,4 | 5,6 | 5,4 | 5,4 | 4,8 |
| 2020 | CT | 5,0 | 5,1 | 5,5 | 5,4 | 5,3 | 4,9 |
| | NT | 5,0 | 5,5 | 5,7 | 5,5 | 5,4 | 4,9 |
| 2021 | CT | 4,9 | 5,0 | 5,4 | 5,3 | 5,2 | 5,0 |
| | NT | 4,9 | 5,4 | 5,6 | 5,4 | 5,3 | 5,0 |
| Average | CT | 5,0 | 5,0 | 5,4 | 5,3 | 5,2 | 4,9 |
| | NT | 5,0 | 5,4 | 5,6 | 5,4 | 5,4 | 4,9 |

Table 4 presents the SOM content based on different tillage practices in the second section of the eight-field crop rotation in the fruit-exchange type and continuous wheat monoculture for the years 2016 to 2021. In this section, CT and NT were compared. For the second section of the eight-field crop rotation, both CT and NT resulted in similar SOM content, with an average of around 4.9%. This indicates that the choice of tillage method did not have a significant impact on SOM content in this section of the rotation. In continuous wheat monoculture, the average SOM content for both CT and NT remained around 4.9%, suggesting that the choice of tillage method had limited effects on SOM content in this scenario.

In light of the results obtained in our study, it is evident that the choice of tillage method (CT or NT) had a limited impact on SOM content within various crop rotations and continuous wheat monoculture, as previously discussed. The SOM content remained relatively stable across the years and rotations, regardless of the specific tillage practice employed. These findings indicate that other factors, such as the selection of crop type and crop rotation, may exert a more substantial influence on SOM content within the studied agricultural landscape. However, it is noteworthy that these conclusions diverge from the outcomes of another research effort conducted in North Kazakhstan. In that study, prolonged agricultural land use was observed to lead to significant changes in chemical indicators. Over the course of a decade, the SOM content within ordinary chernozems exhibited a notable decrease. Specifically, in the arable horizon, the SOM content averaged around 5.5% after 10 years of agricultural use, reflecting a 33% reduction in the upper portion and a 23% decrease in the lower part of this horizon (Oshakbaeva, 2006). Moreover, the results of this prior investigation highlighted that over two decades of plowing ordinary chernozems, the humus content in the arable horizon experienced a slight decline, reaching 5.2%. This decline in humus content amounted to a 32% reduction when compared to virgin soils. In the upper section of the arable layer, humus content measured 5.6%, signifying a 32% reduction in comparison to the humus content of virgin soils. In the lower part of the arable horizon, humus content stood at 4.9%, with a 30% reduction relative to virgin lands (Oshakbaeva, 2006). The disparities between these two studies emphasize the complex and multifaceted nature of soil dynamics in agricultural systems. It is imperative to recognize that soil health and organic matter content are influenced by a myriad of interacting variables, including climatic conditions, agricultural practices, and specific regional characteristics. As such, while our study may suggest a limited impact of tillage practices on SOM content, the contrasting findings from the North Kazakhstan research underscore the necessity for region-specific and comprehensive investigations to guide sustainable land management practices. These insights further underscore the need for context-specific approaches in soil conservation and fertility preservation.

Table 4. SOM content based on different tillage practices in the second section of the eight-field crop rotation in fruit-exchange type and continuous wheat monoculture (2016-2021, %)

| Year | Tillage | Crops of the second section of the crop rotation of the fruit-exchange type | | | | Average by crop rotation | Monoculture of wheat |
|---|---|---|---|---|---|---|---|
| | | Oilseed flax | Wheat after flax | Lentils after wheat | Barley after lentils | | |
| 2016 | CT | 5,4 | 5,7 | 5,6 | 6,3 | 5,5 | 5,0 |
| | NT | 5,4 | 5,5 | 6,2 | 5,7 | 5,5 | 5,0 |
| 2017 | CT | 5,3 | 5,8 | 5,5 | 6,2 | 5,4 | 4,9 |
| | NT | 5,3 | 5,4 | 5,9 | 5,6 | 5,4 | 4,9 |
| 2018 | CT | 5,5 | 6,0 | 5,7 | 5,4 | 5,5 | 4,9 |
| | NT | 5,5 | 5,6 | 6,1 | 5,8 | 5,6 | 4,9 |
| 2019 | CT | 5,4 | 5,9 | 5,6 | 6,3 | 5,5 | 4,8 |
| | NT | 5,4 | 5,5 | 6,0 | 5,7 | 5,5 | 4,8 |
| 2020 | CT | 5,5 | 6,0 | 5,7 | 5,4 | 5,5 | 4,9 |
| | NT | 5,5 | 5,6 | 6,1 | 5,6 | 5,6 | 4,9 |
| 2021 | CT | 4,9 | 5,0 | 5,4 | 5,3 | 5,2 | 5,0 |
| | NT | 4,9 | 5,4 | 5,6 | 5,4 | 5,3 | 5,0 |
| Average | CT | 5,3 | 5,7 | 5,6 | 5,8 | 5,4 | 4,9 |
| | NT | 5,3 | 5,5 | 6,0 | 5,6 | 5,5 | 4,9 |

Previous studies have highlighted the multifaceted interplay between SOM dynamics, tillage practices, crop rotations, and regional conditions. These studies have consistently emphasized the significance of SOM for soil quality and crop productivity (Dick, 1983; Cambardella and Elliott, 1992; La1 et al., 1994; Angers et al., 1997; Suleimenova et al., 2019; Jaziri et al., 2022; Ospanbayev et al., 2023). Specifically, investigations comparing no-tillage (NT) to conventional tillage have often revealed an increase in SOM, favoring NT, especially in the surface soil layer down to the depth of plowing (20-30 cm in most cases). It's worth mentioning that the variation in C content in the surface soil layer is consistent with the outcomes of many studies, with fine-textured soils exhibiting higher C content regardless of tillage practice. Moreover, the long-term implications of tillage and crop rotation on SOC have been a subject of considerable interest. In a 36-year long-term experiment conducted in Canada, it was demonstrated that SOC was significantly higher for NT (2.73%) compared to CT (2.51) (Laamrani et al., 2020). Furthermore, the positive effects of crop rotations on physical, chemical, and biological soil properties have been attributed to higher SOC inputs and the diversity of plant residues returned to soils (Follett, 2001; Dimassi et al., 2013). The combination of NT and crop rotation has been shown to have the potential to further increase SOC and nitrogen content due to improved water use efficiency, particularly in semi-arid areas (Luo et al., 2010; Bahri et al., 2019).

Experimental site in the region's harsh continental climate, characterized by arid summers and frigid winters, suggests that the impact of soil processing and crop rotation on organic matter loss may be relatively minimal in the experimental site. However, it is essential to acknowledge the intricate interplay of diverse factors, including climatic conditions and the regional characteristics that contribute to soil dynamics and organic matter content. These findings underscore the necessity for region-specific and comprehensive investigations to guide sustainable land management practices. The combined insights from these studies underscore the importance of crop diversification and conservation agriculture adoption, particularly in ordinary chernozems in arid regions, to mitigate organic matter loss and enhance soil quality and fertility.

## Conclusion

This study examined the complex relationship between soil management methods, crop rotations, and soil organic matter (SOM) content in the context of moderately arid steppe conditions in Kazakhstan, characterized by a arid continental climate. Through comprehensive analyses spanning multiple years and diverse crop rotations, several key findings emerged. The results suggest that the choice of soil management methods, whether conventional tillage (CT) or no-tillage (NT), had a limited impact on SOM content. Regardless of the specific tillage method employed, SOM content remained relatively stable over various years and rotations. The region's harsh continental climate, with arid summers and frigid winters, appeared to mitigate the effects of soil processing and crop rotations on organic matter loss. However, it is crucial to acknowledge the intricate interplay of diverse factors, including climatic conditions and regional characteristics that contribute to soil dynamics and organic matter content. This study's insights underscore the importance of region-specific and comprehensive research to guide sustainable land management practices. The combined findings from these studies emphasize the significance of crop diversification and the adoption of conservation agriculture, particularly in ordinary chernozems in arid regions. These practices can help mitigate organic matter loss, enhance soil quality, and improve soil fertility. In summary, the research conducted in Kazakhstan's arid steppe region highlights the need to consider local ecological conditions and agricultural practices when addressing soil health and fertility preservation. By doing so, we can develop context-specific approaches to ensure the sustainability of agricultural landscapes and maintain vital soil resources for future generations.

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## References

Angers, D.A., Bolinder, M.A., Carter, M.R., Gregorich, E.G., Drury, C.F., Liang, B.C., Voroney, R.P., Simard, R.R., Donald, R.G., Beyaert, R.P., Martel, J., 1997. Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. *Soil and Tillage Research* 41(3–4): 191-201.

Bahri, H., Annabi, M., M'Hamed, C.H., Frija, A., 2019. Assessing the long-term impact of conservation agriculture on wheat-based systems in Tunisia using APSIM simulations under a climate change context. *Science of The Total Environment* 692: 1223–1233.

Barbera, V., Poma, I., Gristina, L., Novara, A., Egli, M., 2012. Long-term cropping systems and tillage management effects on soil organic carbon stock and steady state level of C sequestration rates in a semiarid environment. *Land Degradation & Development* 23(1): 82-91.

Bünemann, E.K., Bossio, D.A., Smithson, P.C., Frossard, E., Oberson, A., 2004. Microbial community composition and substrate use in a highly weathered soil as affected by crop rotation and P fertilization. *Soil Biology and Biochemistry* 36(6): 889-901.

Cambardella, C.A., Elliott, E.T., 1992. Particulate soil organic-matter changes across a grassland cultivation sequence. *Soil Science Society of America Journal* 56(3): 777-783.

Chatterjee, A., Cooper, K., Klaustermeier, A., Awale, R., Cihacek, L.J., 2016. Does crop species diversity ınfluence soil carbon and nitrogen pools? *Agronomy Journal* 108(1): 427-432.

Dick, W.A., 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. *Soil Science Society of America Journal* 47(1): 102-107.

Dimassi, B., Cohan, J.P., Labreuche, J., Mary, B., 2013. Changes in soil carbon and nitrogen following tillage conversion in a long-term experiment in Northern France. *Agriculture, Ecosystems & Environment* 169: 12–20.

FAO, 2013. Conservation Agriculture in Central Asia: Status, Policy, Institutional Support and Strategic Framework for its Promotion. FAO Sub-Regional Office for Central Asia (FAO-SEC) Ankara, Turkey. 60p. Available at [Access date: 01.04.2023]: http://www.fao.org/docrep/019/i3275e/i3275e.pdf

Farooq, M., Flower, K.C., Jabran, K., Wahid, A., Siddique, K.H.M., 2011. Crop yield and weed management in rainfed conservation agriculture. *Soil and Tillage Research* 117: 172-183.

Follett, R.F., 2001. Soil management concepts and carbon sequestration in cropland soils. *Soil and Tillage Research* 61(1-2): 77–92.

Gülser, C., Kızılkaya, R., Aşkın, T., Ekberli, İ., 2015. Changes in soil quality by compost and hazelnut husk applications in a Hazelnut Orchard. *Compost Science & Utilization* 23(3): 135-141.

İslamzade, R., Hasanova, G., Asadova, S., 2023. Impact of varied NPK fertilizer application rates and seed quantities on barley yield and soil nutrient availability in chestnut soil of Azerbaijan. *Eurasian Journal of Soil Science* 12(4): 371 - 381.

Jacinthe, P.A., Lal, R., 2005. Labile carbon and methane uptake as affected by tillage intensity in a Mollisol. *Soil and Tillage Research* 80(1–2): 35-45.

Jaziri, S., M'hamed, H.C., Rezgui, M., Labidi, S., Souissi, A., Rezgui, M., Barbouchi, M., Annabi, M., Bahri, H., 2022. Long term effects of tillage–crop rotation ınteraction on soil organic carbon pools and microbial activity on wheat-based system in Mediterranean semi-arid region. *Agronomy* 12(4): 953

Kabbozova-Saljnikov, E., Funakawa, S., Ahmetov, K., Kosaki, T., 2004. Soil organic matter status of Chernozem soil in North Kazakhstan: effects of summer fallow. *Soil Biology and Biochemistry* 36(9): 1373-1381.

Kızılkaya, R., Hepşen Türkay, F.Ş., 2014. Vermicomposting of anaerobically digested sewage sludge with hazelnut husk and cow manure by earthworm Eisenia foetida. *Compost Science & Utilization* 22(2): 68-82.

Laamrani, A., Voroney, P.R., Berg, A.A., Gillespie, A.W., March, M., Deen, B., Martin, R.C., 2020. Temporal Change of soil carbon on a long-term experimental site with variable crop rotations and tillage systems. *Agronomy* 10(6): 840.

Lal, R., Mahboubi, A.A., Fausey, N.R., 1994. Long-term tillage and rotation effects on properties of a central Ohio soil. *Soil Science Society of America Journal* 58(2): 517-522.

Li, H., Mollier, A., Ziadi, N., Shi, Y., Parent, L.E., Morel, C., 2017. The long-term effects of tillage practice and phosphorus fertilization on the distribution and morphology of corn root. *Plant and Soil* 412: 97–114.

Luo, Z., Wang, E., Sun, O., 2010. Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. *Agriculture, Ecosystems & Environment* 139(1-2): 224–231.

Madari, B., Machado, P.L.O.A., Torres, E., de Andrade, A.G., Valencia, L.I.O., 2005. No tillage and crop rotation effects on soil aggregation and organic carbon in a Rhodic Ferralsol from southern Brazil. *Soil and Tillage Research* 80: 185-200.

Madejón, E., Murillo, J.M., Moreno, F., López, M.V., Arrue, J.L., Alvaro-Fuentes, J., Cantero, C., 2009. Effect of long-term conservation tillage on soil biochemical properties in Mediterranean Spanish areas. *Soil and Tillage Research* 105(1): 55-62.

Mazzoncini, M., Antichi, D., Bene, C.D., Risaliti, R., Petri, M., Bonari, E., 2016. Soil carbon and nitrogen changes after 28 years of no-tillage management under Mediterranean conditions. *European Journal of Agronomy* 77: 156-165.

Montgomery, D.R., 2007. Soil erosion and agricultural sustainability. *The Proceedings of the National Academy of Sciences* 104 (33): 13268-13272.

Oshakbaeva Zh.O., 2006. Changes in the basic properties of the chernozems of the Kostanay region during long-term development. 125 p. Dissertation for the degree of Candidate of Sciences. Almaty, Kazakhstan. [in Russian]

Ospanbayev, Z., Doszhanova, A., Abdrazakov, Y., Zhapayev, R., Sembayeva, A., Zakieva, A., Yertayeva, Z., 2023. Tillage system and cover crop effects on organic carbon and available nutrient contents in light chestnut soil. *Eurasian Journal of Soil Science* 12(3): 238-243.

Quinton, J., Govers, G., Van Oost, K. Bardgett, R.D., 2010. The impact of agricultural soil erosion on biogeochemical cycling. *Nature Geoscience* 3: 311–314.

Salvo, L., Hernández, J., Ernst, O., 2010. Distribution of soil organic carbon in different size fractions, under pasture and crop rotations with conventional tillage and no-till systems. *Soil and Tillage Research* 109(2): 116-122.

Saparov, A., 2014. Soil Resources of the Republic of Kazakhstan: Current Status, Problems and Solutions. In: Novel Measurement and Assessment Tools for Monitoring and Management of Land and Water Resources in Agricultural Landscapes of Central Asia. Mueller, L., Saparov, A., Lischeid, G., (Eds.). Environmental Science and Engineering. Springer International Publishing. Switzerland. pp.61-73.

Sombrero, A., de Benito, A., 2010. Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. *Soil and Tillage Research* 107(2): 64-70.

Suleimenova, N., Makhamedova, B., Orynbasarova, G., Kalykov, D., Yertayeva, Z., 2019. Impact of resource conserving technologies (RCT) on soil physical properties and rapeseed (Brassica napus L.) yield in irrigated agriculture areas of the South-Eastern Kazakhstan. *Eurasian Journal of Soil Science* 8(1): 83 - 93.

Tiemann, L.K., Grandy, A.S., Atkinson, E.E., Marin-Spiotta, E., McDaniel, M.D., 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. *Ecology Letters* 18(8): 761-771.

VandenBygaart, A.J., Bremer, E., McConkey, B.G., Janzen, H.H., Angers, D.A., Carter, M.R., Drury, C.F., Lafond, G.P., McKenzie, R.H., 2010. Soil organic carbon stocks on long-term agroecosystem experiments in Canada. *Canadian Journal of Soil Science* 90(4): 543-550.

Walkley, A., Black, C.A., 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29–38.

West, T.O., Post, W.M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Science Society of America Journal* 66(6): 1930-1946.

Xu, N., Wilson, H.F., Saiers, J.E., Entz, M., 2013. Effects of crop rotation and management system on water-extractable organic matter concentration, structure, and bioavailability in a chernozemic agricultural soil. *Journal of Environmental Quality* 42(1): 179-190.

Zhang, Z., Qiang, H., McHugh, A.D:, He, J., Li, H., Wang, Q., Lu, Z., 2016. Effect of conservation farming practices on soil organic matter and stratification in a mono-cropping system of Northern China. *Soil and Tillage Research* 156: 173-181.

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# Improving the growth of *Glycyrrhiza Glabra* L. in saline soils using bioagent seed treatments

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## Abstract

Licorice (*Glycyrrhiza glabra* L.), known for its salt and drought tolerance, presents a potential solution for addressing soil salinity and desertification challenges in arid areas. Since the natural habitat of this plant is dwindling sharply in the Aral Sea regions due to negative human interventions, so it is vital to create production technologies with biological means. This study determined the agronomic characteristics of licorice when bioagents i.e. Geohumate, Aminomax and Caliphos were used as a seed treatment. Results showed that the application of these biostimulators significantly improved seed germination and plant growth compared to the control. Especially the effect was more pronounced with Geohumate as the seed germination increased by 36.4%, whereas the impacts of Aminomax and Caliphos were 17.5% and 12.4% higher, respectively as compared to the control group. Likewise, under the open-field condition, plant growth and development were greater with the bioagent applications. In regards the root biomass, the highest record with a 29.1% increase was achieved after the Geogumat treatment, while Aminomax and Caliphos applications exhibited 24.4 and 23.9% higher values, respectively as compared to the control values. The amounts of ash, glycyrrhizic acid, extractive compounds and flavonoids were increased by 26.5%, 22.0, 9.4% and 10.4%, respectively, compared to the respective control values due to the positive effect of the Geogumat treatment. Furthermore, the improved organic and chemical contents of soil were explained by the bioremediation functions of licorice plus bioagents efficiency. Using bioagents in licorice production could be a valuable approach for maintaining ecosystem function and stability in saline lands.

**Keywords:** Licorice (*Glycyrrhiza Glabra* L.), seed treatment, bio-agents, saline soil, seed germination, growth dynamics, root yield.



## Introduction

The shrinking of the Aral Sea was accompanied by decertification, salination and land degradation, negatively impacting overall agricultural sustainability in this region. Over time, the increased use of fertilizers and pesticides exacerbated the situation, resulting in groundwater and soil pollution, leading to considerably falling crop productivity (Kushiev et al., 2021). These factors ultimately created a vicious cycle of environmental degradation, jeopardizing the prospect of agricultural production. The leading causes of further development of salinity in the area are the Aral Sea disaster and the arid climate associated with a high level of soluble salt in the irrigated land and underground water (Khaitov et al., 2020; Qureshi and Daba, 2020). Furthermore, these challenges were intensified with anthropogenic factors and climate change as the

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main driving forces of ecological, environmental, and economic disaster. As a result, the area has experienced significant crop biodiversity reductions and overall ecosystem instability, decreasing crop productivity by 30-40%.

There are many degraded and abandoned lands in the Aral Sea region, whereas more than 90% of irrigated land is affected by salinity (Khaitov et al., 2022). Increased salinity levels in this region have restricted the growth of traditional crops. An urgent need is to restore salt-affected soils to their production potential while promoting environmentally sustainable development. The "*biosaline approach*" developed by the International Center for Biosaline Agriculture proposes modern techniques to rehabilitate abandoned salt-affected lands as a potential science-based solution. This approach is based on adaptable technology packages composed of salt-tolerant halophytes integrated with appropriate land and crop management systems.

Licorice (*Glycyrrhiza glabra*) is one of the existing native halophyte plants with salt and drought tolerance abilities in the Aral Sea regions. The plant is perennial and grows well in harsh environmental conditions because of its deep root system. It is used in several applications such as in medicine, cosmetics, manufacturing due to it's highly rich in nutritional profile. Therefore, this halophyte has a great economic value. Its natural distribution can be found in the deltas of the Amudarya river (on the territory of the Republic of Karakalpakstan and Khorezm province) and Syrdarya river and on the banks of small rivers in Fergana valley, Surkhandarya and Syrdarya provinces of Uzbekistan. Due to pharmacological properties i.e. glycyrrhizin and oleanane-type triterpene saponins in licorice roots, the demand for licorice grown and processed in Uzbekistan has steadily grown since 2000 (Khaitov et al., 2021; Mambetnazarov et al., 2021). Therefore, the over-exploitation has greatly decreased natural reserves of licorice in recent years. In fact, natural licorice habitats have decreased by 5.8-fold in Karakalpakstan during the last half century, from 38 thousand to 6.5 thousand hectares (Khaitov et al., 2021). These alarming records show this plant is in danger of extinction. Undoubtedly, the dwindling of the natural habitats of wild licorice creates ecological disasters, e.g., sandstorms, drought, air, soil and water pollution, soil salinization (Mambetnazarov et al., 2021).

Unfortunately, the local populace harvests wild licoricey roots, but its' cultivation is quite limited. Even though licorice is indigenous salt and drought-tolerant halophyte plant, it's not widely accepted by small and marginal farmers for subsistence farming systems. As a fragment of climate-resilient agriculture, improving licorice production has a great potential to rehabilitate abandoned saline lands. Licorice improves the physical and chemical properties of soil while enriching it with organic matters and restoring biological activities. These functions allow to provide the basis for sustainable reproduction of soil fertility and optimize environmental functions.

Very few research and crop improvement activities have been conducted on licorice so far. Development of licorice cultivation technologies with suitable seed treatment agents could also be used commercially. This research hypothesis that if licorice could grow under harsh conditions, biological agents might enhance crop productivity and soil quality, thereby rejuvenating the dryland cropping system. Although, studies exhibiting the role of bioagents to stimulate licorice growth, especially at the initial growth period and to alleviate salt stress are quite limited. Furthermore, using modern knowledge, innovation and technologies will bring added value by providing empowering opportunities.

Although, the region has suitable environmental conditions for the sustainable production of licorice, there was no research on using biostimulators for improving germination and growth under open-field conditions. Therefore, this research aims to determine the effectiveness of biological agents such as Geogumat, Aminomax, and Caliphos on the agronomic performance of licorice in saline areas.

## Material and Methods

### The study area

This study consisted of two series of licorice experiments under lab and open field conditions during 2018-2020 at the experimental station of the Institute of Agriculture and Agrotechnologies located in Nukus, Karakalpakstan (42.28°N 59.36°E), the north-west of Uzbekistan. Winter is severe in this area with absolute minimum air temperatures ranging from -10.3 up to 0.0°C intervals in December and January. In contrast, summer is long, dry and very hot, with an absolute maximum of 41.0-45.3°C (Figure 1). The desert region's harsh environment is characterized by high climatic fluctuation and recurrent periods of extreme drought. In this area, there are 270–280 days without frost overall, and the average annual evapotranspiration is up to 2000 mm. The annual rainfall ranges from 80 to 140 mm, although the most of it occurs from January to April, just before the start of the vegetative period. During the research period, 2018 was drier with only 83,0 mm of precipitation.

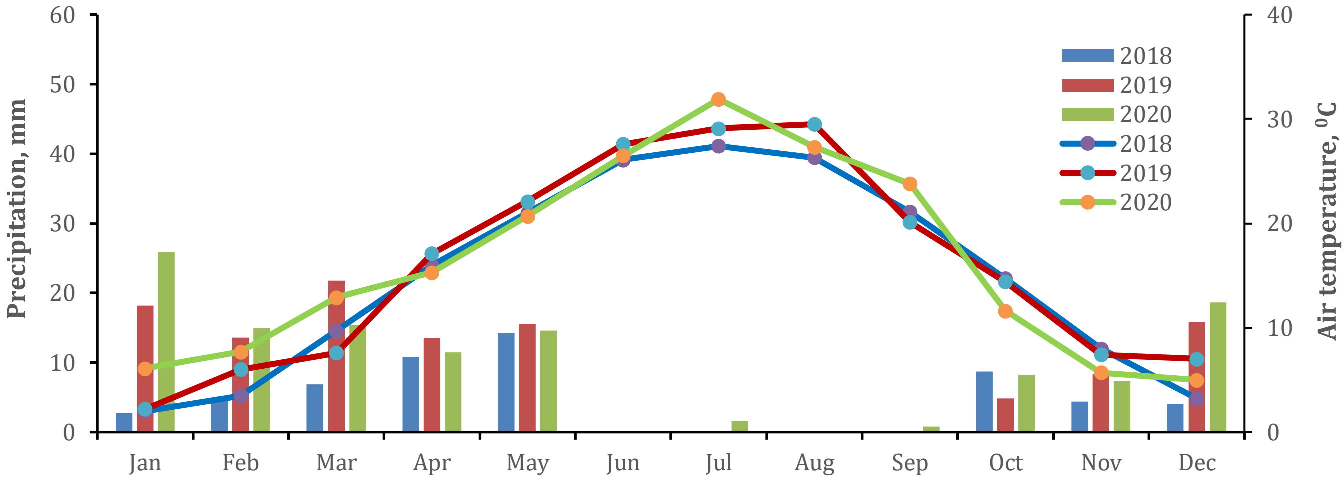


Figure 1. Climate records (2018-2020)

## Soil properties

Meadow-alluvial soil in the experimental field had an overall bulk density of 1.4 g/cm$^3$, this amount has changed 1.35 g/cm$^3$ in 0-30 cm and 1.38 g/cm$^3$ in 0-100 cm soil horizons. The enhanced soil bulk density in the ploughing horizon shows that the macroaggregates tolerant to water leaching underwent dispargation. The humus content in these soils is very low, only containing 0.5-0.6% in 0-30 cm soil ploughing depth (Table 1). The soil ploughing depth had total N content 0.030-0.050 %, total phosphorous 0.160-0.175% and overall potassium 1.78-1.85%. The pH value of the soil was 7.4 (slightly alkaline) with moderate salinity EC 5.7 dSm$^{-1}$. The mineralization level of underground water was 2.0-3.0 g L$^{-1}$, but during the vegetation season this characteristic is likely to increase due to the location in 2-3 meter depth.

Table 1. Agrochemical characteristics of the soil affected by *Glycyrrhiza glabra* cultivation.

| Treatments | Humus, % | N, % | P, % | K, % | $NO_3$, mg kg$^{-1}$ | $P_2O_5$, mg kg$^{-1}$ | $K_2O$, mg kg$^{-1}$ |
|---|---|---|---|---|---|---|---|
| At the beginning of the experiment (2018) | | | | | | | |
| | 0.610d | 0.072c | 0.142b | 1.145a | 13.2d | 17.56a | 174.7a |
| At the end of the experiment (2020) | | | | | | | |
| Control | 0.632c | 0.090b | 0.125c | 1.100b | 14.0c | 13.35c | 145.5b |
| Geogumat | 0.660a | 0.107a | 0.145a | 1.000b | 17.7a | 14.07b | 140.4c |
| Aminomax | 0.641b | 0.092b | 0.135b | 0.870c | 14.3b | 14.03b | 140.1c |
| Caliphos | 0.640b | 0.092b | 0.140b | 0.800c | 14.0c | 14.00b | 141.3c |

Means marked with different letters (a to d) represent significant differences ($p<0.05$) according to the Tukey's LSD test.

## Biofertilizers

*Geogumat* consisted of more than 20 microorganisms including Bacillus megaterium, Bacillus mucilaginosus, Basillus Subtilis and etc. It is liquid of 12% organic fertilizer and formed by microelements. There is Humic acid at least 32% and Fulfa and other organic acids consist of at least 25.0%. This biofertilizer positively impacts seed germination, root system development, and seedling growth, enhancing tolerance to environmental stresses and crop yield by 15-20%. In addition, it improves soil quality and productivity of mineral fertilizers.

*Aminmax* is organic fertilizer formed by 16% organic matters, 10% organic carbon, 10.2% overall free aminoacids, 10% humic and pulvo acids, 0.5% N, 1.5% $K_2O$, 0.6% MnO, 0.1% Mn, 0.1% Mo, 0.14% Zn. The level of pH is 4-6. It is used to rejuvenate soil microflora and thereby improve nutrients uptake by plants. It enhances seed germination and usually foliar treatment is useful for plant growth stimulation.

*Caliphos* is considered as liquid form of NPK. It consist of 1% N, 1.0% $NO_3$, 10.2% $P_2O_5$, 25% $K_2O$, 0,6% B, 0,1% Zn, pH is equal to 4-6. This bioagent is essential to increase nutrients for plant uptake, enhance vegetative and generative organs, thereby improving crop yield.

## Greenhouse Experiment

Three bioagents i.e., Geogumat, Aminmax, Caliphos were compared against the control variable on licorice seed germination using a factorial experiment design with three replications in the greenhouse (25$^0$C/15$^0$C; 14h day:10h night periodicity) with relative humidity between 65% and 75%. Each Petri dish contained 100 seeds previously cleaned. For both sets of experiments, 10 min surface sterilization of licorice seeds was done with 0.1% mercuric chloride. Analysis of seed germination and survivability were revealed as per standard techniques (Uzpiti, 2007). Firstly, the germinated seeds were calculated starting 5 days 10 days after sowing and seedling viability was found at 20 days.

Three types of saline soils representing the most common types of salinity i.e., low 2.4±1.1 $Na^+$ mM/100 g soil, moderate 8.5±1.2 $Na^+$ mM/100 g soil, high 15.6±1.7 $Na^+$ mM/100 g soil were used for the pot experiments. Pot seedlings were irrigated with the same amount of water (~200 ml each every 3 days).

**Field experiment practices and methods**

Split-plot treatment structure in a randomised complete block design were used in three replications. The total land for this experiment constituted 0.288 hectares, including each plot area was 240 square meter: 4.8 m x 50 m (8 rows, each one had 0.6 m width and 50 m length), while the accounting area was 120 square meters. These field experiments were conducted according to the guidelines entitled "Methods of Field Experiments" (UzPITI, 2007). Fodder productivity, root mass and seed yield parameters were determined on 1 square meter area in each plot before recording an average value. Plant density was found at two stages: after seedling emergence and at the end of vegetation. Agronomic parameters such as plant height, weight, leaf and pod numbers were carried out on the 25 labelled plants in each plot.

The following observations were determined in the field experiments: number of leaves, plant height, biomass of plants, specific leaf weights (leaf dry weight, leaf: shoot dry ratio, shoot dry matter), leaf area and content of chlorophyll. A leaf area was measured using a LI-COR LI-30004 portable leaf area meter, and the total chlorophyll content was measured with a Minolta SPAD-502. The total chlorophyll content was measured every five days, beginning a week after germination until plant final harvest.

The chosen field was ploughed in 28-30 cm depth in 1-5 October 2018, following laser levelling activities. Then, the field was divided into small sections (0,03-0,05 ha) to carry out salt leaching process with 2500-3200 $m^3$/ha water in late October. At mid-November, 80% annual norms of phosphorous and potassium fertilizers for licorice cultivation were applied under the plough. Spring began with field tilling, harrowing and cultivating. Seed planting started in 22-24 of April when the land heated enough under sunshine. The seed planting aggregate SN-500 was fixed at norms of 10 kg/ha when the seeds were soaked for 36 hours with appropriate biostimulator.

The optimal rate of mineral fertilizer $N_{100}P_{140}K_{80}$ was provided according to the fertilizer standards. The field was irrigated after the seed planting process in order to improve germination and get vigorous seedlings. Following weeding and cultivation activities in June, the full fertilization norm of N and the remaining 20% portions of phosphorous and potassium fertilizers were applied before furrow irrigation. The furrow irrigation was applied five times at 800-1000 m3/ha norms each time, totalling 4000-5000 $m^3$/ha for the entire season.

Root mass was estimated at the end of every season by digging up to 1 meter with monometer method and drying at 70$^0$C for 72 hours in the drier equipment. While leaf area was determined by taking 20 samples on 1 $cm^2$ with special equipment. The leaf area of each sample was found with the following formula:

leaf area ($cm^2$) = x / y, where x is the weight (g) of the area covered by the leaf outline, and y is the weight of one $cm^2$ of the same graph paper. Then, the photosynthetic efficiency was determined by the ratio between plant biomass and leaf area per day during the vegetation period.

Plant extracts, i.e., ash, glycyrrhizic acid, extractive compounds and flavonoids were determined by spectrophotometry in the Metlertoledo laboratory complex.

**Data analysis**

All experiments were carried out in triplicates and values are expressed as means with standard deviations (±SD). Graphics were drawn using MS Office Excel 2007. Statistical analysis was conducted with a one-way ANOVA tool (CropStat program).

## Results

**Seed germination at different salinity**

Data presented in Table 2 shows that the seed germination in all treatments increased progressively with increasing seed water soaking from 12 hours to 36 hours. The bioagent x water soaking interaction significantly impacted the germination of licorice seeds under lab conditions. Licorice seed reached to 85.0% germination at 20 days after a 36-hour water soaking period when seeds were treated with Geogumat. In this case, the treatment with Geogumat increased seed germination by 36.4%, while Aminomax and Caliphos enhanced this indicator by 17.5% and 12.4%, respectively, compared to the control variable.

Table 2. Seed germination % (lab experiment).

| Treatments | Water soaking period of seeds | 10 days after | 15 days after | 20 days after |
|---|---|---|---|---|
| Control | 12 hours | 10.1g | 35.3e | 39.1e |
| Geogumat | | 32.7d | 61.4b | 72.3b |
| Aminomax | | 25.6e | 50.1d | 60.2c |
| Caliphos | | 18.7f | 50.3d | 59.7c |
| Control | 24 hours | 30.4d | 44.7e | 50.8d |
| Geogumat | | 40.5b | 64.6ab | 75.9b |
| Aminomax | | 38.6c | 60.4b | 64.7c |
| Caliphos | | 36.2c | 52.8c | 54.4d |
| Control | 36 hours | 36.1c | 48.4d | 54.1d |
| Geogumat | | 46.7a | 68.7a | 85.0a |
| Aminomax | | 42.4b | 62.5b | 63.6c |
| Caliphos | | 40.6b | 55.4c | 60.8c |

Means marked with different letters (a to f) represent significant differences ($p<0.05$) according to the Tukey's LSD test.

Similarly, as shown in Figure 2, licorice seeds germinated vigorously under less saline soil in the pot experiments. However, the seed treatment with Geogumat showed a significant ($p<0.05$) increase (83.5%) in seed germination, while this characteristic was 72.3% and 70.4% higher under Aminomax and Caliphos applications, respectively compared to the control variable. The increased concentration of soil salinity caused a considerable decrease in seed germination in all treatments. At the moderate soil salinity, the highest seed germination record was detected in the Geogumat seed application with a 74.1% increase, followed by Aminomax and Caliphos treatments with increments of 65.6% and 55.4%, respectively, while this indicator reached to 52.2% in the control variable. Under high saline soil conditions, licorice seeds did not germinate at all, regardless of the seed treatment methods.

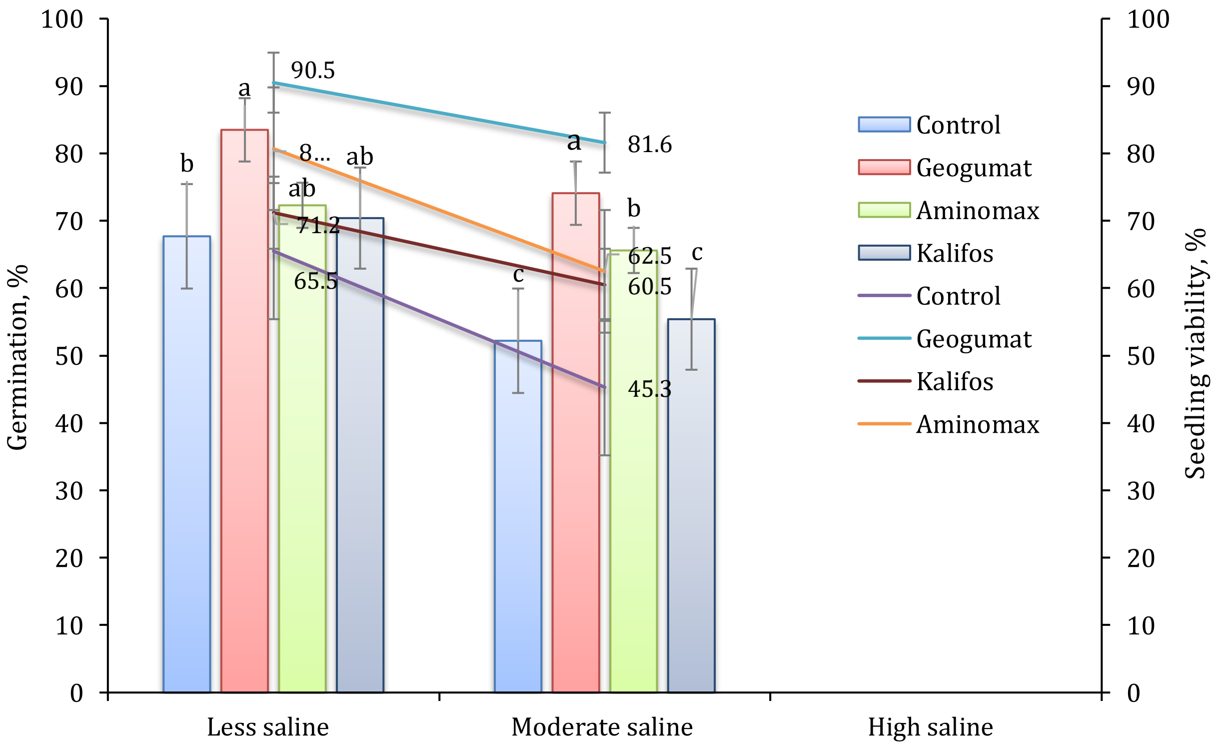


Figure 2. Seed germination of licorice under different soil salinity conditions (greenhouse experiment).

Analyses of seedlings viability exhibited the highest values by the Geogumat treatment from 90.5% in less saline soils and 81.6% in moderate saline soils, followed by the Aminomax (80.7% and 62.5%) and Caliphos seed treatments (71.2% and 60.5%) accordingly.

Overall, the bioagent application substantially alleviated the soil salinity effect by enhancing seed germination and seedling viability indicators. The effect was greater by Geogumat, followed by Aminomax and Caliphos applications promoting the studied parameters to a significant extent, whereas no significant difference was detected between the two latter applications.

**Plant growth characteristics under open-field conditions**

The positive effects of Geogumat, Aminomax and Caliphos to stimulate the germination, growth and development of licorice in the saline soils of Karakalpakstan have been identified in Table 3. The seed stimulation was more pronounced with Geogumat than the other bioagents, causing 76.6% germination. Whereas Aminomax and Caliphos treatments showed 70.3% and 70.4% seed germination, respectively. At the same time, this indicator in the control treatment was only 61.4%.

Table 3. Growth parameters of Glycyrrhiza glabra (at the end of vegetation period).

| Treatments | 2018 | | | | 2019 | | | 2020 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Germina tion (%) | Shoot height (cm) | Fruit branches | Plant density | Shoot height (cm) | Fruit branches | Plant density | Shoot height (cm) | Fruit branches | Plant density |
| Control | 61.4c | 86.6c | 5.5d | 158.0c | 119.4d | 5.8d | 138.5c | 118.9c | 5.6d | 121.1c |
| Geogumat | 76.6a | 103.7a | 8.2a | 171.8a | 153.7a | 8.8a | 150.3a | 132.5a | 8.3a | 131.4a |
| Aminomax | 70.3b | 100.8b | 7.4b | 165.5b | 147.3b | 8.0b | 144.5b | 130.4ab | 7.5b | 126.7b |
| Caliphos | 70.4b | 98.5b | 6.3c | 163.4 | 135.6c | 7.1c | 142.5b | 127.2b | 6.5c | 125.5b |

Means marked with different letters (a to d) represent significant differences ($p<0.05$) according to the Tukey's LSD test.

In the first year, considering shoot height of 86.6 cm tall and fruit branches 5.5 pieces in the control variable, whereas the Geogumat seed treatment enhanced the growth of shoot height and fruit branches by 19.7% and 49.1%, accordingly. Regardless of the bioagent applications, the plant gradually increased the shoot and root weights with time passage. The application of Aminomax and Caliphos stimulated the growth to a significant extent in both licorice shoots and roots, despite the inhibiting effect of salt stress.

As shown in Table 4, similar growth characteristics were detected in the following years of the experiment. However, in the third year, the plant started to allocate more photosynthetic materials to enhance root development, whereas shoot and leaf mass considerably declined compared to the second year. Seed treatment with Geogumat enhanced root biomass by 29.1% than that in the control, while Aminomax and Caliphos applications exhibited 24.4 and 23.9% higher values, respectively, indicating a positive effect in regards to plant development under soil salinity.

Table 4. Dry matter accumulation in licorice under the influence of the bioagents (2018-2020)

| Treatments | Root, g | Leaf, g | Shoot, g | Total, g |
|---|---|---|---|---|
| | | 2018 | | |
| Control | 14.1c | 15.4c | 38.5d | 68d |
| Geogumat | 21.5a | 33.0a | 45.5a | 100a |
| Aminomax | 20.3b | 31.3b | 42.3b | 93.9b |
| Caliphos | 20.0b | 30.9b | 40.9c | 91.8c |
| | | 2019 | | |
| Control | 37.5c | 39.4d | 87.5d | 164.4d |
| Geogumat | 42.9a | 56.5a | 110.7a | 210.1a |
| Aminomax | 40.5b | 50.3b | 105.1b | 195.9b |
| Caliphos | 40.0b | 47.3c | 100.8c | 188.1c |
| | | 2020 | | |
| Control | 40.2c | 35.6c | 80.1d | 155.9d |
| Geogumat | 51.9a | 50.8a | 100.7a | 203.4a |
| Aminomax | 50ab | 46.7b | 95.4b | 192.1b |
| Caliphos | 49.8b | 45.1b | 90.7c | 185.6c |

Means marked with different letters (a to d) represent significant differences ($p<0.05$) according to the Tukey's LSD test.

All three bioagents showed a positive effect on the plant measurements and root development, however, the highest achievements were recorded at the Geogumat application. Nevertheless, the overall contributions of the two bioagents i.e. Aminomax and Caliphos reached to a certain extent and in most cases, significantly differentiated against the control.

**Yield characteristics and phytochemical compounds**

As presented in Table 5, straw and root yield traits considerably enhanced with every passing year, even though the plant continued to grow. Considering total values, the highest indicators of the straw and root yields were observed at the Geogumat application, which exerted by 17.9% and 44.7% compared to the control. The effect of Aminomax and Caliphos treatments also reached a significant level in some growth parameters.

Photosynthetic efficiency in response to the bioagents application was positive, especially in the second and third experiment years. This parameter was 20.8%, 5.7% and 4.7% greater in Geogumat, Aminomax and Caliphos treatments, respectively than that in the control (2019). According to the observed parameters, the highest values were found at the Geogumat treatment, followed by Aminomax treatment and the lowest parameters were recorded at the Caliphos treatment.

The effects of Geogumat to induce phytohormone production was considerably higher compared to the non-treated control under salinated soils (Table 5), exhibiting the positive changes of the phytochemical compounds in the licorice roots in association with the bioagents treatments. Phytohormones were promoted in the Geogumat treated plants, most probably due to the microbial combinations contained in this bioagent. Therefore, the highest records were detected at the Geogumat application, increasing the amounts of ash, glycyrrhizic acid, extractive compounds and flavonoids by 26.5%, 22.0, 9.4% and 10.4%, respectively as compared to the respective control values. These characteristics similarly responded under the treatments of Aminomax, although all values reached a significant level as compared to the control. While phytohormone production tended to be lower in Caliphos treatment, and there was no significant difference between the untreated control in most indicators.

Table 5. Straw and root yields of *Glycyrrhiza glabra*.
Means marked with different letters (a to c) represent significant differences (p<0.05) according to the Tukey's LSD test.

| Treatments | 2018 | | | 2019 | | | 2020 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Photosynthetic efficiency (g/m² per day) | Straw yield (Mg/ha) | Root yield (Mg/ha) | Photosynthetic efficiency (g/m² per day) | Straw yield (Mg/ha) | Root yield (Mg/ha) | Photosynthetic efficiency (g/m² per day) | Straw yield (Mg/ha) | Root yield (Mg/ha) |
| Control | 9.8c | 1.64c | 1.1c | 10.6c | 4.31c | 3.2c | 10.8c | 4.78c | 4.4c |
| Geogumat | 11.6a | 2.02a | 2.8a | 12.8a | 4.99a | 4.1a | 12.6a | 5.65a | 5.4a |
| Aminomax | 10.4b | 1.85b | 2.3b | 11.2b | 4.72b | 3.8b | 11.4b | 5.16b | 5.0b |
| Caliphos | 10.2b | 1.83b | 2.0b | 11.1b | 4.61b | 3.7b | 11.2b | 4.97b | 4.6b |

# Discussion

## Seed germination and plant growth

Licorice with stress tolerance features can grow in extremely harsh environments and might be used to battle desertification in arid regions. In addition, the halophytic functions of licorice in conjunction with bioagents application could alleviate salinity stress more effectively, contributing to rejuvenate agroecosystems in the region. This study highlighted to improvement licorice productivity with bioagents in the harsh climatic area because of its high survivability and significance associated with acclimation to climate change. These resistance inducers can improve seed germination, plant growth, root development, and photosynthetic efficiency, increase biomass and alter specific abiotic stress tolerances to cope with the adverse consequence of salinity (Koch et al., 2010; Hao et al., 2019). Previous studies also showed that bioagent treatment improved seed germination of licorice seedlings under saline stress although Amin et al. (2014), Mogle and Maske (2012) reported a positive effect of bioagents against seed-borne diseases.

In the present study, the germination rate of licorice seeds was significantly enhanced with an increasing water-soaking period in conjunction with the bioagent treatments. A significant increase in plant characteristics was observed in the seed-treated licorice under salt stress because of the alleviation effect of the bioagent. This positive effect is dependent upon the bioagents functionality. Geogumat significantly stimulated seed germination of licorice in both greenhouse and open-field land conditions. The efficacy of the two bioagents, Aminomax and Caliphos, was lower than that of Geogumat in terms of germination, growth, development, root and biomass yield.

## Root yield and phytohormone production

Bioagents are also known as stress-regulating organisms that help plants within the nutrient uptake, biotic and abiotic stress management (Omara et al., 2019; Bayadilova et al., 2022), improve soil health and plant growth promotion (Saleem et al., 2021; Hasna et al., 2022). Furthermore, biological organisms even promote phytohormones like auxin and cytokinin in some plants (Hafez et al., 2020), provoking metabolite accumulation and increasing enzyme activities (Irani and Todd, 2016). It needs to be emphasized that enhanced growth of licorice despite salt stress is due to the beneficial effect of the bioagents on assisting better nutrient supply (Johny et al., 2021).

In our study, the Geogumat application positively influenced in metabolic activity, which is reflected in facilitating the diversion of assimilates from vegetative growth to reproductive growth of licorice. The plants treated with the bioagents showed better phytohormone production performance than the control. In accordance with our result, a similar effect to overcome the adverse effects of salinity was achieved with the application of 2.8 ds/m $SiO_2$ for improved growth and yield of *Glycyrrhiza uralensis* (Cui et al., 2021). These researchers also pointed out the vital role of the synthesis and accumulation of metabolite production on salt tolerance, yield and quality increase of the plant.

Our results showed that considerably improved soil humus and nutrient status after the seed treatment with Geogumat played an essential role on the significantly increased growth and yield of *G. glabra*. In addition, this positive trend under open-field arid agriculture conditions might be due to the number of favourable assets, i.e. this plant lowers the saline groundwater, increases water-resistant aggregates, reduces bulk density and its roots penetrate to a depth of 3.5–4 m.

**Soil health**

The abundant literature indicated that licorice has a valuable bioremediation function for the reclamation of saline soils and restoration of irrigated cropping systems (Qadir et al., 2009; Gafurova and Juliev, 2021). After four years of cropping with licorice, wheat grain yield increased nearly 3-fold, as indicated in earlier studies of Kushiev et al. (2005). These authors also declared that because of setting up licorice plantations on abandoned land in the Hungry Steppes of Uzbekistan, the agrochemical, agrophysical and ameliorative properties of the soil were improved. In addition, improved soil indices i.e. biological functions, chemical compositions and soil physical structures due to licorice cultivation, might facilitate to enhance to the number of beneficial microbes in the root rhizosphere which in turn, promote the secretion of organic acids and lower the pH in the soil (Hosseini et al., 2022). It is well-known that beneficial microbes improve plant growth, nutrient acquisition, and synthesis of various metabolites, phytohormones and enzymes, promoting plant tolerance to biotic and abiotic stresses (Khaitov et al., 2019).

These results indicate that the bioagent application is crucial for licorice production in salt-affected regions. Thereby, the salt tolerance ability of licorice is essential in sustaining agricultural productivity to optimize environmental functions and food security in salt-ridden regions. licorice cultivation might be the most effective technique to mitigate the severe side effects of environmental challenges in the Aral Sea regions, including sandstorms, soil salinization, climate change and water scarcity (Kushiev et al., 2017). In accordance with the science-based information and applied knowledge, this practice might be one of the salinity management and climate-smart agriculture (CSA) strategies.

To our knowledge, the positive results obtained with the licorice seed - Geogumat treatment in the present study is the first report indicating this technique's efficacy in overcoming the negative effects of salinity. Hence, an alternative strategy of bioagent supplementation in licorice production can be considered as a practical approach to developing a highly value-added sustainable crop production system.

## Conclusion

This study provides new insights regarding the efficacies of bioagents i.e. Geogumat, Aminomax and Caliphos on licorice seed germination, plant growth and phytohormone productivity under saline soils of the Aral Sea region. Geogumat was more effective than the other two bioagents, while increased the morphological and physiological parameters of licorice considerably compared to the control. The efficacies of Aminomax and Caliphos resulted in a statistically significant extent and exhibited salt alleviation function. Geogumat having facilitated the highest phytohormone extracts and photosynthesis makes the plant more resistant to this stress condition. Furthermore, the improved soil organic and chemical contents were explained by bioremediation functions of licorice plus the efficiencies of the bioagents.

Those positive statements in response to the Geogumat application as a seed treatment for licorice production can be recommended into agricultural production as a promising technology that may formulate a modern strategy to rejuvenate salt-affected lands.

## References

Amin, M., Fitsum, S., Selvaraj, T., Mulugeta, N., 2014. Field management of anthracnose (Colletotrichum lindemuthianum) in common bean through fungicides and bioagents. *Advances in Crop Science and Technology* 2(2): 2-6.

Bayadilova, G., Zhylkibayev, A., Yessenbayeva, J., Yelibayeva, G., Kazkeyev, D., Karasseva, V.M. 2022. Effect of different organic wastes on biological properties of maize (Zea Mays Indendata) rhizosphere. *Eurasian Journal of Soil Science* 11(2): 141-150.

Cui, J., Zhang, E., Zhang, X., Wang, Q., 2021. Silicon alleviates salinity stress in licorice (Glycyrrhiza uralensis) by regulating carbon and nitrogen metabolism. *Scientific Reports* 11(1): 1-12.

Gafurova, L., Juliev, M., 2021. Soil Degradation Problems and Foreseen Solutions in Uzbekistan. In: Regenerative agriculture: what's missing? what do we still need to know? Dent, D., Boincean, B. (Eds.). Springer, Cham. pp. 59-67.

Hafez, Y.M., Attia, K.A., Kamel, S., Alamery, S.F., El-Gendy, S., Al-Doss A.A., Abdelaal, K.A., 2020. Bacillus subtilis as a bio-agent combined with nano molecules can control powdery mildew disease through histochemical and physiobiochemical changes in cucumber plants. *Physiological and Molecular Plant Pathology* 111:101489.

Hao, Z., Xie, W., Jiang, X., Wu, Z., Zhang, X., Chen, B. 2019. Arbuscular mycorrhizal fungus improves rhizobium–glycyrrhiza seedling symbiosis under drought stress. *Agronomy* 9(10): 572.

Hena, H., Khanam, M., Rahman, G.M., Afrad, M.S.I., Alam, M.S., 2022. Isolation and characterization of salt tolerant bacteria from saline soils of Bangladesh. *Eurasian Journal of Soil Science* 11(4): 284-294.

Hosseini, M.S., Ebrahimi, M., Abadía, J., Kadkhodaei, S., Amirian, R., 2022. Growth, phytochemical parameters and glycyrrhizin production in licorice (Glycyrrhiza glabra L.) grown in the field with saline water irrigation. *Industrial Crops and Products* 177: 114444.

Johny, L., Cahill D.M., Adholeya, A., 2021. AMF enhance secondary metabolite production in ashwagandha, licorice, and marigold in a fungi-host specific manner. *Rhizosphere* 17: 100314.

Irani, S., Todd, C.D., 2016. Ureide metabolism under abiotic stress in Arabidopsis thaliana. *Journal of Plant Physiology* 199: 87–95.

Khaitov, B., Karimov, A., Khaitbaeva, J., Sindarov, O., Karimov, A., Li, Y. 2022. Perspectives of Licorice Production in Harsh Environments of the Aral Sea Regions. *International Journal of Environmental Research and Public Health* 19(18): 11770.

Khaitov, B., Karimov, A., Toderich, K., Sultanova, Z., Mamadrahimov, A., Allanov, K., Islamov, S., 2020. Adaptation, grain yield and nutritional characteristics of quinoa (Chenopodium quinoa) genotypes in marginal environments of the Aral Sea basin. *Journal of Plant Nutrition* 44(9): 1365-1379.

Khaitov, B., Allanov, K., Islam K.R., Park, K.W. 2019. Bio-inoculant improves nitrogen-use efficiency and cotton yield in saline soils. *Journal of Plant Nutrition and Soil Science* 182(3): 393-400.

Khaitov, B., Urmonova, M., Karimov, A., Sulaymonov, B., Allanov, K., Israilov, I., Sottorov, O., 2021. Licorice (Glycyrrhiza glabra)—Growth and phytochemical compound secretion in degraded lands under drought stress. *Sustainability* 13(5): 2923.

Koch, E., Schmitt, A., Stephan, D., Kromphardt, C., Jahn, M., Krauthausen, H.J., Forsberg, G., Werner, S., Amein, T., Sandra, A.I., Tinivella, F., Gullino, M., Roberts, S., Wolf, J.V., Groot, S.P., 2010. Evaluation of non-chemical seed treatment methods for the control of Alternaria dauci and A. radicina on carrot seeds. *European Journal of Plant Pathology* 127(1): 99-112.

Kushiev, H., Noble, A.D., Abdullaev, I., Toshbekov, U., 2005. Remediation of abandoned saline soils using Glycyrrhiza glabra: A study from the Hungry Steppes of Central Asia. *International Journal of Agricultural Sustainability* 3(2): 102-113.

Kushiev, H.H., Kenjaev, A., Mirzabaev, A., Noble, A.D., Uzaydullaev, S., 2017. Economic aspects remediation of saline soils using licorice: the case of Mirzachul area in Uzbekistan. Proceedings of the International Scientific and Practical Conference World Science. Tashkent, Uzbekistan. pp. 48-56.

Kushiev, K., Ismailova, K.M., Rakhmonov, I., Kenjaev, A., 2021. The role of licorice for remediation of saline soils. *Open Journal of Science and Technology* 4(1): 10-20.

Mambetnazarov, A.B., Aybergenov, B.A., Kurbaniyazova, B.J., Jumatova, R.M., Turimbetov, M. S.M., Sabirova, G., Sabirov, G., 2021. To the development of optimal methods for licorice seeds growing (Glycyrrhiza glabra L.) in irrigated lands of the Republic of Karakalpakstan. IOP Conference Series: Earth and Environmental Science 937: 032102.

UzPITI, 2007. Methods of Field Experiments. Tashkent, Uzbekistan.

Mogle, U.P., Maske, S.R., 2012. Efficacy of bioagents and fungicides on seed mycoflora, germination and vigour index of cowpea. *Science Research Reporter* 2(3): 321-326.

Omara, R.I., El-Kot, G.A., Fadel, F.M., Abdelaal, K.A., Saleh, E.M., 2019. Efficacy of certain bioagents on patho-physiological characters of wheat plants under wheat leaf rust stress. *Physiological and Molecular Plant Pathology* 106: 102-108.

Qadir, M., Noble, A.D., Qureshi, A.S., Gupta, R.K., Yuldashev, T., Karimov, A., 2009. Salt-induced land and water degradation in the Aral Sea basin: A challenge to sustainable agriculture in Central Asia. *Natural Resources Forum* 33(2): 134-149.

Qureshi, A.S., Daba, A.W., 2020. Evaluating growth and yield parameters of five Quinoa (Chenopodium quinoa W.) genotypes under different salt stress conditions. *Journal of Agricultural Science* 12(3): 128-140.

Raza, A., Tabassum, J., Fakhar, A.Z., Sharif, R., Chen, H., Zhang, C., Varshney, R.K., 2022. Smart reprogramming of plants against salinity stress using modern biotechnological tools. *Critical Reviews in Biotechnology* 43(7): 1035-1062.

Saleem, S., Iqbal, A., Ahmed, F., Ahmad, M., 2021. Phytobeneficial and salt stress mitigating efficacy of IAA producing salt tolerant strains in Gossypium hirsutum. *Saudi Journal of Biological Sciences* 28(9): 5317-5324.

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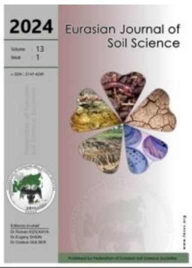

# Enhancing iron concentration in bread wheat through Fe-EDTA fortification

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## Abstract

Iron (Fe) malnutrition in humans is a global concern which can be revised by improved Fe density in staple crops. A field experiment was performed to evaluate the effect of chelated iron on growth, yield and iron concentration in bread wheat (cv. Moomal) at Tando Jam Pakistan. The treatments included, Control (No Fe-EDTA), Soil supplement of Fe-EDTA (@ 2 kg Fe $ha^{-1}$), Soil + foliar supplement of Fe-EDTA (@ 2 kg $ha^{-1}$ and 0.2% Fe at booting, flowering, and milky stage), and Foliar supplement of Fe-EDTA (@ 0.2% Fe at booting, flowering and milky stages). The defined growth and yield traits of wheat were increased with Fe-EDTA applications over control treatment. Among different Fe-EDTA application methods, there was no significant difference for most of the growth and yield parameters (excluding spike length, number of spikelets $spike^{-1}$, and 1000 grain weight). The amount of Fe in wheat grains was significantly higher in all Fe-EDTA treatments over control, with maximum value (86.54 ± 5.57 mg $kg^{-1}$) in the treatment where Fe-EDTA was applied in soil + foliar. Similarly, a high Fe build up in surface soil was obtained with treatment of Fe-EDTA in soil + foliar. Overall, with various Fe-EDTA treatments, an increase of 21.2 to 29.1% in grain yield and 1.9 to 4.3 times in Fe concentration of wheat grains was achieved in current study. It is suggested that the Fe should be included in wheat production technology to attain better yield and Fe concentration in grains.

**Keywords:** Fe-EDTA, Fe-malnutrition, biofortification, wheat production, Fe fertilization.



## Introduction

Iron (Fe) is an important element essentially required by all living organisms (Taskin and Gunes, 2022). In humans, Fe insufficiency is a prevalent and significant nutritional deficit that poses a substantial threat to human health. According to an estimate, 34% of the population of the world suffers from Fe deficiency, out of which majority belongs to developing countries (Owaidah et al., 2020).

Among various human groups, children, adolescents, and young and pregnant women are more susceptible to iron deficiency (Abu-Ouf and Jan, 2015; Ramzani et al., 2016; Ali et al. 2020). The primary health consequences associated with iron deficiency comprehends fetal loss, impaired mental abilities, impaired immunity, and reduced work capability (Gombart et al., 2020; Grzeszczak et al., 2020; Midya et al., 2021).

In developing countries, the primary factor contributing to iron malnutrition can be attributed to the consumption of diets with low iron content and/or poor iron assimilation from the ingested food (Liberal et al., 2020). In these countries, the cereal crops are the major food crops which are inherently low in Fe and other micronutrients (Senguttuvel et al., 2023). Low Fe concentration in cereal crops may be associated to low Fe content in soils and its accessibility to plants (Zou et al., 2019). According to an estimate, 30% soils of the

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world are Fe deficient (Boamponsem et al., 2017; Mahender et al., 2019). The problem of Fe deficiency is most common in alkaline and calcareous soils (Rashid, 1996; Hsieh and Waters, 2016). Cultivation of crops in Fe deficient and/or alkaline-calcareous soils reduces the crops growth and productivity, and Fe concentration in grains (Hafeez et al., 2021; Turan et al., 2022).

Agronomic biofortification is a term used to describe the practice of augmenting the nutritional composition of food crops through fertilization techniques (Akram et al., 2020; Bughio et al., 2021). In case of Fe malnutrition in resource-poor populations, agronomic biofortification has emerged as a promising strategy to improve iron intake and combat iron deficiency (Bhardwaj et al., 2022; Kiran et al., 2022). Iron can be supplemented to crop plants using different sources including $FeSO_4$, Fe-EDTA, Fe-DTPA, Fe-EDDHA, Fe-citrate and Fe-IDHA (Chatterjee et al., 2018; Shaddox et al., 2019; Ay et al., 2022). However, the efficiency of Fe sources in promoting crop development and increasing Fe content is influenced by many factors. These factors encompass the solubility and stability of the Fe sources, their ability to permeate through the cuticle when applied foliar, their capacity to be taken up by root cells when applied to the soil, and their ability to be transported to the shoot (Fernández and Brown, 2013).

A little information is present in literature, where the efficiency of Fe-EDTA has been tested with respect to improving Fe density in cereal grains. Many studies have been performed to evaluate the impacts of Fe application (as Fe-Sulphate) for growth and yield improvement (e.g., Abbas et al., 2009; Ali, 2012). Hence, this study is an effort to enhance Fe in wheat crop through agronomic approach (fertilizer application). Wheat (*Triticum aestivum* L.) is selected for this study because it is a chief source of diet in humans particularly in South Asian region, Central Asia and Middle Eastern countries where it provides approximately 50% of the everyday calorie intake (Cakmak et al., 2010; Sial et al., 2018). In Pakistan, wheat is a staple food crop and is cultivated generally on more than 9.0 million hectares area (PES, 2022). We hypothesize that this form of Fe will be more bioavailable to the plants with the ultimate profit of yield and Fe quantity in wheat grains. The present research was laid out with the objectives (i) to determine the effect of Fe application (as Fe-EDTA) on growth, yield and Fe quantity in wheat grains, and (ii) to propose the appropriate method of Fe application that enhances production, and Fe in wheat grains and soil.

## Material and Methods

The experiment was performed at the field of Southern Wheat Section, Agriculture Research Institute (ARI) Tando Jam (25°25'00.2"N, 68°32'39.9"E) during Rabi season of 2017-18. A piece of land (10 m × 15 m = 150 $m^2$) was ploughed, levelled and divided into 16 equal experimental units of 6 $m^2$ (3 m × 2 m) for the experiment. The seeds of wheat variety "Moomal" were hand drilled at the seed rate of 50 kg per acre.

### Experimental Design and Treatments

The research was organized in Randomized Complete Block Design (RCBD). The experiment included four treatments, each repeated four times; T1: Control (No Fe), T2: Soil supplement (2 kg Fe $ha^{-1}$), T3: Soil + Foliar supplement (2 kg Fe $ha^{-1}$ + 0.2% Fe at booting, flowering and milky stage), and T4: Foliar supplement (0.2% Fe at booting, flowering and milky stage).

### Fertilization scheme

The NPK fertilizers were supplemented to all plots @ 168 kg N, 84 kg $P_2O_5$ and 60 kg $K_2O$ $ha^{-1}$ as recommended by Khokhar (2015). The recommended amount of phosphorus, potassium and a fraction of N was supplemented at the time of sowing, while remaining nitrogen was given as Urea in 2 equivalent splits. The 1st split of N was applied with second irrigation while the 2nd split was given with third irrigation.

### Agronomic observations

At harvest, five healthy plants were randomly selected from each replication plot for the selected agronomic observations. Plant height and spike length were recorded with measuring scale. Tillers and spikelets number were manually counted. Thousand grains were counted and weighed on digital balance. For yield purpose, the plants from every replication plot were reaped using 0.5 $m^2$ wooden frame. Afterwards, the plants were threshed manually and separated into grains and straw, which were weighed on a digital balance. Harvest index was computed by adopting the formula as given by Iqbal et al. (2017).

$$\text{Harvest index (\%)} = \text{grain yield (g)} / \text{biological yield (g)} \times 100$$

### Plant analysis

The grains from each replication plot were grinded using grinder machine (Geepas model No. GCG289). The flour samples were digested and analyzed for iron concentration by following the procedure as outlined by Estefan et al. (2013). In brief, 01-gram wheat flour was added with di-acid mixture ($HNO_3$-$HClO_4$, 2:1), left for overnight, digested, cooled, filtered and raised to 50 ml with distilled water, and analyzed for the Fe concentration using Atomic Absorption Spectrometer (AAS, NOVAA 400, Germany).

### Soil sampling and Analysis

Composite soil samples were gathered at the depth of 0-15 cm before land preparation and after harvest of wheat crop using stainless steel auger. The samples (prior to wheat sowing) were thoroughly processed and subjected to the determination of various properties (pH, EC, organic matter content, lime content, texture and Fe) by adopting the standard procedures drafted by Estefan et al. (2013). For Fe analysis, 10 grams soil was added 20 mL AB-DTPA solution, which was shaken on a mechanical shaker, filtered and subsequently used for the determination of Fe concentration by AAS. We recognized that the experimental soil was clay in texture, moderately alkaline in reaction (pH 8.25 ± 0.2), non-saline (EC 0.29 ± 0.06 dS $m^{-1}$), marginal in organic matter content (1.20 ± 0.12%), moderately calcareous (7.73 ± 0.13%) and adequate in Fe concentration (5.65 ± 0.25 mg $kg^{-1}$). Soil samples, after harvest of crop, were randomly collected from each replication, processed, and analyzed for Fe concentration only.

### Statistical analysis

The gathered plant and soil data were subjected to normality test, Anderson-Darling test, prior to conduct of Analysis of Variance (ANOVA) approach by Minitab 17 software. A one-way ANOVA technique was used to determine the significant difference among treatments' means, at a *P* value of 0.05. Any significant data was further subjected to Tukey's (HSD) test to compute the level of significant difference among treatments.

## Results

### Effect of Fe-EDTA application methods on growth and yield components of bread wheat

The supplementation of Fe-EDTA resulted in significant improvements in selected aspects of wheat growth and yield compared to the control treatment (Figure 1 and 2, P<0.05). The applications of Fe-EDTA resulted in an increase of plant height to 20.1%, tillers per plants to 15.3%, spike length to 20.9%, spikelets per spike to 24.5%, 1000-grain weight to 68.7%, straw yield to 18.3%, grain yield to 29.1%, and harvest index to 4.2% over the control treatment. Except for spike length, number of spikelets per spike, and 1000 grain weight, most of the growth and yield characteristics were found to be statistically identical among the various Fe-EDTA application methods. Notably, the combined application of Fe-EDTA (soil + foliar) resulted in substantially longer spikes, and a greater value for spikelets and grain weight.

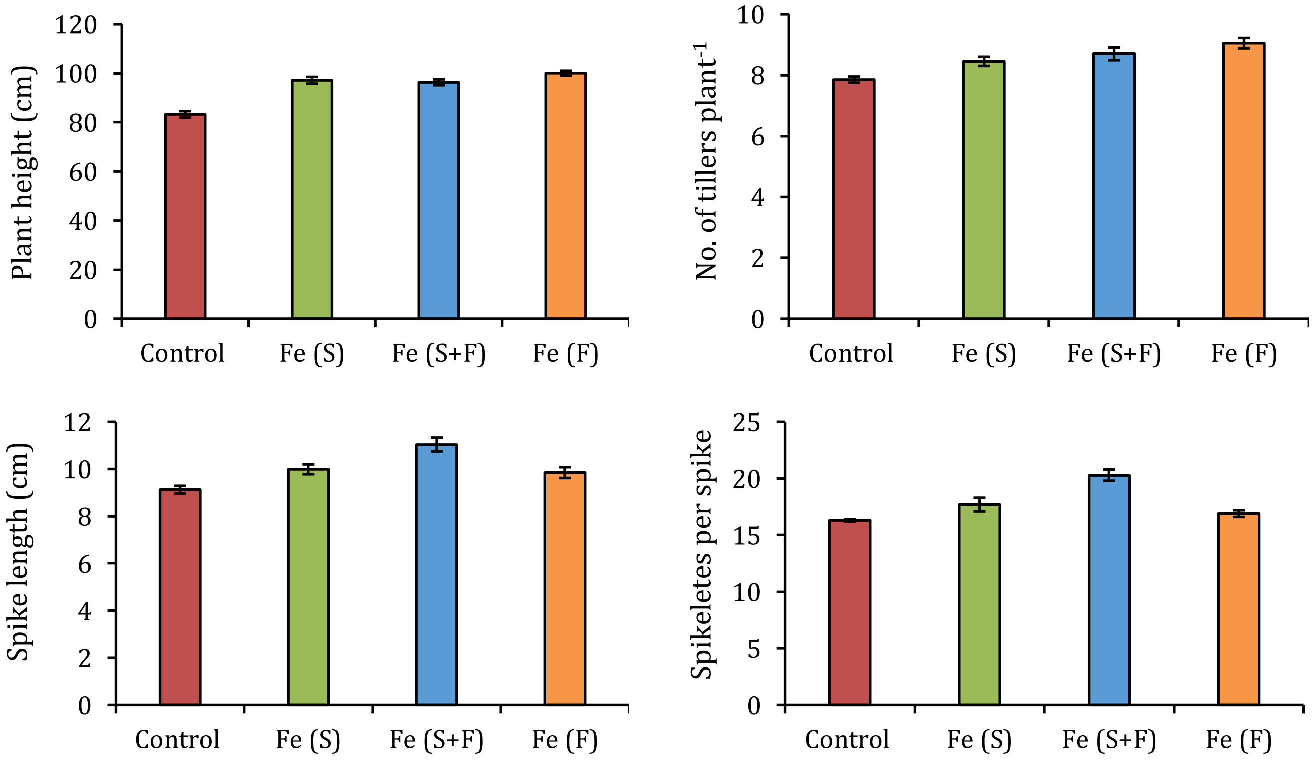


Figure 1. Impact of Fe-EDTA application on growth characteristics of bread wheat
S= (Soil Application), S+F= (Soil + Foliar), F= (Foliar Application)

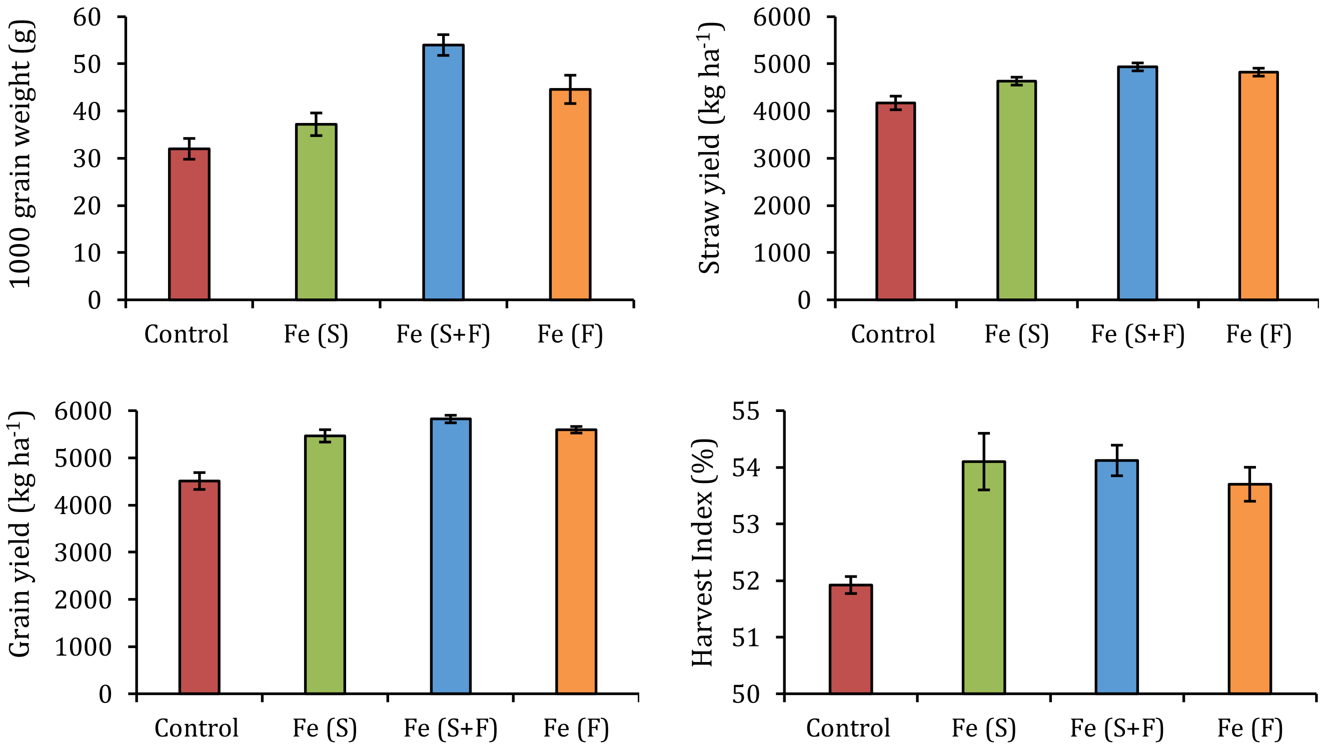


Figure 2. Impact of Fe-EDTA application on yield characteristics of bread wheat

## Effect of Fe-EDTA application methods on Fe concentration in grains of bread wheat

The impact of Fe-EDTA applications on the Fe concentration in wheat grains was found statistically significant (P<0.05, Table 1). The wheat plants that received Fe-EDTA applications by defined methods exhibited a notable increase in Fe accumulation in their grains, ranging from 2 to 4 times higher compared to the plants of control group. Significant variations were also observed in Fe accumulation among the different Fe-EDTA application methods, whereby the plants treated with Fe-EDTA through a combination (soil + foliar) exhibited significantly highest Fe concentration (86.54 ± 5.57 mg $kg^{-1}$) than the other two methods (soil and/or foliar).

Table 1. Fe concentration in grains (mg $kg^{-1}$) of bread wheat as influenced by Fe-EDTA application

| Fe application methods | Fe in grains (mg $kg^{-1}$) | Times increase over control |
|---|---|---|
| Control | 19.89 ± 2.90 $^{C}$ | --- |
| Fe-EDTA in soil | 38.63 ± 1.44 $^{B}$ | 1.9 |
| Fe-EDTA in soil + foliar | 86.54 ± 5.57 $^{A}$ | 4.3 |
| Fe-EDTA foliar | 50.60 ± 4.65 $^{B}$ | 2.5 |

Each value is mean ± SE ($n$ = 4); means followed by different letters show significant variation among each other ($P$ < 0.05) as a function of Fe-EDTA application methods

## Influence of Fe-EDTA application methods on Fe buildup in post-harvest soil

The outcome of Fe-EDTA applications on Fe concentration (mg $kg^{-1}$) in surface soil was highly significant ($P$ < 0.05, Table 2). Wheat plants which were treated with Fe-EDTA through soil + foliar application significantly enhanced Fe concentration in soil (8.89 ± 1.07 mg $kg^{-1}$) than the control treatment (6.22 ± 0.25 mg $kg^{-1}$). With respect to control, the plots which were subjected to Fe-EDTA through various application methods increased the Fe concentration in soil from 3% to 42.9%. No significant difference was found among various Fe-EDTA application methods for Fe concentration in surface soil.

Table 2. Influence of Fe-EDTA application on Fe concentration (mg $kg^{-1}$) in postharvest soil

| Fe application methods | Fe in soil (mg $kg^{-1}$) | % increase over control |
|---|---|---|
| Control | 6.22 ± 0.25 $^{B}$ | --- |
| Fe-EDTA in soil | 8.17 ± 0.36 $^{AB}$ | 31.3 |
| Fe-EDTA in soil + foliar | 8.89 ± 1.07 $^{A}$ | 42.9 |
| Fe-EDTA foliar | 6.41 ± 0.30 $^{AB}$ | 3.0 |

## Discussion

The application of Fe-EDTA in bread wheat resulted in substantial improvements in targeted growth and yield parameters, when compared to the control treatment. These findings highlight the importance of iron as a micronutrient for bread wheat and underscore the potential of Fe-EDTA application as an effective Fe source for promoting plant growth, optimizing yield, and improving overall productivity. Iron is very important to the growth of wheat because it is involved in important processes like photosynthesis, chlorophyll formation, enzyme activity, respiration, food uptake, and protein synthesis (Frossard et al., 2000; Wiedenhoeft, 2006). Similar positive impacts of iron on the upgrowth and productivity of wheat have been documented not only in Pakistan but also in other regions worldwide (Abbas et al., 2009; Habib, 2009; Armin et al., 2014; Bakhtiari et al., 2015).

The Fe concentration in wheat grains was significantly higher (two to four times) when the Fe-EDTA was applied in soil, foliar and/or soil + foliar than the control treatment. A rise in iron concentration in grains may be related to Fe application to wheat crop and its better mobility from soil to grains and/or leaf to grains. A good remobilization of Fe from shoots (77% of the whole shoot Fe) to grains of wheat has also been documented previously (Garnett and Graham, 2005). Many studies have shown a rise in iron accumulation in wheat grains with the submission of various Fe treatments (Habib, 2009; Pahlavan-Rad and Pessarakli 2009; Zhang et al., 2010; Aciksoz et al., 2011). However, in current study the increment in iron quantity was many orders of magnitude higher than the cited studies. A high Fe density in wheat grains might be associated to coordination of Fe and EDTA. The EDTA has been documented to escalate the concentration of coordinated ions in plants (Vassil et al., 1998). It is speculated that synthetic chelates (including EDTA) increase the mobility of ions by two mechanisms, (i) by destroying the physiological root barriers that are normally involved in controlling the uptake and mobility of ions, and (ii) destabilizing root surrounding plasma membrane (a barrier forming agent) by removal of its stabilizing ions (e.g., $Zn^{2+}$ and $Ca^{2+}$) (Vassil et al., 1998). In addition, Lindsay (1995) suggested that chelating agents are useful because they increase the total Fe concentration in soil solution, enhance diffusion gradients and reduce Fe depletion zones in rhizosphere.

Among three Fe-EDTA treatments, there was significantly higher Fe concentration in wheat grains when the wheat crop was subjected to soil + foliar application of Fe-EDTA. Such an increase in wheat grains may be associated to exposure, uptake and absorption of Fe by both pathways (roots and leaves). The combined approach of soil and foliar application provides iron through both root and leaf pathways, increasing the chances of iron absorption by the plants. It facilitates efficient translocation of iron within the plant, aiding its transport to the developing grains. The synergy between soil and foliar applications may further enhance iron uptake and accumulation. These scientific reasons explain the observed increase in iron concentration in wheat grains.

There was a significantly higher Fe concentration in surface soil where the Fe-EDTA was applied in soil + foliar than the plots where no Fe-EDTA application was made. Relatively high Fe concentration in soil + foliar treatment is possibly because of exposure of soil with Fe by both means (soil + droppings during foliar spray). The retention of Fe in soil may be associated to the process of adsorption, whereby inorganic colloids (clays, metal(s) of oxides, hydroxides, carbonates and phosphates) and organic colloids (organic matter, and certain algae and bacteria) retain metal ions (Bradl, 2004). In current study, the texture of the soil was Clay (with > 46% clay fraction) and the organic matter was moderate (> 1%), hence a high adsorption of Fe was expected. A greater retention and lower solubility and bioavailability of Fe is also correlated to high pH and soil calcareousness (Bradl, 2004; Ramzani et al., 2016). In current study, the soil was moderately to slightly alkaline in reaction (pH > 8.0) and moderately calcareous in nature (> 7%), hence high retention of Fe was anticipated. The pH also affects to stability of chelates to bind Fe; it has been documented that EDTA loses significant Fe when the pH increases above 6.0 (Lindsay, 1995).

Despite yielding an obvious outcome in our study that documents the benefits of Fe usage in wheat husbandry, mainly by soil+foliar fertilization, the study also possesses certain limitations. The first limitation pertains to the extent of the experiment. Since the experiment spanned only one growing season, it is crucial to replicate it at multiple locations having varied environmental conditions, soil types and wheat varieties to reach to more robust ending. A second potential limitation relates tothe price of Fe-EDTA, which is relatively higher than the commonly used source of Fe ($FeSO_4$). Future studies should be devised where these two sources of Fe may be compared for their efficiency, economic returns and health benefits.

## Conclusion

The applications of Fe-EDTA significantly enhanced the defined growth and yield components, and Fe concentration in wheat grains and post-harvest soil than control treatment. Among the different tested Fe application methods, the outcome of combined soil + foliar supplement of Fe-EDTA was relatively better for most of the parameters. We suggest that the combined soil + foliar application of Fe-EDTA (@ 2 kg Fe $ha^{-1}$ + 0.2% Fe at booting, flowering and milky stage) should be adopted for selected wheat cultivar (Moomal) to attain maximum crop growth and yield, and Fe concentration in grains.

## References


Abbas, G., Khan, M.Q., Khan, M.J., Hussain, F., Hussain, I., 2009. Effect of iron on the growth and yield contributing parameters of wheat (Triticum aestivum L.). *Journal of Animal and Plant Sciences* 19(3): 135-139.

Abu-Ouf, N.M., Jan, M.M., 2015. The impact of maternal iron deficiency and iron deficiency anemia on child's health. *Saudi Medical Journal* 36(2): 146–149.

Aciksoz, S.B., Yazici, A., Ozturk, L., Cakmak, I., 2011. Biofortification of wheat with iron through soil and foliar application of nitrogen and iron fertilizers. *Plant and Soil* 349: 215-225.

Akram, M.A., Depar, N., Irfan, M., 2020. Agronomic zinc biofortification of wheat to improve accumulation, bioavailability, productivity and use efficiency. *Eurasian Journal of Soil Science* 9(1): 75-84.

Ali, E.A., 2012. Effect of iron nutrient care sprayed on foliage at different physiological growth stages on yield and quality of some durum wheat (Triticum durum L.) varieties in sandy soil. *Asian Journal of Crop Science* 4(4): 139-149.

Ali, S.A., Abbasi, Z., Shahid, B., Moin, G., Hambidge, K.M., Krebs, N.F., Westcott, J.E., McClure, E.M., Goldenberg, R.L., Saleem, S., 2020. Prevalence and determinants of anemia among women of reproductive age in Thatta Pakistan: Findings from a cross-sectional study. *PLOS ONE* 15(9): e0239320.

Armin, M., Akbari, S., Mashhadi, S., 2014. Effect of time and concentration of nano-Fe foliar application on yield and yield components of wheat. *International Journal of Biosciences* 4(9): 69-75.

Ay, A., Demirkaya, S., Kızılkaya, R., Gülser, C., 2022. The effects of two Fe-EDDHA chelated fertilizers on dry matter production and Fe uptake of tomato seedlings and Fe forms of a calcareous soil. *Eurasian Journal of Soil Science* 11(3): 259-265.

Bakhtiari, M., Moaveni, P., Sani, B., 2015. The effect of iron nanoparticles spraying time and concentration on wheat. *Biological Forum: An International Journal* 7(1): 679-683.

Bhardwaj, A.K., Chejara, S., Malik, K., Kumar, R., Kumar, A., Yadav, R.K., 2022. Agronomic biofortification of food crops: An emerging opportunity for global food and nutritional security. *Frontiers in Plant Science* 13: 1055278.

Boamponsem, G.A., Leung, D.W.M., Lister, C., 2017. Insights into resistance to Fe deficiency stress from a comparative study of ın vitro-selected novel Fe-efficient and Fe-inefficient potato plants. *Frontiers in Plant Science* 8: 1581.

Bradl, H.B., 2004. Adsorption of heavy metal ions on soils and soil constituents. *Journal of Colloid and Interface Science* 277: 1-18.

Bughio, Z.R., Bhatti, S.M., Depar, N., Rajpar, I., Sarki, M.S., Bughio, H.R., 2021. Enhancement of zinc concentration and bioavailability in rice grains by zinc application methods. *Pakistan Journal of Agricultural Sciences* 58(5): 1483-1490.

Cakmak, I., Pfeiffer, W.H., McClafferty, B., 2010. Biofortification of durum wheat with zinc and iron. *Cereal Chemistry* 87(1): 10-20.

Chatterjee, A., Lovas, S., Rasmussen, H., Goos, R., 2018. Foliar application of iron fertilizers to control iron deficiency chlorosis of soybean. *Crops and Soils* 51(4): 44-51.

Estefan, G., Sommer, R., & Ryan, J., 2013. Methods of soil, plant, and water analysis: A manual for the West Asia and North Africa region. 3rd Edition. International Center for Agricultural Research in the Dry Areas (ICARDA), Beirut. 243p.

Fernández, V., Brown, P.H., 2013. From plant surface to plant metabolism: the uncertain fate of foliar-applied nutrients. *Frontiers in Plant Science* 4: 289.

Frossard, E., Bucher, M., Machler, F., Mozafar, A., Hurrell, R., 2000. Potential for increasing the content and bioavailability of Fe, Zn, and Ca in plants for human nutrition. *Journal of the Science of Food and Agriculture* 80: 861-879.

Garnett, T.P., Graham, R.D., 2005. Distribution and remobilization of iron and copper in wheat. *Annals of Botany* 95(5): 817-826.

Gombart, A.F., Pierre, A., Maggini, S., 2020. A review of micronutrients and the ımmune system–working in harmony to reduce the risk of ınfection. *Nutrients* 12(1): 236.

Grzeszczak, K., Kwiatkowski, S., Kosik-Bogacka, D., 2020. The role of Fe, Zn, and Cu in pregnancy. *Biomolecules* 10(8): 1176.

Habib, M., 2009. Effect of foliar application of Zn and Fe on wheat yield and quality. *African Journal of Biotechnology* 8(24): 6795-6798.

Hafeez, M.B., Ramzan, Y., Khan, S., Ibrar, D., Bashir, S., Zahra, N., Rashid, N., Nadeem, M., Rahman, S.U., Shair, H., Ahmad, J., Hussain, M., Irshad, S., Al-Hashimi, A., Alfagham, A., Diao, Z.H., 2021. Application of zinc and iron-based fertilizers ımproves the growth attributes, productivity, and grain quality of two wheat (*Triticum aestivum*) cultivars. *Frontiers in Nutrition* 8: 779595.

Hsieh, E.J., Waters, B.M., 2016. Alkaline stress and iron deficiency regulate iron uptake and riboflavin synthesis gene expression differently in root and leaf tissue: Implications for iron deficiency chlorosis. *Journal of Experimental Botany* 67(19): 1-15.

Iqbal, S., Thierfelder, C., Khan, H.Z., Javeed, H.M.R., Arif, M., Shehzad, M., 2017. Maximizing maize quality, productivity and profitability through a combined use of compost and nitrogen fertilizer in a semi-arid environment in Pakistan. *Nutrient Cycling in Agroecosystems* 107: 197-213.

Khan, M.B., Farooq, M., Hussain, M., Shahnawaz, Shabir, G., 2010. Foliar application of micronutrients improves wheat yield and net economic return. *International Journal of Agriculture and Biology* 12(6): 953-956.

Khokhar, H.K., 2015. Effect of different sources of phosphate fertilizers on growth and yield of late sown wheat varieties. MSc Thesis. Sindh Agriculture University, Department of Soil Science, Tandojam, Pakistan, 65p.

Kiran, A., Wakeel, A., Mahmood, K., Mubaraka, R., Hafsa, Haefele, S.M., 2022. Biofortification of staple crops to alleviate human malnutrition: Contributions and potential in developing countries. *Agronomy* 12(2): 452.

Liberal, N., Pinela, J., Vívar-Quintana, A.M., Ferreira, I.C.F.R., Barros, L., 2020. Fighting iron-deficiency anemia: Innovations in food fortificants and biofortification strategies. *Foods* 9(12): 1871.

Lindsay, W.L., 1995. Chemical reactions in soils that affect iron availability to plants. A quantitative approach. In: Iron Nutrition in Soils and Plants. Abadia, J. (Ed.). Vol. 59. Springer, Dordrecht. pp 7-14.

Mahender, A., Swamy, B., Anandan, A., Ali, J., 2019. Tolerance of iron-deficient and -toxic soil conditions in rice. *Plants* 8(2): 31.

Midya, A., Saren, B.K., Dey, J.K., Maitra, S., Praharaj, S., Gaikwad, D.J., Gaber, A., Alhomrani, M., Hossain, A., 2021. Crop establishment methods and integrated nutrient management improve: Part II. nutrient uptake and use efficiency and soil health in rice (Oryza sativa L.) field in the lower indo-gangetic plain, India. *Agronomy* 11(9): 1894.

Owaidah, T., Al-Numair, N., Al-Suliman, A., Zolaly, M., Hasanato, R., Al Zahrani, F., Albalawi, M., Bashawri, L., Siddiqui, K., Alalaf, F., Almomen, A., Sajid, M.R., 2020. Iron deficiency and iron deficiency anemia are common epidemiological conditions in saudi arabia: Report of the national epidemiological survey. *Anemia* Article ID 6642568.

Pahlavan-Rad, M.R., Pessarakli, M., 2009. Response of wheat plants to zinc, iron, and manganese applications and uptake and concentration of zinc, iron, and manganese in wheat grains. *Communications in Soil Science and Plant Analysis* 40(7-8): 1322-1332.

PES, 2022. Pakistan Economic Survey, 2021-2022. Ministry of Finance, Government of Pakistan, Islamabad, Pakistan.

Ramzani, P.M.A., Khalid, M., Naveed, M., Irum, A., Khan, W.D., Kausar, S., 2016. Iron biofortification of cereals grown under calcareous soils, In: Soil Science: Agricultural and Environmental Perspectives. Hakeem, K.R., Akhtar, J., Sabir, M. (Eds.), Springer, Cham. pp. 231-258.

Rashid, A., 1996. Secondary and micronutrients. In: Soil Science Bashir, E., Bantel, R., (Eds.). National Book Foundation, Islamabad, Pakistan, 374p.

Senguttuvel, P., Padmavathi G., Jasmine, C., Sanjeeva R. D., Neeraja C.N., Jaldhani, V., Beulah, P., Gobinath, R., Aravind Kumar, J., Sai Prasad, S.V., Subba Rao L.V., Hariprasad, A.S., Sruthi, K., Shivani, D., Sundaram, R.M., Mahalingam G., 2023. Rice biofortification: breeding and genomic approaches for genetic enhancement of grain zinc and iron contents. *Frontiers in Plant Science 14*: 1138408.

Shaddox, T.W., Fu, H., Gardner, D.S., Goss, R.M., Guertal, E.A., Kreuser, W.C., Miller, G.L., Stewart, B.R., Tang, K., Unruh, J.B., 2019. Solubility of ten iron fertilizers in eleven north American soils. *Agronomy Journal* 111(3): 1498–1505.

Sial, N.A., Abro, S.A., Abbas, M., Irfan, M., Depar, N., 2018. Growth and yield of wheat as affected by phosphate solubilizing bacteria and phosphate fertilizer. *Pakistan Journal of Biotechnology* 15(2): 475-479.

Taskin, M.B., Gunes, A., 2022. Iron biofortification of wheat grains by Foliar application of nano zero-valent iron (nZVI) and other ıron sources with urea. *Journal of Soil Science and Plant Nutrition* 22: 4642-4652.

Turan, M., Ekinci, M., Kul, R., Kocaman, A., Argin, S., Zhirkova, A.M., Perminova, I.V., Yildirim, E., 2022. Foliar applications of humic substances together with Fe/Nano Fe to increase the iron content and growth parameters of spinach (Spinacia oleracea L.). *Agronomy* 12(9): 2044.

Vassil, A.D., Kapulnik, Y., Raskin, I., Salt, D.E., 1998. The role of EDTA in lead transport and accumulation by Indian mustard. *Plant Physiology* 117(2): 447-453.

Wiedenhoeft, A.C., 2006. Plant Nutrition. Chelsea House Publishers, 144p.

Zhang, Y., Shi, R., Rezaul, K.M., Zhang, F., Zou, C., 2010. Iron and zinc concentrations in grain and flour of winter wheat as affected by foliar application. *Journal of Agricultural and Food Chemistry* 58(23): 12268-12274.

Zou, C., Du, Y., Rashid, A., Ram, H., Savasli, E., Pieterse, P.J., Ortiz-Monasterio, I., Yazici, A., Kaur, C., Mahmood, K., Singh, S., Le Roux, M.R., Kuang, W., Onder, O., Kalayci, M., Cakmak, I., 2019. Simultaneous biofortification of wheat with zinc, iodine, selenium, and iron through foliar treatment of a micronutrient cocktail in six countries. *Journal of Agricultural and Food Chemistry* 67(29): 8096–8106.

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# Improving microbial properties in Psamments with mycorrhizal fungi, amendments, and fertilizer

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## Abstract

Psamments is sandy soil with a texture class of fine loamy sand or coarser in all layers, deposited sands such as dunes in beach lands with low soil biological fertility. Adding mycorrhizal, soil amendments, and inorganic fertilizers could improve soil fertility. This research aimed to investigate the effect of mycorrhizal, soil amendments, and inorganic fertilizers on soil organic carbon (SOC), microbial biomass carbon (MBC), glomalin-related soil protein (GRSP), and root infections in Psamments. This research was a pot experimental in screenhouse, arranged in a factorial completely randomized design with three factors: three of mycorrhizal doses, M0 = 0 spore pot$^{-1}$, M1 = 3 spores pot$^{-1}$ and M2 = 6 spores pot$^{-1}$; three types of soil amendments, P0 = non amendment, P1 = cow dung 60 t ha$^{-1}$, P2 = rice husk biochar (RHB) 25 t ha$^{-1}$; and two doses of inorganic fertilizer, A0 = 0 kg ha$^{-1}$, A1 = 100 kg ha$^{-1}$ NPK (15:15:15) fertilizer, replied three times. The results showed that mycorrhizal combination with RHB and inorganic fertilizer increased MBC up to 23 times than control. The combination of mycorrhizal-cow dung-inorganic fertilizer was the highest of total-GRSP (4.4 times) and mycorrhizal dose 6 spores pot$^{-1}$ with both amendments and inorganic fertilizer increase root infection up to 90%. It was proven that mycorrhizal with soil amendments and inorganic fertilizers could improve the microbial properties of Psamments.

**Keywords:** Cow dung, low fertility, rice husk biochar, soil organic, total GRSP.



## Introduction

The nature that finite of land availability causes the emergence of a tight full competition for land use. This usually occurs between the agricultural and non-agricultural sectors, those resulting in actions to convert the function of agricultural land (Agricultural Land Conversion) (Sitko and Jayne, 2014). The agricultural land conversion to non-agricultural functions has increased yearly due to the high human need for shelter (Rondhi et al., 2018). Somehow, the need for food has also increased, in line with the increasing population in Indonesia (Safitri and Sihaloho, 2020). Azadi et al. (2011) also stated that the most common problem in developing countries is a massive population and high food consumption. The better solution to this problem is agricultural extensification by managing sub-optimal soil such as sandy soil or Psamments (Handika et al., 2016).

Countries worldwide know that Indonesia is a very large archipelagic country with a total of 17,480 islands (Torry and Kusumo, 2010) spread from Sabang to Merauke. The ocean bounds each island, and the border between the edge of the island and the ocean is called the coastline (Alfahmi et al., 2019). Indonesia's coastline is composed of loosely structured soil, the particles are not bound together, and there are no clay particles, called sandy soil or Psamments (Vezzani et al., 2018). Psamments in Indonesia, approximately about 1,060,000 ha and potential to cultivate (Kelland et al., 2020). Nevertheless, there are several obstacles in the use of lands such as arid environmental conditions (Meftah et al., 2019), low numbers of microorganisms

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(Pakbaz et al., 2018), and low of biological activities (Wong et al., 2020), so the decomposition process is not going well and humification is not running optimally (Goebel et al., 2011), and not soil aggregation is created. As a result, organic material is not well decomposed and low in content, so the soil fertility is not optimal and less supportive of plant growth. The low biological activity of Psamments is caused by physical problems of the soil and climate, especially microclimate which are less friendly and become a barrier to plants suitable for growth.

Solving the problem of Psamments using mycorrhizal, especially endomycorrhizal according to Bai et al. (2002) was effective because mycorrhizal plays an active role in critical conditions by increasing nutrient uptake of phosphorus (Clausing and Polle, 2020) and other essential microelements (Zn, Co, and Mo), increasing soil aggregation so that soil microbial activity that is beneficial to plants also increases and protects plants from root pathogens (Cheng et al., 2022). Samuel and Veeramani (2021) also stated by their research by comparing the growth of plants with mycorrhizal colonization and none in the same soil conditions. The result showed that plants with mycorrhizal colonization absorb nutrients more significantly than non-mycorrhizal colonization. The problem of Psamments can also be overcome by providing a soil amendment to improve the characteristics of biology, chemistry, and soil physics. The biological characteristics of soils were markedly enhanced by the application of solid biofertilizers and organic amendments, particularly SOC (Fitriatin et al., 2021). Sukartono et al. (2022) reported that biochar-based organic amendments significantly enhanced soil organic carbon and cation exchange capacity in the sandy loam soils. The long-term carbon absorption and glyphosate-biochar interaction during adsorption can be enhanced by rice husk biochar. Enhancing the cation exchange capacity, electrical conductivity, pH $H_2O$, and soil organic matter, Inceptisols ameliorated with rice husk biochar raised the soil surface charge (ΔpH) (Herviyanti et al., 2022) and increased fertilizer absorption by root (Nurmalasari et al., 2021).

Prasad and Kothari (2022), the application of cow dung to soil had some advantages to yield, cation exchange capacity (CEC), soil organic matter percentage, pH, and direct impact on food security and human health. The low fertility of Psamments can be improved by applying inorganic fertilizer (Sharma et al., 2020) because it will provide a sufficient supply of nutrients for plant growth. Various studies that have been conducted have yielded less than optimal results. Hapsoh et al. (2017) state that the application of inorganic fertilizers resulted in the lowest growth because the nutrients supplied by inorganic fertilizers are leached due to sandy soil having loose consistency (Fang et al., 2021). Likewise, a single application of rice husk biochar has no significant effect on SOC. Adding mycorrhizal alone does not significantly affect nutrient absorption (Sun et al., 2022).

The novelty of this research is three treatment combinations of mycorrhizal, soil amendments, and inorganic fertilizer to improve microbial characteristics in Psamments. Thus, the aimed of the research was to investigate the effect of three treatment combinations on soil organic carbon (SOC), microbial biomass carbon (MBC), glomalin-related soil protein (GRSP), and root infections in Psamments through a pot experiment.

## Material and Methods

This research was conducted for 6 months at the green house experimental garden Faculty of Agriculture, Universitas Sebelas Maret located in Jumantono, Karanganyar, Indonesia. A pot experiment arranged with a factorial Completely Randomized Design consisting of three treatment factors: mycorrhizal, types of soil amendments, and doses of inorganic fertilizers. The mychorrhizal fungus used in the experiment is endomycorrhizal, consist of *Glomus manihotis*, *Glomus intraradices*, *Glomus aggrega*tum, *Acaulospora* sp., *Gigaspora* sp., that total spore density is 33.2% spore/50grams. The characteristics of cow dung: pH $H_2O$ (1:5) 7.88; total organic carbon (TOC) 16.62% (dry combustion) (Soil Survey Staff, 2022); total Nitrogen 0.64% (Kjeldahl) (FAO, 2021), and C/N Ratio 26.39. The characteristics of rice husk biochar: water content 8.11%, pH $H_2O$ (1:5) 6.14; total organic carbon (TOC) 18.07%; total Nitrogen 0.54% (Kjeldahl), and C/N Ratio 33.3. Mycorrhizal dose consists of three levels, namely 0 spore/pot (M0), 3 spores/pot (M1), 6 spores/pot (M2), three types of soil amendments: non amendment (P0), cow dung 60 t $ha^{-1}$ (P1), rice husk biochar (RHB) 25 t $ha^{-1}$ (P2), and two levels of inorganic fertilizers, 0 kg $ha^{-1}$ (A0) and 100 kg $ha^{-1}$ (A1) NPK fertilizer (15:15:15). There were 18 treatment combinations with 3 replications so there were 54 experimental units.

The soil used was Psamments from Bantul Regency, Yogyakarta Province, Indonesia. The initial soil analysis of Psamments according to Page et al. (1982), the result showed that pH $H_2O$ (1:2.5) 7.12; soil organic carbon 0.18%; cation exchange capacity 4.43 cmol $kg^{-1}$; total N 0.015%; available $P_2O_5$ 7.34 mg $kg^{-1}$, available K 0.27 cmol $kg^{-1}$; and soil texture was sand (sand 92.23%; silt 6.81%; and clay 0.96%). According to soil fertility category by Husein et al. (2021), the parameters of pH $H_2O$ is neutral, SOC, CEC, total nitrogen, available $P_2O_5$, and available K are very poor. Based on the initial soil analysis, it can be concluded that the Psamments had low fertility. There are many steps of this research. First, sieving soil with a 2 mm sieve to separate the soil fraction from the rock. Next, a quantity of soil weighing 10 kg was carefully measured and thereafter placed within a polybag. Subsequently, the soil was combined with the appropriate soil amendments based on the designated treatment and subjected to a four-week incubation period. After 4 weeks of incubation, planting red chili (*Capsicum annuum* L.) seedlings is carried out together with the mycorrhizal application according to the treatment. Inorganic fertilizers were applied a week after planting.

Watering is done by adding the water until field capacity and weeding every 2 days until 110 days after planting. At 110 days, the soil and root sample was collected. Soil samples were analyzed including SOC (Walkey and Black) (Black et al., 2016), microbial biomass carbon (fumigation and extraction), soil sample extracted with 0.5 M $K_2SO_4$, shaked for 30 minutes and filtered with Whatman 42, and then fumigated, last measured the absorbance using a spectrophotometer at 561 nm (Vance et al., 1987), easily extracted glomalin (EE-GRSP) by autoclaving soil samples with sodium citrate 20 Mm pH 7 for 30 minutes, total-GRSP by autoclaving of soil samples with 50 Mm sodium citrate pH 8 for one hour (Wright and Upadhyaya, 1998). Analysis of root samples includes calculating root infection (Phillips and Hayman, 1970). The data were subjected to statistical analysis using a one-way analysis of variance (ANOVA) test with a significance level of 5% and DMRT test level of 5% with the Minitab version 16. To determine the relationship between variables using the Pearson correlation test.

## Results and Discussion

### Effects of mycorrhizal, soil amendments and inorganic fertilizers on Psamments characteristics

#### Soil organic carbon (SOC)

The application of cow dung significantly affected to increase SOC, levels up to 2.36 times compared to non-amendment (Figure 1). Biochar rice husk application increased SOC value 1.71 times than non-amendment, the lowest is in non-amendment (0.14%). Ebido et al. (2021) reported that the adding of rice husk biochar increased soil organic carbon generally, with the greatest increments (37%) in maximum rate. Organic amendment have been found to contribute more to soil organic carbon (SOC) than inorganic fertilizers (Supriyadi et al., 2018). Saleem et al. (2022) stated that biochar applied to sandy loam soil can increase humic acid, fulfill acid, and impact the soil's total SOC. Baiamonte et al. (2021) also stated that biochar was used as a recommendation for the restoration of degraded and marginal lands through increased SOC and nutrients to increase crop productivity. He et al. (2020) reported that mycorrhizal application contributes to the SOC presence. The mechanism is mycorrhizal symbiosis association shaped extraradical hyphae and its hyphal turnover to the soil and added SOC in the form of glomalin (Paterson et al., 2016; Syamsiyah et al., 2018). This statement was assured by the positive correlation (r=0.467**) between SOC and glomalin. Meanwhile, mycorrhizal hyphae have the ability to accelerate litter's decomposition to aid the accumulation of SOC presence and increase plant capability to uptake Nitrogen (Hodge and Fitter, 2010). Mycorrhizal also has a function to promote SOC's retention into aggregates (Wei et al., 2019).

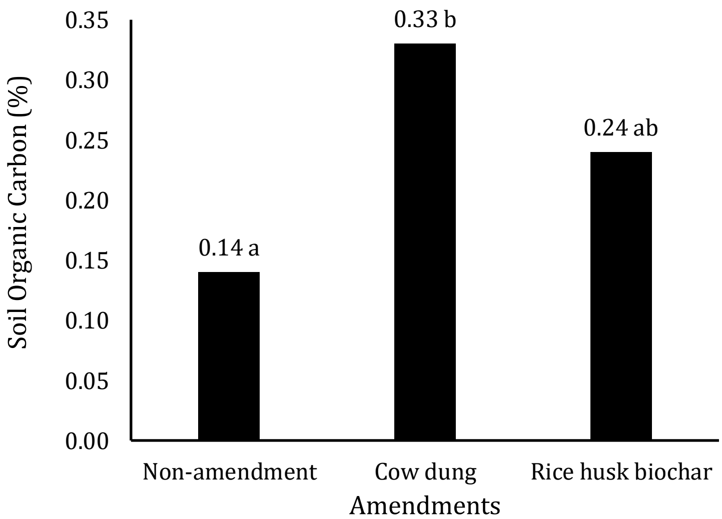


Figure 1. Effect of mycorrhizal, soil amendments, and inorganic fertilizers on soil organic carbon in Psamments
Remarks: Means in a column followed by the same letters show no significant difference in the DMRT test at a 5% significance level.

**Glomalin Related Soil Protein (GRSP)**

GRSP consists of easily extracted glomalin (EE-GRSP) (the latest glomalin fraction) and total-GRSP (the number of old and most recent fractions) (Wright and Upadhyaya, 1998; Rillig 2004; Liu et al. 2020), it is protein-bound soil which is a product of the turnover of hyphal mycelium during mycorrhizal activity (Balami et al., 2020). Recently, the T-GRSP was divided into easily extract glomalin (EE-GRSP) and difficult extract glomalin (DEG), but only T-GRSP and EE-GRSP were measured in this research. It means that EE-GRSP is a component of T-GRSP and build it up.

F test results showed that mycorrhizal treatment, soil amendments, and inorganic fertilizer had a significant effect on easily extracted glomalin (EE-GRSP) (P=0,000**) and T-GRSP (P=0.042 *). Application of mycorrhizal (6 spores/pot) with cow dung (M2P1A0) gave the best EE-GRSP (0.29 mg $g^{-1}$). Interaction of mycorrhizal 6 spores/pot, cow dung, and inorganic fertilizer (M1P1A1) was the highest T-GRSP (0.34 mg $g^{-1}$), increase up to 4.25 times than M0P0A0 that having the lowest value of EE-GRSP (0.05 mg $g^{-1}$) and T-GRSP (0.08 mg $g^{-1}$).

Syamsiyah et al. (2018) mentioned that glomalin as an organic-C deposit in the soil due to its long lifetime in soil, it also contains organic-C as the main binding (Li et al., 2020) material that stabilizes soil. Glomalin contained in the spore walls and hyphal when turnover during fungal activity as the main mechanism for glomalin deposition to the soil also describes the functionality of glomalin away from the hyphal wall to the soil during the life of fungal mycelium (Singh, 2012). The highest EE-GRSP was found in mycorrhizal treatment (6 spores/pot) with cow dung (M2P1A0) with an increase of 5.8 times compared to control (Table 1). Total GRSP was highest in mycorrhizal treatment (3 spores/pot), cow dung, inorganic fertilizer (M1P1A1) with a 4.4 times increase compared to controls (Table 1). Syamsiyah et al. (2018) reported that mycorrhizal application increases available and total glomalin. Increased glomalin caused by mycorrhizal hyphae which are inoculated into the soil will produce a compound in the form of glycoprotein known as glomalin (Rillig, 2004).

Table 1. Effect of mycorrhizal, soil amendments and inorganic fertilizers on easily extracted and total glomalin in Psamments

| **Treatments** | Easily Extracted Glomalin **(EE-GRSP)** | Total glomalin related soil protein **(T-GRSP)** |
|---|---|---|
| | **mg $g^{-1}$** | |
| Control | 0,05 $^{j}$ | 0,08 $^{e}$ |
| No Mycorrhizal-Cow dung-Non fertilizer | 0,16 $^{de}$ | 0,3 $^{a}$ |
| No Mycorrhizal-RHB-No fertilizer | 0,06 $^{j}$ | 0,15 $^{bcde}$ |
| Mycorrhizal 3 spores -No Amendment-No fertilizer | 0,14 $^{defg}$ | 0,21 $^{abcde}$ |
| Mycorrhizal 3 spores -Cow dung -No fertilizer | 0,22 $^{bc}$ | 0,29 $^{ab}$ |
| Mycorrhizal 3 spores -RHB -No fertilizer | 0,06 $^{j}$ | 0,11 $^{de}$ |
| Mycorrhizal 6 spores - No Amendment -No fertilizer | 0,08 $^{ghij}$ | 0,26 $^{abc}$ |
| Mycorrhizal 6 spores – Cow dung -No fertilizer | 0,29 $^{a}$ | 0,3 $^{a}$ |
| Mycorrhizal 6 spores - RHB -No fertilizer | 0,07 $^{hij}$ | 0,09 $^{e}$ |
| No Mycorrhizal-No Amendment-100 kg $ha^{-1}$ inorganic fertilizer | 0,07 $^{ij}$ | 0,08 $^{e}$ |
| No Mycorrhizal-Cow dung-100 kg $ha^{-1}$ inorganic fertilizer | 0,27 $^{ab}$ | 0,31 $^{a}$ |
| No Mycorrhizal-RHB-100 kg $ha^{-1}$ inorganic fertilizer | 0,14 $^{def}$ | 0,11 $^{de}$ |
| Mycorrhizal 3 spores-No Amendment-100 kg $ha^{-1}$ inorganic fertilizer | 0,12 $^{efghi}$ | 0,13 $^{cde}$ |
| Mycorrhizal 3 spores-Cow dung-100 kg $ha^{-1}$ inorganic fertilizer | 0,17 $^{cd}$ | 0,34 $^{a}$ |
| Mycorrhizal 3 spores-RHB-100 kg $ha^{-1}$ inorganic fertilizer | 0,09 $^{ij}$ | 0,11 $^{de}$ |
| Mycorrhizal 6 spores-No Amendment-100 kg $ha^{-1}$ inorganic fertilizer | 0,07 $^{ij}$ | 0,09 $^{de}$ |
| Mycorrhizal 6 spores-Cow dung-100 kg $ha^{-1}$ inorganic fertilizer | 0,1 $^{fghij}$ | 0,23 $^{abcd}$ |
| Mycorrhizal 6 spores-RHB-100 kg $ha^{-1}$ inorganic fertilizer | 0,13 $^{defgh}$ | 0,13 $^{cde}$ |

Remarks: Means in a column followed by the same letters show no significant difference in the DMRT test at a 5% significance level.

Prasad and Kothari (2022) revealed that cow-dung treatment gives high glomalin value because it increases soil nutrition and biological activity, produces growth stimulating substances that cause mycorrhizal hyphae to develop and glomalin as adhesive and hyphae protector (Driver et al., 2005). GRSP with organic carbon and nitrogen in the soil is a source of nutrients available for plants that are very important for nutrient cycles and ecosystems (Treseder and Turner, 2007). McClellan et al. (2022) also mentioned that GRSP operationally defined protein fraction of soil organic matter, that hypothesized to build up contribution to long-term soil aggregation, soil stability, and also long-term soil carbon storage and it means the content of glomalin was affected especially by SOC and SOC itself significantly correlates with GT.

**Microbial Biomass Carbon (MBC)**

F test results showed that the interaction of mycorrhizal, soil amendments, and inorganic fertilizer significantly influenced microbial biomass carbon (P=0,000**). Microbial biomass carbon was the highest in mycorrhizal treatment (6 spores/pot) with biochar rice husk without inorganic fertilizer with a 23-fold increase in control (Figure 2). Mycorrhizal treatment (6 spores/pot), cow dung, and inorganic fertilizer (M2P1A1) increased the level of C-microbial biomass up to 11 times than the control (Figure 2).

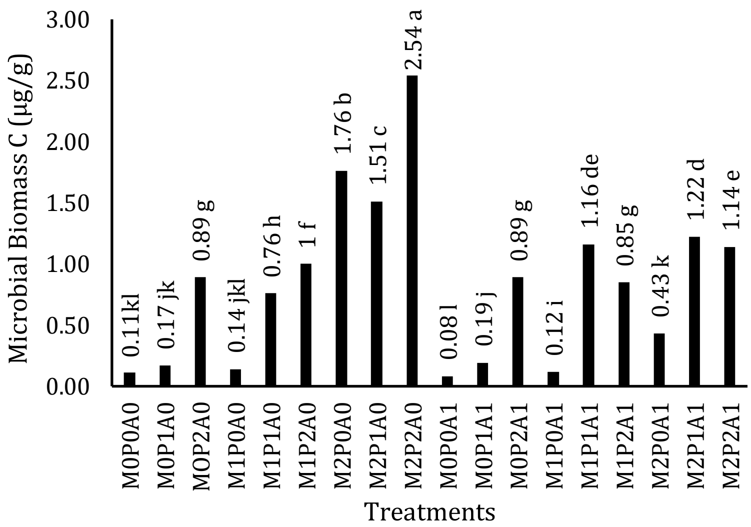


Figure 2. Effect of mycorrhizal, soil amendments, and inorganic fertilizers on carbon microbial biomass in Psamments
Remarks: Means in a column followed by the same letters show no significant difference in the DMRT test at a 5% significance level. M0= 0 spore/pot, M1= 3 spores/pot, M2=6 spores/pot (M2), P0= without amendment, p1=cow dung 60 t ha$^{-1}$, P2= rice husk biochar (RHB) 25 t ha$^{-1}$, A0= 0 kg ha-1, A1 = 100 kg ha$^{-1}$ NPK fertilizer (15:15:15).

Fungal hyphae have a strong interaction with soil microbes (Nichols, 2008; Eddiwal et al., 2018;) along with the addition of biochar rice husk and inorganic fertilizer (Fang et al., 2021) as a source of nutrition for microbial development so that the decomposition process will be faster. Xu et al. (2014) suggested that biochar rice husk application affects soil bacterial community through improving the soil physicochemical characteristics. In line with Xu et al. (2016), the utilization of biochar derived from rice husk in soil has been found to enhance microbial activity, potentially attributed to the presence of labile carbon compounds inside the biochar. This, in turn, leads to an increase in the availability of nitrogen in soils subjected to biochar treatments. Some research result showed that the plant roots have the capacity to facilitate the establishment of some specific consortium of microorganisms while the rhizosphere were invaded by fungi (mycorrhizal), so that will be some association between microorganisms and root surfaces (rhizosphere) and gave some beneficial advantages to both plant and microorganisms (Berendsen et al. 2012; Huang et al. 2019; Gregory, 2022).

Conversely, the presence of increased microbial activity suggests a potential elevation in the rate at which nutrients, such as nitrogen, are cycled. This might potentially lead to a decrease in nitrogen leaching when rice husk biochar is applied. Prasasti and Purwani (2013) revealed that the increase in mycorrhizal dose showed an increase in mycorrhizal colonization. Thus, the extension of mycorrhizal hyphae causes interactions with various rhizobacterium (Sutariati and dan Wahab, 2012) and the population is increasing along with the application of biochar rice husk as an organic material containing organic carbon, humic acid, fulvic acid, and various other nutrients (N, P, K) which are a source of energy for soil microbes to accelerate decomposition and other chemical reaction processes that require microbial assistance.

Xu et al. (2016) also mentioned that biochar rice husk application may develop biogeochemical interfaces (BGIs) through the high porosity and various functional benefits. Hanzel et al. (2013) explained that BGI conditions to the soil could enhance the diversity of niche microhabitats in the soil, hence promoting the formation of diverse bacterial populations and facilitating various biological activities. Bi et al. (2018) explained that arbuscular mycorrhizal inoculation significantly improves the rhizosphere environment for microbes (rhizobacterium) to survive and adapt in the environment, so conducive to soil quality improvement and impact the growth of plants. Thereby MBC is in line with bacterial diversity that would be higher in biochar applications.

**Effects of mycorrhizal, soil amendments, and inorganic fertilizers on root infection in Psamments**

The analysis of varian results showed that mycorrhizal application with amendments and inorganic fertilizers significantly affected the percentage of root infections (p = 0,000**). The highest root infection was found in mycorrhizal treatment (6 spores/plants). It's about a 100% percentage of infection (Figure 3 and 4). Amending and adding mycorrhizal doses increase the percentage of root infections. In line with Bi et al. (2018) that mycorrhizal treatment gives a higher mycorrhizal colonization rate inside the root cell than non-inoculated (control) treatment. Ning et al. (2019) also reported that mycorrhizal treatment improves colonization rate than non-inoculated treatments. Prayudyaningsih and Sari (2016) research results showed that the roots of the host plant which were inoculated with mycorrhizal were infected, while the roots that were not inoculated did not indicate infection. The research results of Chiomento et al. (2022) also revealed the best root infectivity in treatments that were given higher mycorrhizal doses, while the lowest infectivity at the lower dose treatment roots. The extension of colonized hyphae mycorrhiza causes interactions with various rhizobacterium and soil microbes (Nichols, 2008; Eddiwal et al., 2018) which helps mycorrhizal signaling process such as mycorrhization helper bacteria (MHB) and phosphate solubilizing bacteria (PSB) so that it affects the mycorrhizal activity to colonize the roots (Gundale and DeLuca, 2007).

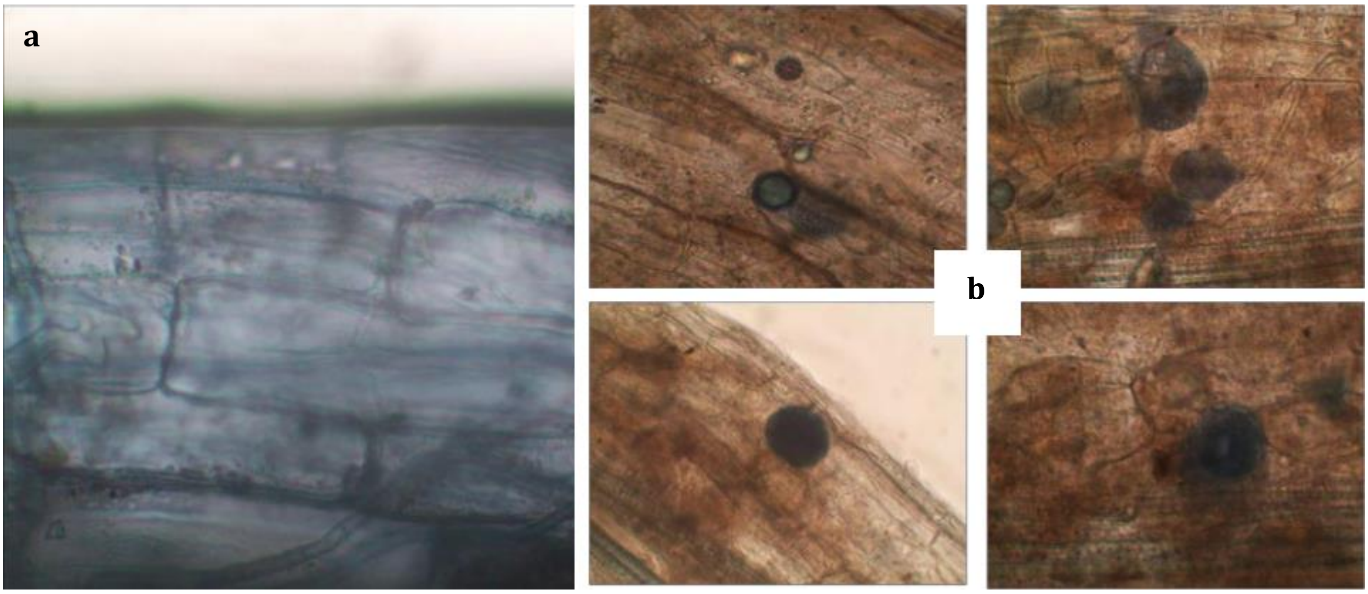


Figure 3. The lowest root infection without mycorrhizal treatment (M0P0A0) (a) and the highest root infection on mycorrhizal 6 spores/pot (M2P0A0) (b)

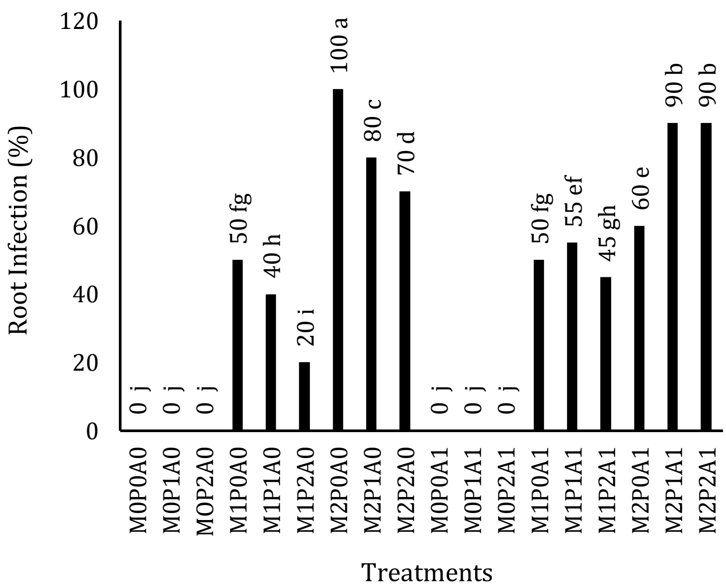


Figure 4. Effect of mycorrhizal, soil amendments, and inorganic fertilizers on root infection in Psamments
Remarks: Means in a column followed by the same letters show no significant difference in the DMRT test at a 5% significance level. M0= 0 spore/pot, M1= 3 spores/pot, M2=6 spores/pot (M2), P0= without amendment, p1=cow dung 60 t $ha^{-1}$, P2= rice husk biochar (RHB) 25 t $ha^{-1}$, A0= 0 kg ha-1, A1 = 100 kg $ha^{-1}$ NPK fertilizer (15:15:15).

### Correlation between SOC, GRSP, MBC, and Root Infection

Correlation test results showed that the parameters relate to mycorrhizal treatment, soil amendments and inorganic fertilizers. A significant correlation between EE-GRSP and soil organic carbon levels (r =0.467**) (Figure 5). A significant positive correlation was observed between EE-GRSP and T-Glomalin (r =0.695**) (Figure 6). The microbial biomass carbon parameter has a very strong correlation with the parameters of root infection (r = 0.488**) (Figure 7). All of these correlations are calculated by the ordinary least square method.

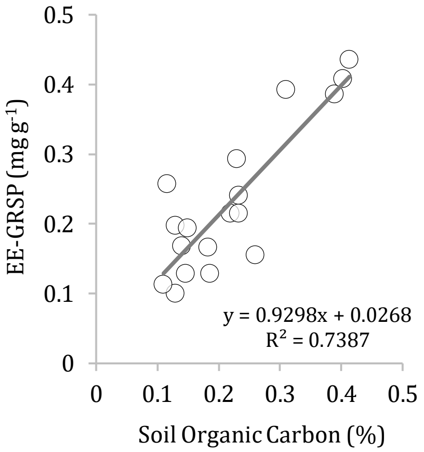


Figure 5. Relation between easily extracted glomalin and soil organic carbon

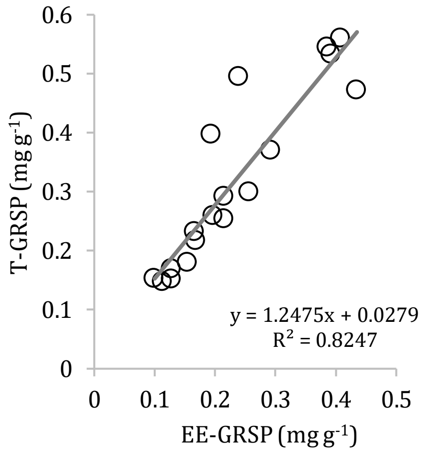


Figure 6. Relation between easily extracted glomalin and total glomalin

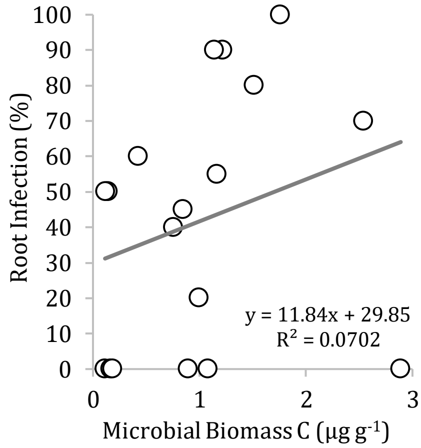


Figure 7. Relation between microbial biomass carbon and root infection

Balami et al. (2020) was reported that carbon in glomalin has a major contribution to increasing SOC (Matos et al. 2022) and has an impact on improving soil for crop production. Singh (2012) also explained that mycorrhizal and GRSP correlate with each other due to their role in building up aggregation then affecting SOC dynamics around the agroecosystem. MVA through its external roots will produce compounds in the form of glomalin glycoprotein and organic acids that can increase SOC levels so that there was a strong positive correlation between glomalin and SOC (Wang et al., 2018). In their study, Wu et al. (2022) report that the application of mycorrhizae has been found to enhance litter decomposition in laboratory trials of short duration. However, it is suggested that these effects may potentially yield beneficial long-term outcomes for soil organic carbon (SOC) accumulation, hence contributing to soil carbon storage. Its short-term effects knew that mycorrhizal vesicular-arbuscular (MVA) enhance the degradation of soil organic matter (SOM) by stimulating decomposers, and moreover the microbial metabolites never lost but they turn into highly stable compounds known as mineral-associated SOM fractions which will be the longest mean residence time in soil. Organic matter sub-soil contains more microbes derived compounds than top-soil and this microbial processes sugar seems to be better associated with mineral phases compared to plant-derived organic matter (Rumpel and Kögel-Knabner, 2011). Thereby, this mechanism which holds particular importance in the sub-soil (clay-minerals presence and sesquioxides) enhancement, represents a considerable potential for mineral-associated organic matter in long-term stabilization (Wu et al., 2022). There was a strong correlation between total and easily extracted glomalin due to their arrangement for presence in the rhizosphere (McClellan et al., 2022).

The findings of this research align with the statement of Spedding et al. (2004) that the activity and density of microbial populations in the soil are determined by changes in the chemical and physical conditions of soil. That is because the extension of mycorrhizal hyphae causes interactions with various rhizobacterium (Budiastuti et al., 2021) and soil microbes (Sodiq et al., 2021). The same statement by (Kilowasid et al., 2021) along with the increase in mycorrhizal dose shows an increase in mycorrhizal colonization. Soil microbes biomass carbon was measured to estimate the presence of microbacterial communities around the rhizosphere by measuring the microbe's organic carbon molecules (Ashraf et al., 2020). There was a microbe that colonized and resided in the root (surrounding rhizosphere) that utilizes its exudates to their metabolism and also a role as a beneficial agent to the plant due to these microbes function (fixation of nitrogen, nutrient uptake enhancement, suppression of plant from diseases) and they called as plant growth promoting rhizobacteria (PGPR) (Kumari et al., 2018).

Microbial biomass carbon demonstrated a very significant correlation with root infection, which agrees with our findings. Living root inputs are more effective than litter inputs in producing fast and slow-cycling SOC, as well as being more efficiently utilized by the soil microbial population, leading to an increase in the pool of mineral-associated SOC (Sokol et al., 2019). This is consistent with the theory of a dissolved organic C route from live roots to microbial biomass, as well as mineral-associated SOC (Cotrufo et al., 2019). The type of mycorrhizal association determines the formation of slow-cycling soil carbon, microbial stabilization which increases with soil depth, secretions and microbial necromass could potentially supplied carbon inputs for mineral-associated soil organic C formation, while C released by roots at deep can be stabilized and contribute to C pool. The presence of roots can enhance the availability of labile carbon to rhizosphere bacteria, resulting in higher rates of SOM mineralization, roots can also contribute to the destabilization by exposing previously protected carbon to decomposition of microbial (Dijkstra et al., 2021). Roots have a substantial impact on the mineralization of soil organic matter, nitrification, and subsequent immobilization driven by microbial. The presence of roots speeds up the decomposition of SOM by up to five times (Gregory, 2022). These findings point to the importance of mycorrhizal fungi in microbial biomass, soil organic carbon, and root infection to improve the Psamments characteristics.

## Conclusion

Psamments have low fertility, especially in the concentration of soil organic carbon, total nitrogen, cation exchange capacity, available phosphor, and available potassium, according to the initial soil analysis and soil fertility category. Adding mycorrhizal, soil amendments, and NPK fertilizers could enhance the problem. Based on the results obtained, several conclusions were drawn that the adding of mycorrhizal, amendments and inorganic fertilizers can increase the MBC (M2P1A1) with an 11-fold increase (1.22 μg/g) than non-mycorrhizal treatment. Mycorrhizal (6 spores/pot) with cow-dung (M2P1A0) gave the best EE-GRSP (0.29 mg $g^{-1}$), and the highest root infection was found in mycorrhizal treatment (6 spores/pot) with a percentage of infection of 100%. A very strong correlation occurs between EE-GRSP and soil organic carbon, EE-GRSP and T-Glomalin; and also microbial biomass carbon and root infection. Mycorrhizal associations are vital for microbial stability; C produced by roots contributes to C storage. Roots could boost the availability of labile carbon to rhizosphere microorganisms, resulting in faster SOM mineralization and SOC stabilization. Soil microbial activities, such as the mineralization of soil organic matter, are influenced considerably by roots. SOM decomposition speeds up when roots are present. These data imply that mycorrhizal fungi play a key role in microbial biomass, soil organic carbon, and root infection. This study showed that combining mycorrhizal fungi with soil amendments and inorganic fertilizers can enhance the properties of Psamments.

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## References

Alfahmi, F., Boer, R., Hidayat, R., Perdinan, Sopaheluwakan, A., 2019. The impact of concave coastline on rainfall offshore distribution over Indonesian maritime continent. *Scientific World Journal* Article ID 6839012.

Ashraf, M. N., Hu, C., Wu, L., Duan, Y., Zhang, W., Aziz, T., Cai, A., Abrar, M.M., Xu, M., 2020. Soil and microbial biomass stoichiometry regulate soil organic carbon and nitrogen mineralization in rice-wheat rotation subjected to long-term fertilization. *Journal of Soils and Sediments* 20(8): 3103–3113.

Azadi, H., Ho, P., Hasfiati, L. 2011. Agricultural land conversion drivers: A comparison between less developed, developing and developed countries. *Land Degradation and Development* 22(6): 596-604.

Bai, Y., Pan, B., Charles, T.C., Smith, D.L., 2002. Co-inoculation dose and root zone temperature for plant growth promoting rhizobacteria on soybean [Glycine max (L.) Merr] grown in soil-less media. *Soil Biology and Biochemistry* 34(12): 1953–1957.

Baiamonte, G., Crescimanno, G., Parrino, F., De Pasquale, C., 2021. Biochar amended soils and water systems: Investigation of physical and structural properties. *Applied Sciences* 11(24): 12108.

Balami, S., Vašutová, M., Godbold, D., Kotas, P., Cudlín, P., 2020. Soil fungal communities across land use types. *IForest-Biogeosciences and Forestry* 13(6): 548-558.

Berendsen, R.L., Pieterse, C.M.J., Bakker, P.A.H.M., 2012. The rhizosphere microbiome and plant health. *Trends in Plant Science* 17(8): 478-486.

Bi, Y., Zhang, Y., Zou, H., 2018. Plant growth and their root development after inoculation of arbuscular mycorrhizal fungi in coal mine subsided areas. *International Journal of Coal Science and Technology* 5(1): 47–53.

Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark, F.E., 2016. Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties. Soil Science Society of America. Madison, Wisconsin, USA. 1159p.

Budiastuti, M.T.S., Purnomo, D., Supriyono, Pujiasmanto, B., Setyaningrum, D., 2020. Effects of light intensity and co-inoculation of arbuscular mycorrhizal fungi and rhizobium on root growth and nodulation of Indigofera tinctoria. *SAINS TANAH - Journal of Soil Science and Agroclimatology* 17(2): 94-99.

Cheng, X.F., Xie, M.M., Li, Y., Liu, B.Y., Liu, C.Y., Wu, Q.S., Kuča, K., 2022. Effects of field inoculation with arbuscular mycorrhizal fungi and endophytic fungi on fruit quality and soil properties of Newhall navel orange. *Applied Soil Ecology* 170: 104308.

Chiomento, J.L.T., Filippi, D., Krasnievicz, G.M., De Paula, J.E.C., Fornari, M., Trentin, T.S., 2022. Arbuscular mycorrhizal fungi potentiate the root system and the quality of goldenberry fruits. *Advances in Horticultural Science* 36(4), 265–273.

Clausing, S., Polle, A., 2020. Mycorrhizal phosphorus efficiencies and microbial competition drive root P uptake. *Frontiers in Forests and Global Change 3*(1): 54.

Cotrufo, M.F., Ranalli, M.G., Haddix, M.L., Six, J., Lugato, E., 2019. Soil carbon storage informed by particulate and mineral-associated organic matter. *Nature Geoscience* 12(12): 989–994.

Dijkstra, F.A., Zhu, B., Cheng, W., 2021. Root effects on soil organic carbon: a double-edged sword. *New Phytologist 230*(1): 60–65.

Driver, J.D., Holben, W.E., Rillig, M.C., 2005. Characterization of glomalin as a hyphal wall component of arbuscular mycorrhizal fungi. *Soil Biology and Biochemistry* 37(1): 101-106.

Ebido, N.E., Edeh, I.G., Unagwu, B.O., Nnadi, A.L., Ozongwu, O.V., Obalum, S.E., Igwe, C.A., 2021. Rice-husk biochar effects on organic carbon, aggregate stability and nitrogen-fertility of coarse-textured Ultisols evaluated using Celosia argentea growth. *Sains Tanah-Journal of Soil Science and Agroclimatology* 18(2): 177–187.

Eddiwal, E., Saidi, A., Husin, E.F., Rasyidin, A., 2018. Pengaruh inokulasi fungi mikoriza arbuskula (FMA) plus organik terhadap pertumbuhan dan produksi jagung pada Ultisol. *Jurnal Solum – Journal of Soil and Land Utilization Management* 15(2): 50-59. [in Indonesian]

Fang, H., Liu, K., Li, D., Peng, X., Zhang, W., Zhou, H., 2021. Long-term effects of inorganic fertilizers and organic manures on the structure of a paddy soil. *Soil and Tillage Research* 213: 105137.

FAO, 2021. Standard operating procedure for soil nitrogen: Kjeldahl method. Rome, Italy. 25p. Available at [Access date: 15.07.2023]: https://www.fao.org/3/cb3642en/cb3642en.pdf

Fitriatin, B.N., Amanda, A.P., Kamaluddin, N.N., Khumairah, F.H., Sofyan, E.T., Yuniarti, A., Turmuktini, T., 2021. Some soil biological and chemical properties as affected by biofertilizers and organic ameliorants application on paddy rice. *Eurasian Journal of Soil Science* 10(2): 105–110.

Goebel, M.O., Bachmann, J., Reichstein, M., Janssens, I.A., Guggenberger, G., 2011. Soil water repellency and its implications for organic matter decomposition - is there a link to extreme climatic events? *Global Change Biology* 17(8): 2640-2656.

Gregory, P.J., 2022. RUSSELL REVIEW Are plant roots only “in” soil or are they “of” it? Roots, soil formation and function. *European Journal of Soil Science* 73(1): e13219.

Gundale, M.J., DeLuca, T.H., 2007. Charcoal effects on soil solution chemistry and growth of Koeleria macrantha in the ponderosa pine/Douglas-fir ecosystem. *Biology and Fertility of Soils* 43(3): 303–311.

Handika, G., Yudono, P., Rogomulyo, R., 2016. Pengaruh waktu penyiangan terhadap pertumbuhan dan hasil kacang hijau ( Vigna radiata (L .) R . Wilczek ) di lahan pasir pantai Samas Bantul. *Vegetalika* 5(4): 25–36. [in Indonesian]

Hanzel, J., Myrold, D., Sessitsch, A., Smalla, K., Tebbe, C.C., Totsche, K.U., 2013. Microbial ecology of biogeochemical interfaces – diversity, structure, and function of microhabitats in soil. *FEMS Microbiology Ecology* 86(1): 1-2.

Hapsoh, Gusmawartati, Amri, A.I., Diansyah, A., 2017. Respons pertumbuhan dan produksi tanaman cabai keriting (Capsicum annuum L.) terhadap aplikasi pupuk kompos dan pupuk anorganik di polibag. *Jurnal Hortikultura Indonesia* 8(3): 203–208. [in Indonesian]

He, J.D., Chi, G.G., Zou, Y.N., Shu, B., Wu, Q.S., Srivastava, A.K., Kuča, K., 2020. Contribution of glomalin-related soil proteins to soil organic carbon in trifoliate orange. *Applied Soil Ecology* 154: 103592.

Herviyanti, Maulana, A., Lita, A.L., Prasetyo, T.B., Monikasari, M., Ryswaldi, R., 2022. Characteristics of inceptisol ameliorated with rice husk biochar to glyphosate adsorption. *SAINS TANAH - Journal of Soil Science and Agroclimatology* 19(2): 230–240.

Hodge, A., Fitter, A.H., 2010. Substantial nitrogen acquisition by arbuscular mycorrhizal fungi from organic material has implications for N cycling. *PNAS- Proceedings of the National Academy of Sciences of the United States of America* 107(31): 13754-13759.

Huang, A. C., Jiang, T., Liu, Y. X., Bai, Y. C., Reed, J., Qu, B., Goossens, A., Nützmann, H.W., Bai, Y., Osbourn, A., 2019. A specialized metabolic network selectively modulates Arabidopsis root microbiota. *Science* 364(6440): eaau6389.

Husein, H. H., Lucke, B., Bäumler, R., Sahwan, W., 2021. A contribution to soil fertility assessment for arid and semi-arid lands. *Soil Systems* 5(3): 42.

Kelland, M. E., Wade, P. W., Lewis, A. L., Taylor, L. L., Sarkar, B., Andrews, M. G., Lomas, M.R., Cotton, T.E.A., Kemp, S.J., James, R.H., Pearce, C.R., Hartley, S.E., Hodson, M.E., Leake, J.R., Banwart, S.A., Beerling, D.J., 2020. Increased yield and CO2 sequestration potential with the C4 cereal Sorghum bicolor cultivated in basaltic rock dust-amended agricultural soil. *Global Change Biology* 26(6): 3658-3676.

Kilowasid, L. M. H., Sanjaya, M. F., Sabaruddin, L., Hasid, R., Sulaeman, D., Nurmas, A., 2021. The use of soil biostructures created by soil fauna ecosystem engineers fed with different organic materials as inoculum source of arbuscular mycorrhiza fungi on cocoa seedling. *SAINS TANAH - Journal of Soil Science and Agroclimatology* 18(2): 166–176.

Kumari, P., Meena, M., Upadhyay, R.S., 2018. Characterization of plant growth promoting rhizobacteria (PGPR) isolated from the rhizosphere of Vigna radiata (mung bean). *Biocatalysis and Agricultural Biotechnology* 16: 155–162.

Li, X., Han, S., Luo, X., Chen, W., Huang, Q., 2020. Arbuscular mycorrhizal-like fungi and glomalin-related soil protein drive the distributions of carbon and nitrogen in a large scale. *Journal of Soils and Sediments* 20(2): 963–972.

Liu, H., Wang, X., Liang, C., Ai, Z., Wu, Y., Xu, H., Xue, S., Liu, G., 2020. Glomalin-related soil protein affects soil aggregation and recovery of soil nutrient following natural revegetation on the Loess Plateau. *Geoderma* 357: 113921.

Matos, P.S., da Silva, F.C., Pereira, M.G., da Silva, E.M.R., Tarré, R.M., Franco, C.A.L., Zonta, E., 2022. Short-term modifications of mycorrhizal fungi, glomalin and soil attributes in a tropical agroforestry. *Acta Oecologica* 114: 103815.

McClellan, S. A., Laws, E. A., Elsey-Quirk, T., 2022. Estimates of protein in coastal marsh soils: A case study of the utility of the Bradford assay for quantifying soil protein. *Geoderma* 410: 115676.

Meftah, O., Guergueb, Z., Braham, M., Sayadi, S., Mekki, A., 2019. Long term effects of olive mill wastewaters application on soil properties and phenolic compounds migration under arid climate. *Agricultural Water Management* 212: 119-125.

Nichols, K.A., 2008. Indirect contributions of AM fungi and soil aggregation to plant growth and protection. In: Mycorrhizae: Sustainable Agriculture and Forestry. Siddiqui, Z.A., Akhtar, M.S., Futai, K. (Eds.). Springer, Dordrecht. pp 177–194.

Ning, Y., Xiao, Z., Weinmann, M., Li, Z., 2019. Phosphate uptake is correlated with the root length of celery plants following the association between arbuscular mycorrhizal fungi, Pseudomonas sp. and biochar with different phosphate fertilization levels. *Agronomy* 9(12): 824.

Nurmalasari, A. I., Supriyono, S., Sri Budiastuti, M.T., Sulistyo, T.D., Nyoto, S., 2021. Composting of rice straw for organic fertilizer and manufacturing rice husk charcoal as planting medium in soybean demonstration plot. *PRIMA - Journal of Community Empowering and Services* 5(2): 102–109.

Page, A.L., Miller, R.H., Keeney, D.R., 1982. Methods of Soil Analysis Part 2: Chemical and Microbiological Properties. 2nd Ed. American Society of Agronomy - Soil Science Society of America, Madison, Wisconsin USA. 1159 p.

Pakbaz, M.S., Behzadipour, H., Ghezelbash, G.R., 2018. Evaluation of shear strength parameters of sandy soils upon microbial treatment. *Geomicrobiology Journal* 35(8): 721-726.

Paterson, E., Sim, A., Davidson, J., Daniell, T.J., 2016. Arbuscular mycorrhizal hyphae promote priming of native soil organic matter mineralisation. *Plant and Soil* 408(1–2): 243-254.

Phillips, J.M., Hayman, D.S., 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. *Transactions of the British Mycological Society* 55(1): 158-161.

Prasad, A., Kothari, N., 2022. Cow products: boon to human health and food security. *Tropical Animal Health and Production* 54(1): 12.

Prasasti, O.H., Purwani, K.I., 2013. Pengaruh mikoriza Glomus fasciculatum terhadap pertumbuhan vegetatif tanaman kacang tanah yang terinfeksi patogen Sclerotium rolfsii. *Jurnal Sains Dan Seni Pomits* 2(2): 74–78. [in Indonesian]

Prayudyaningsih, R., Sari, R., 2016. The application of arbuscular mycorrhizal fungi (AMF) and compost to improve the growth of teak seedlings (Tectona grandis Linn. f.) on limestone post-mining Soil. *Jurnal Penelitian Kehutanan Wallacea* 5(1): 37–46.

Rillig, M.C., 2004. Arbuscular mycorrhizae, glomalin, and soil aggregation. *Canadian Journal of Soil Science* 84(4): 355-363.

Rondhi, M., Pratiwi, P.A., Handini, V.T., Sunartomo, A.F., Budiman, S.A., 2018. Agricultural land conversion, land economic value, and sustainable agriculture: A case study in East Java, Indonesia. *Land 7*(4): 148.

Rumpel, C., Kögel-Knabner, I., 2011. Deep soil organic matter-a key but poorly understood component of terrestrial C cycle. *Plant and Soil* 338(1):143-158.

Safitri, D.R., Sihaloho, E.D., 2020. Lumbung padi Indonesia dan kemiskinan: studi kasus kabupaten kota di Jawa Timur. *Ekonomis: Journal of Economics and Business* 4(1): 56-61. [in Indonesian]

Saleem, H., Ahmad, M., Rashid, J., Ahmad, M., Al-Wabel, M.I., Amin, M., 2022. Carbon potentials of different biochars derived from municipal solid waste in a saline soil. *Pedosphere* 32(2): 283–293.

Sharma, N., Shukla, Y.R., Singh, K., Mehta, D.K., 2020. Soil fertility, nutrient uptake and yield of bell pepper as influenced by conjoint application of organic and inorganic fertilizers. *Communications in Soil Science and Plant Analysis* 51(20): 1626–1640.

Singh, P.K., 2012. Role of glomalin related soil protein produced by arbuscular mycorrhizal fungi : A Review. *Agricultural Science Research Journal* 2(3): 119-125.

Sitko, N.J., Jayne, T.S., 2014. Structural transformation or elite land capture? The growth of "emergent" farmers in Zambia. *Food Policy* 48: 194-202.

Sodiq, A.H., Setiawati, M.R., Santosa, D.A., Widayat, D., 2021. Molecular identification of isolates from local microorganisms as potential biofertilizer. *SAINS TANAH - Journal of Soil Science and Agroclimatology 18*(2): 188–193.

Soil Survey Staff, 2022. Kellogg Soil Survey Laboratory methods manual. Soil Survey Investigations Report No. 42, Version 6.0. Part 1: Current Methods. U.S. Department of Agriculture, Natural Resources Conservation Service, USA. Available at [Access date: 15.07.2023]: https://www.nrcs.usda.gov/sites/default/files/2023-01/SSIR42.pdf

Sokol, N.W., Kuebbing, S.E., Karlsen-Ayala, E., Bradford, M.A., 2019. Evidence for the primacy of living root inputs, not root

or shoot litter, in forming soil organic carbon. *New Phytologist* 221(1): 233–246.
Spedding, T.A., Hamel, C., Mehuys, G.R., Madramootoo, C.A., 2004. Soil microbial dynamics in maize-growing soil under different tillage and residue management systems. *Soil Biology and Biochemistry* 36(3): 499-512.
Samuel, S.S., Veeramani, A., 2021. Advantages of arbuscular mycorrhizal fungi (AMF) production for the profitability of agriculture and biofertilizer industry. In: Mycorrhizal Fungi - Utilization in Agriculture and Industry. Radhakrishnan, R. (Ed.). IntechOpen, pp. 31–46.
Sukartono, Kusumo, B.H., Suwardji, Bakti, A.A., Mahrup, Susilowati, L.E., Fahrudin, 2022. Influence of biochar amendments on the soil quality indicators of sandy loam soils under cassava–peanut cropping sequence in the semi-arid tropics of Northern Lombok, Indonesia. *SAINS TANAH - Journal of Soil Science and Agroclimatology 19*(2): 205–210.
Sun, J., Jia, Q., Li, Y., Zhang, T., Chen, J., Ren, Y., Dong, K., Xu, S., Shi, N.N., Fu, S., 2022. Effects of arbuscular mycorrhizal fungi and biochar on growth, nutrient absorption, and physiological properties of maize (Zea mays L.). *Journal of Fungi*, 8(12): 1275.
Supriyadi, Mustikaningrum, I.A., Herawati, A., Purwanto, P., Sumani, S., 2018. Soil quality assessment in organic and non organic paddy fields in Susukan, Indonesia. *Bulgarian Journal of Agricultural Science*, 24(5): 777–784.
Sutariati, G.A.K., dan Wahab, A., 2012. Karakter fisiologis dan kemangkusan rizobakteri indigenus Sulawesi Tenggara sebagai pemacu pertumbuhan tanaman cabai. *Jurnal Hortikultura* 22(1): 57–64. [in Indonesian]
Syamsiyah, J., Herawati, A., Mujiyo, 2018. The potential of arbuscular mycorrhizal fungi application on aggregrate stability in alfisol soil. *IOP Conference Series: Earth and Environmental Science* 142: 012045.
Torry, A., Kusumo, S., 2010. Optimization of the management and empowerment of the outer islands in order to maintain the integrity of the Republic of Indonesia. *Jurnal Dinamika Hukum* 10(3): 327–337. [in Indonesian]
Treseder, K.K., Turner, K.M., 2007. Glomalin in ecosystems. *Soil Science Society of America Journal* 71(4): 1257-1266.
Vance, E.D., Brookes, P.C., Jenkinson, D.S., 1987. An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry* 19(6): 703–707.
Vezzani, F.M., Anderson, C., Meenken, E., Gillespie, R., Peterson, M., Beare, M.H., 2018. The importance of plants to development and maintenance of soil structure, microbial communities and ecosystem functions. *Soil and Tillage Research* 175: 139-149.
Wang, Q., Li, J., Chen, J., Hong, H., Lu, H., Liu, J., Dong, Y., Yan, C. 2018. Glomalin-related soil protein deposition and carbon sequestration in the Old Yellow River delta. *Science of the Total Environment* 625: 619-626.
Wei, L., Vosátka, M., Cai, B., Ding, J., Lu, C., Xu, J., Yan, W., Li, Y., Liu, C., 2019. The role of arbuscular mycorrhiza fungi in the decomposition of fresh residue and soil organic carbon: A mini-review. *Soil Science Society of America Journal* 83(3): 511-517.
Wong, E.V.S., Ward, P.R., Murphy, D.V., Leopold, M., Barton, L., 2020. Vacuum drying water-repellent sandy soil: Anoxic conditions retain original soil water repellency under variable soil drying temperature and air pressure. *Geoderma* 372: 114385.
Wright, S.F., Upadhyaya, A., 1998. A survey of soils for aggregate stability and glomalin, a glycoprotein produced by hyphae of arbuscular mycorrhizal fungi. *Plant and Soil* 198: 97–107.
Wu, Y., Deng, M., Huang, J., Yang, S., Guo, L., Yang, L., Ahirwal, J., Peng, Z., Liu, W., Liu, L., 2022. Global patterns in mycorrhizal mediation of soil carbon storage, stability, and nitrogen demand: A meta-analysis. *Soil Biology and Biochemistry* 166: 108578.
Xu, H.J., Wang, X.H., Li, H., Yao, H.Y., Su, J.Q., Zhu, Y.G., 2014. Biochar impacts soil microbial community composition and nitrogen cycling in an acidic soil planted with rape. *Environmental Science and Technology* 48(16): 9391–9399.
Xu, N., Tan, G., Wang, H., Gai, X., 2016. Effect of biochar additions to soil on nitrogen leaching, microbial biomass and bacterial community structure. *European Journal of Soil Biology* 74: 1-8.

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# Soil fertility status, productivity challenges, and solutions in rice farming landscapes of Azerbaijan

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## Abstract

Rice, a fundamental staple globally, plays a pivotal role in addressing food security and nutrition. This study explores the intricate interplay between soil characteristics, productivity challenges, and solutions in Azerbaijan's rice farming landscapes, acknowledging the agricultural importance of rice and its contribution to human nutrition. This study aims to assess the physical and chemical properties of soil samples from Azerbaijan's rice cultivation areas, with a focus on nutrient content and the identification of elements limiting productivity and plant nutrition. By synthesizing these perspectives, the study enriches the understanding of the complex relationship between soil fertility class and rice productivity, offering insights for sustainable rice farming. Soil samples were collected from representative rice fields across Azerbaijan and analyzed for various parameters, including soil texture, pH, electrical conductivity, organic matter, and nutrient content. The soil sampling and preparation process maintained the integrity of collected samples, providing a reliable basis for scientific analysis. The results reveal diverse soil properties, with clayey texture prevailing. Soil acidity, salinity, and nutrient deficiencies pose challenges, emphasizing the need for corrective measures. The majority of soils exhibit unsuitable pH levels and elevated sodium content, necessitating interventions such as soil acidification and sodicity remediation. Soil salinity issues highlight the importance of drainage and leaching practices. Low organic matter and nutrient deficiencies, particularly zinc and manganese, underscore the need for targeted interventions, including foliar applications. Overall, Azerbaijan's rice-cultivated areas face challenges related to soil fertility, salinity, and nutrient deficiencies, impacting productivity. Corrective measures, such as soil reclamation, proper fertilization, and foliar applications, are crucial for enhancing crop yields. The study contributes valuable insights for local practices and the broader global pursuit of sustainable rice farming, emphasizing the importance of tailored strategies in addressing specific regional challenges.

**Keywords:** Rice, Soil, Fertility, Salinity, Azerbaijan, Sustainability.



## Introduction

Rice stands as a cornerstone in global agriculture, serving as a vital food source for a substantial portion of the world's population. Its significance extends beyond mere sustenance, playing a critical role in addressing food security and nutritional needs (Fukagawa and Ziska, 2019; Mohidem et al., 2022; Maftukhah et al., 2022). As we delve into the nuances of soil characteristics, productivity challenges, and solutions within the rice farming landscapes of Azerbaijan, it becomes imperative to recognize the agricultural importance of the rice plant and its indispensable role in human nutrition. Globally, rice boasts an average yield of approximately 4.5 tons per hectare, with Turkey exceeding this average at an impressive 8.5 tons per hectare. However, the unique rice

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farming landscape of Azerbaijan presents distinct challenges, reflected in an average yield of 3 tons per hectare—a notable disparity compared to global and regional averages. This yield discrepancy prompts a comprehensive investigation into the multifaceted factors contributing to the suboptimal performance of rice production within the Azerbaijani context. From crop selection to soil preparation, and from disease and pest management to deficiencies in fertilization practices, our study focuses on the intricate interplay of these elements in the fields where rice is cultivated in Azerbaijan.

Looking beyond the borders of Azerbaijan, insights from soil science significantly contribute to our understanding of the intricate relationship between soil characteristics and rice productivity. Simultaneously, an exploration of soil physico-chemical properties underscores the necessity for precise measurements to ensure higher rice production, as exemplified in regions such as Turkey and Japan. The critical role of soil physico-chemical properties in the growth, yield, quality, and market competitiveness of crops is evident, and their degradation leads to decreased soil fertility, nutrients, and overall productivity (Bueno and Ladha, 2009; Gathala et al., 2011; Timsina and Connor, 2001; Fan et al., 2008). In the context of sustainable agro-ecosystems, the enhancement of soil chemical properties can be achieved through fertilization, cropping adjustment, and other farm managerial practices (Gathala et al., 2011; Ladha et al., 2000; 2003). Researchers have extensively studied the variability and impact of soil chemical properties on rice yield. Juhos et al (2016) explored yield determinants by constructing a soil quality index from more than ten chemical and physical indicators on a 225 ha farmland in East Hungary. Similarly, Obade and Lal (2016) tested four methods to construct a soil quality index, identifying properties determining soil physico-chemical and crop yield in private fields of Ohio, US. In Japan, despite rice still being the largest crop, its contribution to gross agriculture output decreased from 27.8% in 1990 to 18.0% in 2016 (Ladha et al., 2003). Under acreage reduction policies, the total planted area of rice decreased by 24% in the past two decades (Mousavi et al., 2009). Compared to other crops, rice yield is more influenced by soil fertility. Therefore, precise measurement of soil properties and their impact on yield is crucial in Japan, where significant soil nutrients are drained by the rich or deposited in dammed rivers (Ladha et al., 2000). A substantial body of literature has focused on the soil chemical properties of paddy fields in Japan. Katayanagi et al (2009) conducted a nationwide analysis of 986 plots, adopting individual indicators such as pH and total carbon. To estimate the effect of soil chemical properties, Matsumoto et al (1995) included the content of available arsenic, phosphorus, and acid ammonium oxalate extractable iron and aluminum. Additionally, Mori et al (2011) represented soil chemical properties by pH, cation exchange capacity, and oxidation-reduction potential. Li et al (2003) assessed the determinacy of soil chemical properties on rice yield, using on-farm data from individual paddy fields.

In this study, we aim to determine the physical and chemical properties of soil samples from Azerbaijan's rice cultivation areas, assessing nutrient content, and identifying soil characteristics and nutrient elements that may limit productivity and plant nutrition in rice farming. Synthesizing these perspectives, our study enriches our understanding of the complex interplay between soil fertility class and rice productivity. By shedding light on challenges specific to Azerbaijan, we aspire not only to enhance local practices but also to contribute valuable insights for the broader global pursuit of sustainable rice farming.

## Material and Methods

### Soil Sampling

In accordance with the 2022 data, rice cultivation is carried out on a total of 3.129,3 hectares in Azerbaijan. The rice cultivation areas in the country are distributed as follows: 1.225,3 hectares in the Lenkeran-Astara economic region (including Astara, Lenkeran, and Masalli districts), 1.820 hectares in the Central Aran economic region (including Agdash, Goychay, Ujar, Yevlakh, and Zardab districts), and 84 hectares in the Shirvan-Salyan economic region (Salyan district). Therefore, a total of 17 soil samples were collected from rice fields, representing the rice cultivation areas in Azerbaijan: 6 samples from the Lenkeran-Astara economic region, 7 samples from the Central Aran economic region, and 4 samples from the Shirvan-Salyan economic region. The soil samples were collected from the 0-20 cm depth at the conclusion of rice harvesting, specifically from rice fields characterized by monoculture rice farming practices, where rice plants are cultivated annually. The locations from which soil samples were obtained are illustrated in Figure 1. Upon collection, soil samples were carefully taken from each rice field, ensuring representation across the entire area. The collected soil samples were subjected to thorough removal of stones and plant residues on the soil surface. Subsequently, the soil samples were transported to the laboratory for further analysis. In the laboratory, the soil samples were processed under controlled conditions. They were first air-dried in a cool and shaded environment to prevent alterations in their chemical composition due to excessive heat or sunlight. Once dried, the soil samples were finely ground after removing any remaining moisture. The grinding process facilitated homogenization and ensured that the soil samples were uniform for subsequent analyses. The sieving of the soil samples through a 2 mm mesh was then conducted to achieve a consistent particle size for optimal analytical results. The prepared soil samples, now in a homogeneous and fine-grained state, were deemed analytically ready and were utilized for subsequent investigations. The entire soil sampling and preparation process aimed to maintain the integrity of the collected samples and provide a reliable basis for the scientific analysis of the soil characteristics in the designated rice fields.


Figure 1. Collection of Soil Samples from Rice-Cultivated Lands in Azerbaijan

## Climate

The annual precipitation and temperature averages of Azerbaijan, along with the Köppen-Geiger classification map (Figure 2), are provided herein. The temperature patterns across Azerbaijan exhibit regularity, influenced by the characteristics of incoming air masses, regional topography, and proximity to the Caspian Sea. The Caspian Sea plays a pivotal role in modulating temperatures in coastal areas situated approximately 20 kilometers away, causing a decrease in summer temperatures and an increase in winter temperatures. Simultaneously, it acts as a mitigating factor against the impact of hot and arid air masses originating from Central Asia. The average annual temperature maintains a range of 14–15°C in regions such as the Kur-Araz Lowland, coastal areas south of the Apsheron Peninsula, and the Lenkoran Lowland. Temperature decreases are observed with proximity to mountainous terrain, with averages of 4–5°C at an altitude of 2,000 meters and 1–2°C at 3,000 meters. Notably, the absolute minimum temperature of −33°C and the absolute maximum temperature of 46°C were recorded in Julfa and Ordubad, respectively. Azerbaijan experiences varying precipitation levels across its regions, with the maximum annual precipitation occurring in Lankaran (ranging from 1,600 to 1,800 mm) and the minimum in the Absheron Peninsula (ranging from 200 to 350 mm). This geographical diversity in precipitation underscores the nuanced climatic conditions within Azerbaijan.

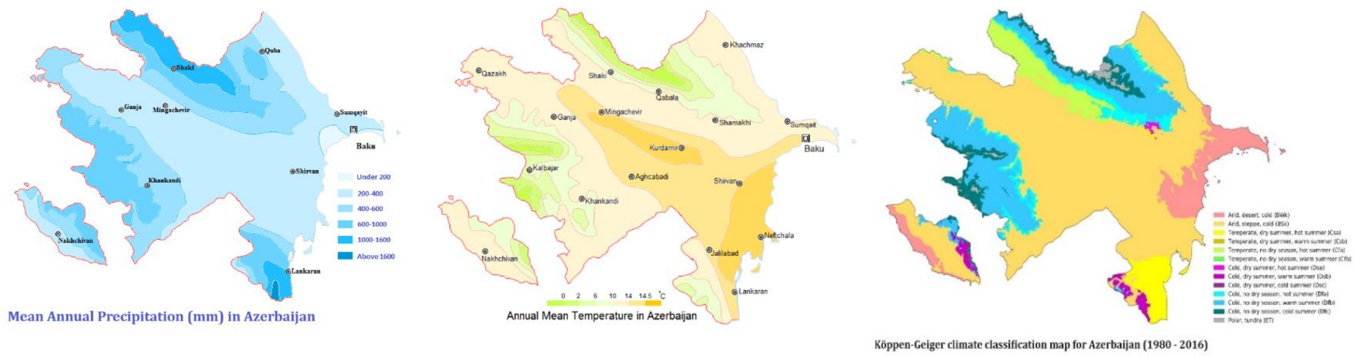


Figure 2. Climatic Overview of Azerbaijan: Precipitation, Temperature, and Köppen-Geiger Classification map

## Soil Analyses

In the conducted soil analyses, various parameters were determined using established scientific methods. The soil texture was determined by the hydrometer method as described by Bouyoucos (1962). The pH and Electrical Conductivity (EC) were measured in a 1:1 (w/v) soil-to-distilled water suspension using a pH meter and EC meter, following the procedures outlined by Peech (1965) and Bower and Wilcox (1965). Organic matter content was assessed through wet oxidation with $K_2Cr_2O_7$, following the method proposed by Walkley and Black (1934). Calcium carbonate ($CaCO_3$) content was determined volumetrically using the Scheibler calimeter, as per the protocol detailed in Rowell (2010). Total nitrogen was quantified using the Kjeldahl method, following the procedures outlined by Bremner (1965). Olsen method with 0.5 M $NaHCO_3$ extraction was employed for the determination of available phosphorus, in accordance with the method introduced by Olsen and Dean (1965). Exchangeable potassium (K) and sodium (Na) were measured using Flame photometry after 1N $NH_4OAc$ extraction, as described by Pratt (1965). Exchangeable calcium (Ca) and magnesium (Mg) were determined by EDTA titration following 1N $NH_4OAc$ extraction, as per the procedures outlined by Heald (1965). Additionally, available iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) were determined in triplicate using the DTPA extraction method, followed by analysis with Atomic Absorption Spectrophotometry, as detailed by Lindsay and Norvell (1978).

**Computation of Soil Fertility Index (SFI)**

Over the years, there are many different soil testing procedures or methods that provide the most reliable prediction of crop yield response to evaluate soil fertility status. Soil fertility status can be evaluated directly or indirectly. Direct evaluations are carried out in the field, greenhouses or laboratory by means of experiments carried out under given climatic and management conditions. Indirect evaluations consist basically in developing and applying models of varying complexity. One of the most suitable models is SFI model. SFI was calculated to qualitative soil fertility classes by means of parametric approach using fifteen parameters for each soil sample point. To develop this model and determine threshold level of each SFI class, some literature such as Lindsay and Norvell (1978), Moran et al. (2000), Arshad and Martin (2002), Lu et al. (2002), Borůvka et al. (2005), Hazelton and Murphy (2007) were used. The fifteen parameters (diagnostic factors) are commonly implemented in physical and chemical characteristics of soil and designated with letters from A to P (Table 1). Each parameter or factor is evaluated ranging between 10 and 100. The least favour value of factor rating is 10 and the most beneficial value of factor rating is 100 for plant growth. In other words, the limiting nature of each SFI classes is taken into account by its effect in reducing productivity.

Table 1. Factor rating each soil parameters

| | Diagnostic Factors | Units | Factor rating 100 | 80 | 50 | 20 | 10 |
|---|---|---|---|---|---|---|---|
| | | | **Available macronutrients** | | | | |
| A | $N_{total}$ | g $kg^{-1}$ | >3,2 | 1,7-3,2 | 0,9-1,7 | 0,45-0,9 | <0,45 |
| B | $P_{av.}$ | mg $kg^{-1}$ | >80 | 25-80 | 8-25 | 2,5-8 | <2,5 |
| C | $K_{exc.}$ | me $100g^{-1}$ | 0,28-0,74 | 0,74-2,56 | 0,23-0,28 | >2,56 | <0,13 |
| D | $Ca_{exc.}$ | me $100g^{-1}$ | 17,5-50 | 5,75-17,5 | 1,19-5,75 | >50 | <1,19 |
| E | $Na_{exc.}$ | me $100g^{-1}$ | <0,20 | 0,21-0,30 | 0,31-0,70 | 0,71-2,00 | >2,00 |
| F | $Mg_{exc.}$ | me $100g^{-1}$ | 1,33-4,00 | 4,00-12,5 | 0,42-1,33 | >12,5 | <0,42 |
| | | | **Available micronutrients** | | | | |
| G | $Mn_{av.}$ | mg $kg^{-1}$ | 14-50 | 4-14 | 50-170 | >170 | <4 |
| H | $Zn_{av.}$ | mg $kg^{-1}$ | 0,7-2,4 | 2,4-8,0 | 0,2-0,7 | >8,0 | <0,2 |
| I | $Fe_{av.}$ | mg $kg^{-1}$ | 2,0-4,5 | 1,0-2,0 | 0,2-1,0 | >4,5 | <0,2 |
| J | $Cu_{av.}$ | mg $kg^{-1}$ | >0,2 | | | | <0,2 |
| | | | **Soil physico-chemical properties** | | | | |
| K | $CaCO_3$ | g $kg^{-1}$ | 50-150 | 10-50 | 150-250 | >250 | <10 |
| L | EC | $dSm^{-1}$ | <2 | 2-4 | 4-6 | 6-8 | >8 |
| M | pH | 1:1, w/v | 6,5-7,5 | 7,5-8,5 | 5,5-6,5 | 4,5-5,5 | >8,5 and <4,5 |
| N | SOM | g $kg^{-1}$ | >30 | 20-30 | 10-20 | 5-10 | <5 |
| O | Texture | | CL, SCL, SiCL | vfSL, L, SiL, Si, <50%C | >50%C, SC, SiC | SL, fSL | S, LS |

$N_{total}$ : Total nitrogen; $P_{av.}$ : Available phosphorus; $K_{exc.}$ : Exchangeable potassium; $Ca_{exc.}$ : Exchangeable calcium; $Mg_{exc.}$ : Exchangeable magnesium; $Mn_{av.}$ : Available manganese; $Zn_{av.}$ : Available zinc; $Fe_{av.}$ : Available iron; $Cu_{av.}$ : Available copper; EC: Electrical conductivity, SOM: Soil organic matter, CL: Clay Loam; SCL: Sandy Clay Loam; vfSL: very fine Sandy Loam; L: Loam; C: Clay, SL: Sandy Loam, fSL: fine Sandy Loam; S: Sand, LS: Loamy Sand, SiCL Silty Clay Loam; SiL; Silty Loam, Si: Silty, SC: Sandy Clay, SiC: Silty Clay

SFI is calculated and using the value of factor rating for each factor as follows (Equation 1);

SFI= Soil Fertility Index

$$SFI = \left[ R_{max} x \sqrt{\frac{A}{100} x \frac{B}{100} x .......} \right] x100 \quad (1)$$

$$R_{max} = \text{Maximum ratio, } \frac{(A + B + .......+O)}{15}$$

A, B... Rating value for each diagnostic factors

SFI of each soil sample point can be classified according to classes indicated in Table 2.

Table 2. Classes and values of soil fertility index.

| Class | Description | Soil Fertility Index |
|---|---|---|
| S1 | Good fertility | >80 |
| S2 | Moderate fertility | 80-50 |
| S3 | Marginal fertility | 50-20 |
| N | Poor fertility | <20 |

## Results and Discussion

The physicochemical properties, nutrient contents, and productivity classes of soils collected from rice cultivation areas in Azerbaijan are presented in Tables 3, 4, 5, and 6. According to the obtained results, soil texture exhibits a wide variability ranging from Sandy Clay Loam (SaCL) texture to heavy clay (C) texture, although soil texture is generally clayey. The soil texture plays a crucial role in influencing the movement and availability of air and water in soil, root growth, water and nutrient uptake, and overall plant growth. Typically, Azerbaijan paddy soils are characterized by a high clay content, which is the predominant component of mineral soil due to its exceptionally high specific surface area. This property allows clayey soils to effectively retain nutrients and water (Hamoud et al., 2019). It can be asserted that a significant majority (>88%) of rice-cultivated areas in Azerbaijan have suitable soil texture and clay content.

Table 3. The coordinates where soil samples were taken and the particle size distribution and bulk density status of the soil

| Lab No | Sampling points | Coordinates | | Partical size distribution | | | |
|---|---|---|---|---|---|---|---|
| | | | | Sand, % | Silt, % | Clay, % | Class |
| 1 | Lenkeran-Astara economic region | 38.6322740 N | 48.8646310 E | 50,69 | 15,91 | 33,41 | SaCL |
| 2 | | 38.4605490 N | 48.8385470 E | 12,94 | 36,55 | 50,51 | C |
| 3 | | 38.6339410 N | 48.8409200 E | 10,51 | 29,66 | 59,83 | C |
| 4 | | 38.9879560 N | 48.7193950 E | 18,23 | 37,16 | 44,61 | C |
| 5 | | 38.6318770 N | 48.8654710 E | 45,83 | 15,25 | 38,91 | SaC |
| 6 | | 38.6328720 N | 48.8646280 E | 4,86 | 34,20 | 60,94 | C |
| 7 | Central Aran economic region | 40.2591950 N | 47.6314250 E | 7,66 | 42,50 | 49,84 | SiC |
| 8 | | 40.2559770 N | 47.6289990 E | 11,55 | 78,58 | 9,87 | SiL |
| 9 | | 40.5438710 N | 47.2880790 E | 6,76 | 7,69 | 85,55 | C |
| 10 | | 40.5664400 N | 47.3426590 E | 8,43 | 31,40 | 60,17 | C |
| 11 | | 40.2532890 N | 47.5357300 E | 17,28 | 37,33 | 45,38 | C |
| 12 | | 40.5070390 N | 47.6789500 E | 4,83 | 15,00 | 80,17 | C |
| 13 | | 40.4983230 N | 47.6842900 E | 7,54 | 30,53 | 61,93 | C |
| 14 | Shirvan-Salyan economic region | 39.9033420 N | 40.0782160 E | 2,68 | 40,68 | 56,64 | SiC |
| 15 | | 39.8355970 N | 49.0250100 E | 13,37 | 20,82 | 65,81 | C |
| 16 | | 39.9027510 N | 49.0793570 E | 4,90 | 16,02 | 79,07 | C |
| 17 | | 39.9016200 N | 49.0666840 E | 4,04 | 29,15 | 66,81 | C |
| | | | *Min.* | *2,68* | *7,69* | *9,87* | |
| | | | *Max.* | *50,69* | *78,58* | *85,55* | |
| | | | *Mean* | *13,65* | *30,50* | *55,85* | |

Approximately 82% of rice soils in Azerbaijan exhibit an alkaline reaction (pH > 7.3). The elevated pH levels in the soils may stem from high lime or sodium content. When evaluated based on lime content (Table 4), the soils are generally classified as calcareous (5-15%) and highly calcareous (>15%). Furthermore, about 94% of the soils have a high exchangeable sodium content (>0.7 me Na $100g^{-1}$), indicating sodicity in approximately 35% of these soils based on the Exchangeable Sodium Percentage (ESP) value (>10%), and a risk of sodicity (5-10%) in 14% of the soils (Table 5). Both the high soil pH and elevated sodium content are unsuitable for rice cultivation. The optimal pH level for rice cultivation is around 6 (Abdul Halim et al., 2018). Therefore, corrective measures are essential, such as applying soil acidifying materials (e.g., powdered or liquid sulfur compounds) in soils without sodium-related issues to lower soil pH. For soils with high ESP, remediation methods involving the removal of sodium from the soil, such as applying gypsum ($CaSO_4$) to the soil and leaching sodium from the soil, are necessary. The electrical conductivity (salinity) of the soils exhibits a wide range, ranging from 0.40 to 14.41 $dSm^{-1}$, with some rice fields indicating a significant salinity issue. In 70% of the sampled points, the salinity level is deemed unsuitable for rice cultivation. Moreover, approximately 70% of the sampled areas exhibit a severe salinity problem (>4 $dSm^{-1}$). For rice cultivation, electrical conductivity values below 0.90 $dSm^{-1}$ are recommended (USDA, 2001), highlighting the unsuitability of the soil in the sampled locations for rice crops. In fields with salinity issues, after the implementation of drainage systems, it is crucial to leach the soil to remove excess salts. In 65% of the collected soil samples, the organic matter content is low (<1.70%), 24% exhibit a moderate level (1.70% – 3.00%), and 12% are considered sufficient (>3%). In fields with insufficient organic matter, enhancing soil organic matter content to the 3% level, using composts with low salt content derived from plant and animal sources, becomes crucial for the sustainable utilization of the soils.

Table 4. The chemical properties of the soils along with the total nitrogen (N) and available phosphorus (P) content

| No | pH | EC, $dSm^{-1}$ | $CaCO_3$, % | Organic matter, % | Total N, % | Available P, mg $kg^{-1}$ |
|---|---|---|---|---|---|---|
| 1 | 7,70 | 0,51 | 12,93 | 1,61 | 0,18 | 24,26 |
| 2 | 7,09 | 2,15 | 5,44 | 3,17 | 0,29 | 31,92 |
| 3 | 6,63 | 0,59 | 6,37 | 3,13 | 0,29 | 15,24 |
| 4 | 7,96 | 13,07 | 4,93 | 1,87 | 0,24 | 16,72 |
| 5 | 7,64 | 0,62 | 9,90 | 1,15 | 0,16 | 25,28 |
| 6 | 5,72 | 0,79 | 5,13 | 1,40 | 0,22 | 12,43 |
| 7 | 8,04 | 14,41 | 17,12 | 1,37 | 0,11 | 2,47 |
| 8 | 8,17 | 7,62 | 15,06 | 0,88 | 0,09 | 3,38 |
| 9 | 7,86 | 4,77 | 6,69 | 2,47 | 0,23 | 4,97 |
| 10 | 7,92 | 2,97 | 15,93 | 1,81 | 0,20 | 2,72 |
| 11 | 7,70 | 2,13 | 15,94 | 1,24 | 0,16 | 10,43 |
| 12 | 7,78 | 0,40 | 17,11 | 1,86 | 0,24 | 5,64 |
| 13 | 7,82 | 1,55 | 17,33 | 1,21 | 0,20 | 24,56 |
| 14 | 7,77 | 12,24 | 17,60 | 0,97 | 0,10 | 1,41 |
| 15 | 7,89 | 1,80 | 18,22 | 1,38 | 0,16 | 6,44 |
| 16 | 7,95 | 13,40 | 17,34 | 0,98 | 0,10 | 4,37 |
| 17 | 7,97 | 5,19 | 19,18 | 1,66 | 0,19 | 33,11 |
| *Min.* | *5,72* | *0,40* | *4,93* | *0,88* | *0,09* | *1,41* |
| *Max.* | *8,17* | *14,41* | *19,18* | *3,17* | *0,29* | *33,11* |
| *Mean* | *7,62* | *4,95* | *13,07* | *1,66* | *0,18* | *13,26* |

Table 5. The contents of exchangeable cations (Na, K, Ca, and Mg) in the soils

| No | Na, me $100g^{-1}$ | K, me $100g^{-1}$ | Ca, me $100g^{-1}$ | Mg, me $100g^{-1}$ | ESP, % | Ca/Mg | Ca/K | Mg/K |
|---|---|---|---|---|---|---|---|---|
| 1 | 0,51 | 0,27 | 26,74 | 5,49 | 1,54 | 4,87 | 99,72 | 20,49 |
| 2 | 4,03 | 0,18 | 35,03 | 10,29 | 8,13 | 3,40 | 195,64 | 57,47 |
| 3 | 0,76 | 0,36 | 29,92 | 17,86 | 1,55 | 1,68 | 83,47 | 49,82 |
| 4 | 1,71 | 0,44 | 19,58 | 6,37 | 6,08 | 3,08 | 44,50 | 14,47 |
| 5 | 0,52 | 0,30 | 26,93 | 7,61 | 1,47 | 3,54 | 88,52 | 25,02 |
| 6 | 0,74 | 0,55 | 21,35 | 13,39 | 2,05 | 1,59 | 38,64 | 24,24 |
| 7 | 32,89 | 0,50 | 29,89 | 13,58 | 42,80 | 2,20 | 59,57 | 27,06 |
| 8 | 13,16 | 0,45 | 56,77 | 17,22 | 15,03 | 3,30 | 125,71 | 38,13 |
| 9 | 7,83 | 1,08 | 34,38 | 20,89 | 12,20 | 1,65 | 31,84 | 19,34 |
| 10 | 2,87 | 0,84 | 37,83 | 16,30 | 4,96 | 2,32 | 45,04 | 19,42 |
| 11 | 1,30 | 1,07 | 25,98 | 11,06 | 3,31 | 2,35 | 24,29 | 10,34 |
| 12 | 0,73 | 0,58 | 20,39 | 8,97 | 2,39 | 2,27 | 35,23 | 15,49 |
| 13 | 2,06 | 0,66 | 19,71 | 9,00 | 6,56 | 2,19 | 29,68 | 13,56 |
| 14 | 23,71 | 0,94 | 42,69 | 11,49 | 30,08 | 3,71 | 45,37 | 12,21 |
| 15 | 2,78 | 1,02 | 22,48 | 15,11 | 6,72 | 1,49 | 22,05 | 14,83 |
| 16 | 26,10 | 1,23 | 29,80 | 13,77 | 36,81 | 2,16 | 24,14 | 11,15 |
| 17 | 10,11 | 1,54 | 24,27 | 11,56 | 21,29 | 2,10 | 15,74 | 7,50 |
| *Min.* | *0,51* | *0,18* | *19,58* | *5,49* | *1,47* | *1,49* | *15,74* | *7,50* |
| *Max.* | *32,89* | *1,54* | *56,77* | *20,89* | *42,80* | *4,87* | *195,64* | *57,47* |
| *Mean* | *7,75* | *0,71* | *29,63* | *12,35* | *11,94* | *2,58* | *59,36* | *22,38* |

Approximately 24% of the soils have low total nitrogen content (<0.150%), 64% exhibit a moderate level (0.150%–0.250%), and 12% are determined to have a high level (>0.250%). For phosphorus availability, 59% of the soil samples have low levels (<13 mg $kg^{-1}$), 29% are at a moderate range (13–30 mg $kg^{-1}$), and 12% are considered sufficient (>30 mg $kg^{-1}$). In all soils, exchangeable calcium (Ca) and magnesium (Mg) contents are determined to be high (>10 me Ca $100g^{-1}$, >3 me Mg 100 $g^{-1}$). Furthermore, 94% of the soils have high exchangeable sodium (Na) content (>0.7 me Na $100g^{-1}$), 41% have high exchangeable potassium (K) content (>0.7 me K 100 $g^{-1}$), and 42% exhibit a moderate level (0.3–0.7 me 100 $g^{-1}$) of exchangeable K (Table 5). The relationships between basic cations (Ca, Mg, and K) in the soil are crucial for plant nutrition and fertilization. For optimal plant nutrition, the recommended Ca/K ratio is 12, Ca/Mg ratio is 6, and Mg/K ratio is 2. However, in all sampled soils, the Ca/Mg ratio is <6, Ca/K ratio is >12, and Mg/K ratio is >2 (Hazelton and Murphy, 2007). This indicates that, even in the presence of sufficient available potassium in the soil, plants would respond positively to potassium, emphasizing the necessity for potassium fertilization in rice-cultivated soils in Azerbaijan. Therefore, in all rice cultivation areas in Azerbaijan, it is imperative to apply potassium to the soil before seed or seedling planting.

Table 6. The available microelement content (Fe, Cu, Zn, and Mn) of the soils along with fertility classes

| No | | Fe, mg kg$^{-1}$ | Cu, mg kg$^{-1}$ | Zn, mg kg$^{-1}$ | Mn, mg kg$^{-1}$ | SFI | Fertility class |
|---|---|---|---|---|---|---|---|
| 1 | | 65,50 | 7,54 | 0,58 | 23,01 | 206,08 | S1 |
| 2 | | 52,75 | 13,23 | 0,30 | 73,78 | 52,35 | S2 |
| 3 | | 61,85 | 14,96 | 1,42 | 67,70 | 93,34 | S1 |
| 4 | | 51,68 | 9,00 | 1,38 | 47,72 | 57,32 | S2 |
| 5 | | 58,62 | 8,07 | 0,72 | 20,63 | 367,67 | S1 |
| 6 | | 218,82 | 21,14 | 1,34 | 116,85 | 62,67 | S2 |
| 7 | | 3,16 | 1,84 | 0,30 | 2,40 | 1,50 | N |
| 8 | | 6,21 | 1,80 | 0,31 | 3,76 | 0,23 | N |
| 9 | | 35,71 | 7,74 | 0,43 | 7,34 | 21,48 | S3 |
| 10 | | 25,80 | 6,82 | 0,32 | 15,03 | 11,47 | N |
| 11 | | 23,47 | 5,45 | 0,28 | 6,24 | 71,74 | S2 |
| 12 | | 53,49 | 12,65 | 1,11 | 9,58 | 62,74 | S2 |
| 13 | | 48,58 | 10,52 | 0,54 | 10,52 | 43,89 | S3 |
| 14 | | 9,27 | 0,85 | 0,17 | 1,29 | 0,73 | N |
| 15 | | 43,21 | 7,25 | 0,31 | 3,89 | 4,05 | N |
| 16 | | 18,47 | 3,61 | 0,22 | 9,20 | 2,14 | N |
| 17 | | 72,54 | 8,80 | 3,73 | 20,58 | 57,32 | S2 |
| | *Min.* | *3,16* | *0,85* | *0,17* | *1,29* | | |
| | *Max.* | *218,82* | *21,14* | *3,73* | *116,85* | | |
| | *Mean* | *49,95* | *8,31* | *0,79* | *25,85* | | |

In all collected soil samples, the copper (Cu) and iron (Fe) contents are above the critical deficiency threshold (0.2 mg Cu kg$^{-1}$; 2.5 mg Fe kg$^{-1}$). This suggests that there would unlikely be a deficiency of Cu and Fe in rice cultivation. However, 52% of the soils exhibit manganese (Mn) levels below the critical threshold (14 mg Mn kg$^{-1}$), and 65% have zinc (Zn) levels below the critical threshold (0.7 mg Zn kg$^{-1}$) (Lindsay and Norvell, 1978). This indicates a potential risk of Zn and Mn deficiency in rice cultivation areas in Azerbaijan. Therefore, in the case of deficiencies, foliar application of these micronutrients might be necessary.

Furthermore, the productivity classes of the collected soils have been calculated and are presented in Table 6. Accordingly, 18% are classified as S1 (Good fertility), 35% as S2 (Moderate fertility), 12% as S3 (Marginal fertility), and 35% as N (Poor fertility). This indicates a significant overall low fertility capacity in rice-cultivated areas in Azerbaijan, primarily attributed to two factors. Firstly, in areas with salinity, the removal of salt by leaching, application of gypsum to soils in areas with barrenness to remove sodium, and in areas with low organic matter, increasing soil organic matter levels with low-salt plant-based composts are necessary. Secondly, proper fertilization from both soil and foliar sources is crucial. In rice cultivation, before sowing with seeds or seedlings, the application of potassium fertilizers is essential based on soil analysis results (Hossain et al., 2023; İslamzade et al., 2023), in addition to nitrogen (N) and phosphorus (P). Given the alkaline reaction of the regional soils, chemical fertilizers used must have a physiological acid reaction. Moreover, there is a dramatic Ca/K imbalance in the regional soils, and providing the required potassium from the soil through fertilization will not be feasible. Therefore, during the tillering period of the rice plant, balanced NPK + micronutrients (e.g., 17-17-17+me), and during the heading period, potassium-rich NPK+ micronutrients (e.g., 9-9-25+me) with zinc application should be carried out through foliar spraying. Thus, it is indisputable that proper soil reclamation and correct fertilization of rice fields will lead to increased crop yields.

## Conclusion

In conclusion, this study comprehensively examined the physical and chemical properties of soil samples from rice cultivation areas in Azerbaijan, aiming to assess nutrient content, soil characteristics, and potential limitations on productivity and plant nutrition in rice farming. The results revealed a diverse range of soil properties, including variations in soil texture, pH levels, salinity, and nutrient content. The identified challenges, such as alkaline soil pH and high salinity, pose significant obstacles to rice cultivation. Recommendations for corrective measures, including the application of soil acidifying materials and the implementation of remediation methods for sodicity and salinity, were discussed. Moreover, the study highlighted the importance of proper fertilization, emphasizing the need for potassium application in rice-cultivated soils. Notably, micronutrient deficiencies, particularly in zinc and manganese, were identified, suggesting the potential necessity for foliar applications to address these deficiencies. The findings underscore the complexity of soil fertility in Azerbaijan's rice fields, calling for tailored strategies to enhance local practices and contribute valuable insights for sustainable rice farming globally. In summary, addressing the identified soil challenges and implementing appropriate corrective measures, along with precise fertilization strategies, will undoubtedly play a pivotal role in enhancing the fertility and productivity of rice-cultivated areas in Azerbaijan, ultimately contributing to the global pursuit of sustainable rice farming.

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## References

Abdul Halim, N.S., Abdullah, R., Karsani, S.A., Osman, N., Panhwar, Q.A., Ishak, C.F., 2018. Influence of soil amendments on the growth and yield of rice in acidic soil. *Agronomy* 8(9): 165.

Arshad, M.A., Martin, S., 2002. Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture Ecosystem and Environment* 88(2): 153-160.

Borůvka, L., Vacek, O., Jehlička, J., 2005. Principal component analysis as a tool to indicate the origin of potentially toxic elements in soils. *Geoderma* 128(3-4): 289-300.

Bouyoucos, G.J., 1962. Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal* 54(5): 464-465.

Bower, C.A., Wilcox L.V., 1965. Soluble Salts. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 933-951.

Bremner, J.M., 1965. Total nitrogen, In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 1149-1176.

Bueno C.S., Ladha, J.K., 2009. Comparison of soil properties between continuously cultivated and adjacent uncultivated soils in rice-based systems. *Biology and Fertility of Soils* 45(5): 499–509.

Fan, M.S., Jiang, R.F., Zhang, F.S., Lü, S.H., Liu, X. J., 2008. Nutrient management strategy of paddy rice-upland crop rotation system. *The Journal of Applied Ecology* 19(2): 424–432. [in Chinese]

Fukagawa, N.K., Ziska, L.H., 2019. Rice: Importance for Global Nutrition. *Journal of Nutritional Science and Vitaminology* 65: S2-S3.

Gathala, M.K., Ladha, J.K., Saharawat, Y.S., Kumar, V., Kumar, V., Sharma, P.K., 2011. Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice-wheat rotation. *Soil Science Society of America Journal* 75(5): 1851–1862.

Hamoud, Y.A., Guo, X., Wang, Z., Shaghaleh, H., Chen, S., Hassan, A., Bakour, A., 2019. Effects of irrigation regime and soil clay content and their interaction on the biological yield, nitrogen uptake and nitrogen-use efficiency of rice grown in southern China. *Agricultural Water Management* 213: 934-946.

Hazelton, P., Murphy, B., 2007. Interpreting soil test results. What do the numbers mean? CSIRO Publishing, Melbourne. Australia. 152p.

Heald, W.R., 1965. Calcium and Magnesium. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 999-1010.

Hossain, M., Rahman, M., Morshed, M., Uddin, M., Hera, M., Sultana, N., Hashem, M., 2023. Yield response of rice (Oryza sativa L.) to elevated potassium applied under the irrigated ecosystem of Bangladesh. *Eurasian Journal of Soil Science* 12(2): 104 - 110.

İslamzade, R., Hasanova, G., Asadova, S., 2023. Impact of varied NPK fertilizer application rates and seed quantities on barley yield and soil nutrient availability in chestnut soil of Azerbaijan. *Eurasian Journal of Soil Science* 12(4): 371 - 381.

Juhos, K., Szabo, S., Ladanyi, M., 2016. Explore the influence of soil quality on crop yield using statistically-derived pedological indicators. *Ecological Indicators* 63: 366–373.

Katayanagi, N., Fumoto, T., Hayano, M., Takata, Y., Kuwagata, T., Shirato, Y., Sawano, S., Kajiura, M., Sudo, S., Ishigooka, Y., Yagi, K., 2016. Development of a method for estimating total CH4 emission from rice paddies in Japan using the DNDC-Rice model. *Science of The Total Environment* 547: 429-440.

Ladha, J.K., Fischer, K.S., Hossain, M., Hobbs, P.R., Hardy, B., 2000. Improving the productivity of rice–wheat systems of the Indo-Gangetic Plains: A synthesis of NARS-IRRI partnership research. IRRI Discussion Paper No. 40. IRRI, Los Baños, the Philippines.

Ladha, J.K., Pathak, H., Padre, A.T., Dawe, D., Gupta, R.K., 2003. Productivity trends in intensive rice–wheat cropping systems in Asia. In: Improving the productivity and sustainability of rice–wheat systems: Issues and impacts. Ladha, J.K., Hill, J.E., Duxbury, J.M., Gupta, R.K., Buresh, R.J., (Eds.). ASA, CSSA, and SSSA, Madison, WI, USA. pp.45–76.

Li, D., Nanseki, T., Chomei, Y., Fukuhara, Y., 2018. Impact of soil chemical properties on rice yield in 116 paddy fields sampled from a large-scale farm in Kinki Region, Japan. IOP Conference Series: Earth and Environmental Science 185: 012026.

Lindsay, W.L., Norvell, W.A., 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal* 42(3): 421-428.

Lu, D., Moran, E., Mausel, P., 2002. Linking Amazonian secondary succession forest growth to soil properties. *Land Degradation and Development* 13(4): 331-343.

Maftukhah, R., Ngadisih, N., Murtiningrum, M., Mentler, A., Keiblinger, K., Melcher, A., Zehetner, F., Kral, R., 2022. Contrasting rice management systems – Site-specific effects on soil parameters. *Eurasian Journal of Soil Science* 11(3): 225-234.

Matsumoto, S., Kasuga, J., Taiki, N., Makino, T., Arao, T., 2015. Inhibition of arsenic accumulation in Japanese rice by the application of iron and silicate materials. *Catena* 135: 328-335.

Mohidem, N.A., Hashim, N., Shamsudin, R., Che Man, H. 2022. Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. *Agriculture* 12(6): 741.

Moran, E.F., Brondizion, E.S., Tucker, J.M., da SilvaForsberg, M.C., McCracken, S., Falesi, I., 2000. Effects of soil fertility and land use on forest succession in Amazonia. *Forest Ecology and Management* 139(1-3): 93-108.

Mori, M., Kotaki, K., Gunji, F., Kubo, N., Kobayashi, S., Ito, T., Itabashi, H., 2016. Suppression of cadmium uptake in rice using fermented bark as a soil amendment. *Chemosphere* 148: 487-494.

Mousavi, S.F., Yousefi-Moghadam, S., Mostafazadeh-Fard, B., Hemmat, A., Yazdani, M.R., 2009. Effect of puddling intensity on physical properties of a silty clay soil under laboratory and field conditions. *Paddy and Water Environment* 7(1): 45–54.

Obade, V.P., Lal, R., 2016. Towards a standard technique for soil quality assessment. *Geoderma* 265: 96-102.

Olsen,S.R., Dean, L.A., 1965. Phosphorus. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 1035-1049.

Peech, M., 1965. Hydrogen-Ion Activity. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 914-926.

Pratt, P.F., 1965. Potassium. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 1022-1030.

Rowell, D.L., 1996. Soil Science: methods and applications. Longman, UK. 350p.

Timsina, J., Connor, D.J., 2001. Productivity and management of rice-wheat cropping systems: Issues and challenges. *Field Crops Research* 69(2): 93–132.

USDA, 2001. Soil Quality Test Kit Guide. United States Department of Agriculture, Agricultural Research Service, Natural Resources Conservation Service, Soil Quality Institute. USA. 82p. Available at [Access date: : 11.07.2023]: https://www.nrcs.usda.gov/sites/default/files/2022-10/Soil%20Quality%20Test%20Kit%20Guide.pdf

Walkley, A., Black, C.A., 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29–38.

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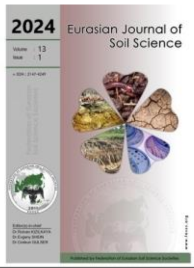


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# Enhancing phosphorus use efficiency in wheat grown on alkaline calcareous soils

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## Abstract

Phosphorus (P) use efficiency is crucial for sustainable wheat production, particularly on alkaline calcareous soils. This study investigates the relative importance of two factors; P acquisition efficiency (PAE) and P utilization efficiency (PUtE), in determining P use efficiency (PUE) in wheat. A field trial with ten wheat genotypes was conducted under two P levels (no P application and P application at 110 kg $P_2O_5$ $ha^{-1}$). Results revealed significant genetic variability in PUE, PAE, and PUtE among wheat genotypes under varying P availabilities. Genotypes MK-4 and MK-8 exhibited superior PUE, making them ideal candidates for soils with differing P levels. PAE played a more substantial role in influencing PUE, with PUtE contributing less to the variability. The findings underscore the importance of improving PAE, particularly for wheat genotypes grown in P-deficient conditions. Moreover, selecting genotypes with lower grain P concentration can enhance PUtE, contributing to improved PUE. These insights can improve breeding efforts and crop management practices to enhance P use efficiency in wheat, ultimately reducing production costs and fertilizer demand, especially in P-limited alkaline calcareous soils.

**Keywords:** Alkaline-calcareous soil, P acquisition efficiency, P utilization efficiency, P use efficiency, wheat genotypes.



## Introduction

About 30% of the world's cultivated soils are inherently deficient in phosphorus (P) nutrient, therefore, crop production can be sustained only by the regular application of inorganic P fertilizers on these soils (Kochian, 2012). The phosphatic fertilizers are primarily derived from extracted rock phosphate, a finite resource which is anticipated to exhaust by the end of this century (Cordell et al., 2009). Moreover, crops can uptake only 15-20% of the fertilizer P during the year of its application. The remaining P forms insoluble complexes with sesquioxides in acidic soils and with calcium carbonate in alkaline soils and becomes unavailable for plant uptake (Baker et al., 2015). Hence, more attentions are being directed to the efficient utilization of P resources (Cordell et al., 2009).

Crop productivity on P-limited soils can be significantly impacted by breeding for P use efficiency (PUE) and providing farmers with improved crop cultivars, in addition to crop management techniques (Thornton et al., 2014). Analogous to nitrogen use efficiency defined by Moll et al. (1982), PUE can be calculated as grain yield per unit of P supply from soil plus fertilizer, and incorporates both P acquisition efficiency (PAE) and P utilization efficiency (PUtE). Plants can compensate for P deficiency in two ways: either by increasing their P intake from phosphorus-deficient media (PAE) and/or by effectively using the P they already have internally (PUtE) (Karthikeyan et al., 2014). Various morphological, physiological and biochemical traits underlying efficient P acquisition include the modifications in root structure and architecture (Niu et al., 2013), the release of organic acids and phosphatases into the rhizosphere (White et al., 2013) and the overexpression of high-affinity root P transporters (Amtmann and Armengaud, 2009). Higher P utilization is facilitated by effective recycling and reuse of the acquired P (Marschner, 2012), induction of $P_i$ independent metabolic pathways

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(Sulpice et al., 2014), and increased synthesis of P-free cellular macromolecules (Byrne et al., 2011; Lambers et al., 2012).

In Pakistan, the situation is more critical as more than 90% of cultivated soils are P deficient (Memon, 2005). Furthermore, the fertilizer industry in Pakistan is totally dependent on the imports of mined rock phosphate, the raw material for P fertilizers. Therefore, crop production in Pakistan is highly vulnerable to price fluctuation and supply disruption of rock phosphate. In Pakistan, wheat is grown on an area of more than 9.0 million hectares as a staple food grain (Government of Pakistan, 2022), and consumes 2.27 million tons, almost 50% of the annual fertilizer nutrients (4.55 million tons) used by the crops in the country (NFDC, 2019-20). Enhancing P use efficiency in wheat crop alone can significantly lower production costs and future fertilizer requirements. There have been documented genetic differences in wheat for P usage efficiency in the literature (Yaseen and Malhi, 2009a; Abbas et al., 2018a; Irfan et al., 2018). However, there is a dearth of information about the relative significance of PAE and PUtE for wheat P usage efficiency especially in alkaline calcareous soils. According to Wang et al. (2010), when the P supply is enough, PUtE is more significant than PAE. However, under limited P conditions, PAE becomes exceedingly important. Genetic variations in PAE were mainly responsible for the higher P efficiency in low P acidic soil-grown soybean and common bean (Beebe et al., 2006), maize (Bayuelo-Jiménez and Ochoa-Cadavid, 2014), rice (Panigrahy et al., 2009), and potato (Sandaña, 2016). Sandaña and Pinochet (2014) evaluated wheat and pea genotypes in high P fixing acidic soils and ascribed differences in PUE to contrasting PUtE in these crops. According to Manske et al. (2001), P uptake under P-deficient conditions in both acidic and calcareous soil accounted for 71–100% of the variation in wheat grain production, whereas P utilization efficiency in the calcareous soil was more important for grain yield under high P conditions. Conversely, Yang et al. (2022) observed that the genetic variation in PUE of wheat genotypes was primarily explained by PUtE under both high and low P circumstances in a purple lithomorphic soil. These several studies have demonstrated that crop species, environmental factors, and soil P condition can all affect the relative significance of PAE and PUtE. The goal of the current study was to evaluate the differences in PUE amongst wheat genotypes as well as the relative contributions of PAE and PUtE to PUE in the case of both high and low P availability in Pakistan's alkaline calcareous soils. We hypothesized that i) there exists large genetic variations in PAE and PUtE of wheat genotypes, and ii) PAE will be more crucial than PUtE in high P fixing alkaline-calcareous soils. The outcomes of this study will help identify ideal P efficient genotypes for low P input farming systems of Pakistan, and expedite future efforts in wheat breeding and P management.

## Material and Methods

### Description of experimental site, design and treatments

In Rabi 2017-18, a field trial was carried out at the experimental farm of the Nuclear Institute of Agriculture (NIA), Tandojam. Before the start of the experiment, soil was sampled from 20 cm depth and analyzed for various physical and chemical properties. The soil was non-saline ($EC_e$= 2.1 dS $m^{-1}$) and alkaline in reaction ($pH_e$= 8.2) with a clay loam textural class (21.7% sand, 42.2% silt and 36.1% clay). It had 0.69% organic matter, 0.073% Kjeldahl nitrogen and 187 mg $kg^{-1}$ ammonium acetate ($NH_4OAc$) extractable potassium. The value of P availability index as determined by Olsen (1954) was 8.2 mg $kg^{-1}$. Split-plot design was used in the experiment, with genotypes assigned to subplots and P levels given to main plots. The treatments were factorial combinations of two P levels [zero/no P application (low P) and P application @110 kg $P_2O_5$ $ha^{-1}$ (high P)] and 10 wheat genotypes/varieties (MK-1, MK-2, MK-3, MK-4, MK-5, MK-6, MK-7, MK-8, MK-9 and NIA-Sunder). The seed material of genotypes was collected from Plant Breeding and Genetics Division of NIA, Tandojam. Genotypes MK-1 to MK-9 are the advanced wheat lines/future candidate varieties, while NIA-Sundar is released wheat variety and has demonstrated high P efficiency in previous studies (Abbas et al., 2018a,b). There were three replications of each treatment. In low P treatment, P supply was calculated as initial Olsen's P (8.2 mg $kg^{-1}$) in the upper 20 cm soil layer with soil bulk density of 1.42 g $cm^{-3}$ at planting, while in high P treatment, the projected P supply was the total of Olsen's P and added P (110 kg $P_2O_5$ $ha^{-1}$ or 48 kg P $ha^{-1}$) (Valle et al., 2011).

### Crop culture

The crop was sown on November 15, 2017. Seeds were sown with the help of dibbler with one seed per hole, maintaining 3 inches plant to plant and 12 inches row to row distance. Five rows (3 m long) of each genotype were sown in each subplot. The main plots received 150 kg nitrogen (N) and 60 kg potash ($K_2O$) per hectare. These nutrients plus 110 kg $P_2O_5$ $ha^{-1}$ in high P treatment were incorporated into 20 cm soil with the help of cultivator prior to sowing. The fertilizer sources for N, K and P were urea, sulfate of potash (SOP, 50% $K_2O$) and triple superphosphate (TSP, 46% $P_2O_5$). The plots were irrigated with canal water as and when required. The crop was maintained free from weeds and other biotic stresses.

### Crop measurements: yield attributes, P analysis and efficiency indices

At crop maturity, five plants of each genotype from each subplot were selected randomly and their plant height was measured with the help of meter rod from the stem base to the top of spike (awns excluded) of the tallest culm and averaged. The number of tillers of the selected plants was counted and spikes form the main tillers were cut with scissor to measure their lengths from first node of rachis to the top of spike excluding awns (Liu et al., 2022). Each spike was threshed with hand to count number of grains per spike. The grains obtained from these spikes were pooled with the rest of produce from the respective experimental unit to obtain the grain yield. To separate the grains and straw, the crop was harvested by hand and threshed. 100-grain weight of randomly sampled hundred kernels was recorded with the help of top-loading digital balance. Grain and straw samples of each genotype from each subplot were oven-dried at 70 $^{o}$C for 72 hours. After the dry grain and straw samples were finely ground, 0.5 g of the material was digested in 10 mL di-acid mixture of nitric and perchloric acid (Miller, 1998). The phosphorus contents of the digest were measured by spectrophotometer using the method of Chapman and Pratt (1961). By multiplying the dry matter yield by the P concentration, P uptake in grain or straw was determined. P uptake in grain and straw was added together to get the total P uptake. The relative tolerance to P deficiency stress known as the phosphorus stress factor (PSF) was determined by dividing the difference in grain yield at two P levels by the grain yield attained at high P level. Other P efficiency indices e.g. P harvest index (PHI), quotient of P utilization (QPUt), P utilization efficiency (PUtE), P acquisition efficiency (PAE) and P use efficiency (PUE) were calculated by the following formulas of Gill et al. (2004) and Parentoni and Souza Júnior (2008):

$$\text{PSF (\%)} = \frac{\text{Grain yield at high P (kg ha}^{-1}) - \text{Grain yield at low P (kg ha}^{-1})}{\text{Grain yield at high P (kg ha}^{-1})} \times 100$$

$$\text{PHI (kg kg}^{-1}) = \frac{\text{P uptake in grain (kg ha}^{-1})}{\text{Total P uptake (kg ha}^{-1})}$$

$$\text{QPUt (kg kg}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{P uptake in grain (kg ha}^{-1})}$$

$$\text{PUtE (kg kg}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Total P uptake (kg ha}^{-1})}$$

$$\text{PAE (kg kg}^{-1}) = \frac{\text{Total P uptake (kg ha}^{-1})}{\text{P supply (kg ha}^{-1})}$$

$$\text{PUE (kg kg}^{-1}) = \text{PUtE} \times \text{PAE}$$

According to Moll et al. (1982), the relative significance of PAE and PUtE in the P usage efficiency was investigated. This methodology determines the relative contribution of two experimentally obtained variables (e.g. PAE and PUtE) to a third variable (e.g. PUE), which is derived by multiplying PAE and PUtE. An additive relationship [log PUE (Y) = log PAE ($X_1$) + log PUtE ($X_2$)] was created by applying a logarithmic modification to the multiplicative relationship (PUE = PAE × PUtE). The relative importance of PAE over PUE was a function of the product of two quantities: a) the coefficient of correlation between variable ($X_1$) and (Y) or $r_{X1Y}$, and b) the ratio of the standard deviation of $X_1$ and Y ($S_{X1}/S_Y$). Similarly, the relative contribution to the P utilization efficiency (PUtE) of the P harvest index (PHI) and the quotient of P utilization (QPUt) was found.

### Statistical analysis

Analysis of variance (ANOVA) was used to analyze the data regarding different growth, yield, and P-related characteristics for the split-plot design. Tukey's honestly significant difference (HSD) approach was used to separate the treatment means at the 5% probability level (Gomez and Gomez, 1984).

## Results

### Growth and yield related attributes

Wheat genotypes (G) differed significantly ($P < 0.05$) for plant height, tiller count plant$^{-1}$, spike length, number of grains spike$^{-1}$and 100-grain weight at each phosphorus (P) level (Table 1). However, P levels and P × G interactions could not produce significant effect on the above mentioned attributes except no. of grains spike$^{-1}$. Mean plant height varied between 86.78 (MK-5) to 105.89 cm (MK-2) at deficient P and between 88.89 (MK-6) to 105.3 cm (MK-7) at adequate soil P level (Table 2). Across the two P levels, MK-2 exhibited the highest while MK-5 revealed the lowest plant height. Tiller count plant$^{-1}$ increased from 7.72 at deficient P to 8.23 at high P, although non-significantly. However, genotypes produced significant variations for tiller count, with MK-5 and MK-3 producing maximum and minimum tillers per plant, respectively across both P levels (Table 2). Likewise, spike length increased from 12.81 cm at deficient P to 13.0 cm at high P supply. The longer spikes were produced by MK-3 at both P levels while MK-6 produced shorter spikes (Table 2). Increasing P level from deficient to sufficient range resulted in higher number of grains per spike (from 68.17 to 73.03). Averaged across two P levels, genotypes MK-3 and MK-7 produced the highest number of grains per spike while MK-1 exhibited the lowest value. Phosphorus application could not significantly (P > 0.05) increase the 100-grain weight of wheat genotypes. Genotype MK-3 and MK-8 exhibited the lowest and the highest 100-grain weight, respectively, at both P levels (Table 2).

Table 1. Means and mean squares of phosphorus level (P), genotype (G) and P × G interaction for various traits of wheat genotypes at low (0 kg $P_2O_5$ $ha^{-1}$) and high P (110 kg $P_2O_5$ $ha^{-1}$) level.

| Traits | Low P Mean | High P Mean | Mean square P (df:1) | Mean square G (df:9) | Mean square P×G (df:9) |
|---|---|---|---|---|---|
| Plant height (cm) | 95.99 | 96.88 | 11.97 ns | 203.39*** | 5.03 ns |
| No. of tillers plant$^{-1}$ | 7.72 | 8.33 | 5.61 ns | 9.19*** | 0.551 ns |
| Spike length (cm) | 12.81 | 13.13 | 1.56 ns | 6.89*** | 0.12 ns |
| No. of grains spike$^{-1}$ | 68.17 | 74.03 | 516.27*** | 251.71*** | 15.64 ns |
| 100-grain weight (g) | 4.22 | 4.26 | 0.03 ns | 0.66*** | 0.01 ns |
| Grain yield (t ha$^{-1}$) | 4.55 | 4.83 | 1.17* | 1.92*** | 0.14** |
| Straw yield (t ha$^{-1}$) | 7.99 | 8.33 | 1.71 ns | 7.62*** | 1.38*** |
| Total yield (grain + straw) (t ha$^{-1}$) | 12.55 | 13.16 | 5.56 ns | 14.52*** | 1.76** |
| Grain P concentration (mg g$^{-1}$) | 3.05 | 2.99 | 0.04 ns | 0.35** | 0.03 ns |
| Straw P concentration (mg g$^{-1}$) | 0.56 | 0.63 | 0.06 ns | 0.07* | 0.01 ns |
| Grain P uptake (kg ha$^{-1}$) | 13.79 | 14.41 | 5.61 ns | 14.42*** | 1.88* |
| Straw P uptake (kg ha$^{-1}$) | 4.52 | 5.15 | 5.86*** | 5.39*** | 0.97* |
| Total P uptake (kg ha$^{-1}$) | 18.32 | 19.56 | 22.85 ns | 24.13*** | 4.00* |
| P stress factor (%) | 5.64 | - | - | 86.99*** | - |
| P harvest index (kg kg$^{-1}$) | 0.76 | 0.74 | 0.01 ns | 0.01*** | 0.001 ns |
| Quotient of P utilization (kg kg$^{-1}$) | 331.64 | 336.54 | 360.44 ns | 3991.41*** | 282.05 ns |
| P utilization efficiency (kg kg$^{-1}$) | 250.54 | 247.12 | 176 ns | 1996*** | 427* |
| P acquisition efficiency (kg kg$^{-1}$) | 0.79 | 0.27 | 3.93** | 0.02*** | 0.01*** |
| P use efficiency (kg kg$^{-1}$) | 195.61 | 67.81 | 244865*** | 1521*** | 440 ns |

* = Significant at $P < 0.05$, ** = Significant at $P < 0.01$, *** = Significant at $P < 0.001$, ns = non-significant at $P > 0.05$

Table 2. Performance of wheat genotypes for plant height, tiller count plant$^{-1}$, spike length, no. of grains spike$^{-1}$ and 100-grain weight at low (0 kg $P_2O_5$ $ha^{-1}$) and high P (110 kg $P_2O_5$ $ha^{-1}$) level.

| Genotypes | Plant height (cm) | | Tillers count plant$^{-1}$ | | Spike length (cm) | | No. of grains spike$^{-1}$ | | 100-grain weight (g) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Low P | High P | Low P | High P | Low P | High P | Low P | High P | Low P | High P |
| MK-1 | 96.28 | 96.44 | 7.44 | 8.22 | 13.28 | 13.50 | 64.33 | 74.33 | 4.34 | 4.37 |
| MK-2 | 105.89 | 104.33 | 6.78 | 7.33 | 13.17 | 13.33 | 65.33 | 72.33 | 4.48 | 4.33 |
| MK-3 | 88.78 | 88.89 | 6.22 | 6.56 | 11.00 | 11.17 | 63.67 | 65.33 | 3.69 | 3.71 |
| MK-4 | 97.78 | 98.11 | 9.78 | 11.56 | 14.22 | 14.78 | 79.00 | 89.67 | 4.49 | 4.57 |
| MK-5 | 86.78 | 90.00 | 8.22 | 8.00 | 12.83 | 13.06 | 65.00 | 70.67 | 4.07 | 4.19 |
| MK-6 | 89.44 | 89.67 | 7.56 | 7.67 | 11.89 | 12.94 | 66.00 | 69.00 | 3.96 | 4.02 |
| MK-7 | 100.50 | 105.33 | 7.11 | 7.33 | 11.22 | 11.50 | 60.67 | 67.33 | 3.85 | 3.97 |
| MK-8 | 96.44 | 97.22 | 8.89 | 9.33 | 13.78 | 13.89 | 77.67 | 81.33 | 4.81 | 4.78 |
| MK-9 | 99.50 | 99.28 | 6.67 | 8.11 | 13.44 | 13.72 | 68.67 | 77.00 | 4.43 | 4.58 |
| NIA-Sunder | 98.50 | 99.56 | 8.56 | 9.22 | 13.28 | 13.44 | 71.33 | 73.33 | 4.08 | 4.12 |
| $HSD_{0.05}$, P | - | | - | | - | | 0.79 | | - | |
| $HSD_{0.05}$, G | 5.91 | | 1.81 | | 1.08 | | 5.96 | | 0.34 | |
| $HSD_{0.05}$, P × G | - | | - | | - | | - | | - | |

$HSD_{0.05}$ = Honestly Significant Difference at 5% probability level, P = phosphorus levels, G = genotypes, P × G = interaction between phosphorus levels and genotypes

### Grain, straw and total yield

The main and interaction effects of P and G had a significant ($P < 0.05$) impact on the grain yield of wheat genotypes (Table 1). Grain yield increased, on average, from 4.55 t ha$^{-1}$ with deficient P to 4.83 t ha$^{-1}$ (6 % increase) at adequate P supply across all genotypes. The genotype MK-4 and MK-8 produced the highest grain yield while MK-3 and MK-7 produced the lowest grain yield at both P levels. Phosphorus levels could not significantly ($P < 0.05$) influence straw and total yield of wheat genotypes; however, genotypic response for straw yield was variable at each P level. Across the two P levels, MK-4 showed the highest straw as well as total yield while MK-3 exhibited the lowest straw and total yield (Table 3).

Table 3. Performance of wheat genotypes for grain, straw and total yield, and phosphorus stress factor (PSF) at low (0 kg $P_2O_5$ $ha^{-1}$) and high P (110 kg $P_2O_5$ $ha^{-1}$) level.

| Genotypes | Grain yield (t $ha^{-1}$) | | Straw yield (t $ha^{-1}$) | | Total yield (t $ha^{-1}$) | | PSF (%) |
|---|---|---|---|---|---|---|---|
| | Low P | High P | Low P | High P | Low P | High P | |
| MK-1 | 4.80 | 4.89 | 8.36 | 9.47 | 13.16 | 14.35 | 1.71 |
| MK-2 | 4.69 | 4.79 | 8.92 | 8.30 | 13.61 | 13.09 | 2.02 |
| MK-3 | 3.55 | 4.04 | 5.95 | 6.05 | 9.50 | 10.09 | 13.04 |
| MK-4 | 5.05 | 6.10 | 9.00 | 10.28 | 14.05 | 16.38 | 17.08 |
| MK-5 | 4.45 | 4.56 | 6.96 | 7.23 | 11.41 | 11.80 | 2.25 |
| MK-6 | 4.20 | 4.47 | 8.10 | 6.55 | 12.30 | 11.03 | 6.07 |
| MK-7 | 3.90 | 4.13 | 8.30 | 8.85 | 12.20 | 12.99 | 5.62 |
| MK-8 | 5.48 | 5.48 | 8.49 | 8.19 | 14.00 | 13.68 | 0.06 |
| MK-9 | 4.78 | 5.00 | 7.16 | 8.19 | 11.94 | 13.19 | 4.20 |
| NIA-Sunder | 4.64 | 4.86 | 8.66 | 10.13 | 13.33 | 14.99 | 4.34 |
| $HSD_{0.05}$, P | 0.23 | | - | | - | | - |
| $HSD_{0.05}$, G | 0.39 | | 0.82 | | 1.37 | | 6.18 |
| $HSD_{0.05}$, P × G | 0.63 | | 1.31 | | 2.19 | | 3.68 |

$HSD_{0.05}$ = Honestly Significant Difference at 5% probability level, P = phosphorus levels, G = genotypes, P × G = interaction between phosphorus levels and genotypes

The term "phosphorus stress factor" (PSF) describes the wheat genotypes' relative tolerance to P deprivation. Table 3 shows that it differed considerably ($P < 0.05$) amongst wheat genotypes. The PSF showed a wide genetic variability in wheat genotypes for grain yield in response to elevated P levels, ranging from 0.06 to 17.08 %. Because genotype MK-8's PSF value was less than one, it did not respond to a high P level. Higher PSF values, however, indicate that MK-3 and MK-4 are highly P responsive (Table 3).

## Phosphorus concentration and uptake

Wheat genotypes differed significantly in P concentration present in grain and straw at each P level (Table 1). There was no discernible increase in P concentration in either grain or straw with a higher P level. As P increased, the concentration of P in the grain actually slightly reduced, demonstrating the dilution effect of yield increase on grain P concentration. The P concentration in grain and straw of wheat genotypes, respectively, ranged from 2.76 to 3.43 mg $kg^{-1}$ and 0.41 to 0.72 mg $kg^{-1}$, in the absence of P fertilization. Application of P at the rate of 110 kg $P_2O_5$ $ha^{-1}$ caused variations in grain P concentration ranging from 2.80 to 3.21 mg $kg^{-1}$ and straw P concentration from 0.52 to 0.80 mg $kg^{-1}$ (Table 4).

Table 4. Phosphorus concentration and uptake in grain and straw of wheat genotypes grown at low (0 kg $P_2O_5$ $ha^{-1}$) and high P (110 kg $P_2O_5$ $ha^{-1}$) level.

| Genotypes | P concentration (mg $g^{-1}$) | | | | P uptake (kg $ha^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Grain | | Straw | | Grain | | Straw | | Total | |
| | Low P | High P | Low P | High P | Low P | High P | Low P | High P | Low P | High P |
| MK-1 | 2.89 | 3.02 | 0.68 | 0.64 | 13.96 | 14.70 | 5.69 | 6.02 | 19.65 | 20.72 |
| MK-2 | 2.76 | 2.80 | 0.64 | 0.75 | 12.98 | 13.40 | 5.70 | 6.32 | 18.69 | 19.72 |
| MK-3 | 3.43 | 3.47 | 0.41 | 0.64 | 12.19 | 14.02 | 2.46 | 3.89 | 14.64 | 17.91 |
| MK-4 | 2.94 | 2.88 | 0.55 | 0.54 | 14.81 | 17.62 | 4.98 | 5.57 | 19.79 | 23.19 |
| MK-5 | 3.36 | 3.18 | 0.68 | 0.65 | 15.00 | 14.53 | 4.75 | 4.74 | 19.75 | 19.27 |
| MK-6 | 3.43 | 3.21 | 0.72 | 0.80 | 14.46 | 14.39 | 5.84 | 5.21 | 20.33 | 19.61 |
| MK-7 | 2.81 | 2.70 | 0.45 | 0.67 | 10.85 | 11.14 | 3.75 | 5.89 | 14.61 | 17.03 |
| MK-8 | 3.03 | 2.90 | 0.62 | 0.64 | 16.76 | 15.85 | 5.26 | 5.22 | 22.02 | 21.08 |
| MK-9 | 2.82 | 2.96 | 0.42 | 0.52 | 13.38 | 14.78 | 3.00 | 4.23 | 16.38 | 19.00 |
| NIA-Sunder | 2.96 | 2.82 | 0.45 | 0.43 | 13.57 | 13.66 | 3.80 | 4.38 | 17.38 | 18.05 |
| $HSD_{0.05}$, P | - | | - | | - | | 0.03 | | - | |
| $HSD_{0.05}$, G | 0.59 | | 0.31 | | 1.69 | | 1.13 | | 2.29 | |
| $HSD_{0.05}$, P ×G | - | | - | | 2.72 | | 1.81 | | - | |

$HSD_{0.05}$ = Honestly Significant Difference at 5% probability level, P = phosphorus levels, G = genotypes, P × G = interaction between phosphorus levels and genotypes

Only genotypic and G × P factors significantly impacted the P absorption in grain (Table 1). On an average, P uptake in grain increased from 13.80 (without P) to 14.41 kg $ha^{-1}$(with P addition). Among various genotypes, MK-8 and MK-4 were the highest accumulator of P in grain while MK-7 accumulated the least P in grain, when averaged across two P levels. Phosphorus uptake in straw increased significantly (14% over control/no P) when adequate P was added into soil. Genotypes varied substantially for straw P uptake, with MK-2 and

MK-3 accumulating the highest and the lowest P in straw, respectively. Overall, it ranged from 2.46 to 5.84 kg $ha^{-1}$ at deficient P level and from 3.89 to 6.32 kg $ha^{-1}$ under high P treatment (Table 4). The amount of total P uptake increased, though non-significantly, from 18.32 kg $ha^{-1}$ under P deficiency to 19.56 kg $ha^{-1}$ in P-treated soil. Overall, it ranged from 14.61 to 22.02 kg $ha^{-1}$ at deficient P level and from 17.03 to 23.19 kg $ha^{-1}$ under P adequacy (Table 4).

**Phosphorus use efficiency and its components**

The phosphorus harvest index (PHI) shows the amount of P that has accumulated in grain in relation to the overall amount of P at crop harvest (grain + straw). While genotypes showed significant diversity for P allocation to grains at both P levels, the PHI was not significantly ($P < 0.05$) impacted by P levels (Table 1). The PHI varied from 65.44 to 78.51% at high P and from 69.71 to 83.16% at low P. According to Table 5's PHI values, wheat genotypes assigned the majority of the P reserves to grain.

The capacity of a crop to yield grain per unit of P collected in the above-ground portions is determined by the quotient of P utilization (QPUt). Table 1 shows that there was no significant ($P > 0.05$) impact of the P levels and G × P interactions on the QPUt. At both P levels, however, genotypic effects were more noticeable. QPUt ranged in magnitude from 289 to 372 kg $kg^{-1}$ at high P treatment and from 291 to 362 kg $kg^{-1}$ at low P treatment. MK-3 and MK-7 showed the lowest and greatest values of QPUt, respectively, when averaged over both P levels (Table 5).

Table 5. Phosphorus use efficiency and its components of wheat genotypes at low (0 kg $P_2O_5$ $ha^{-1}$) and high P (110 kg $P_2O_5$ $ha^{-1}$) level.

| Genotypes | P harvest index (kg $kg^{-1}$) | | Quotient of P utilization (kg $kg^{-1}$) | | P utilization efficiency (kg $kg^{-1}$) | | P acquisition efficiency (kg $kg^{-1}$) | | P use efficiency (kg $kg^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Low P | High P | Low P | High P | Low P | High P | Low P | High P | Low P | High P |
| MK-1 | 0.72 | 0.71 | 344 | 333 | 245 | 236 | 0.84 | 0.29 | 207 | 69 |
| MK-2 | 0.70 | 0.70 | 362 | 358 | 252 | 244 | 0.80 | 0.28 | 202 | 67 |
| MK-3 | 0.83 | 0.79 | 293 | 289 | 243 | 226 | 0.63 | 0.25 | 152 | 57 |
| MK-4 | 0.75 | 0.76 | 341 | 346 | 257 | 264 | 0.85 | 0.33 | 217 | 86 |
| MK-5 | 0.76 | 0.76 | 298 | 314 | 226 | 237 | 0.85 | 0.27 | 191 | 64 |
| MK-6 | 0.72 | 0.73 | 291 | 311 | 207 | 228 | 0.87 | 0.28 | 180 | 63 |
| MK-7 | 0.74 | 0.65 | 360 | 372 | 267 | 243 | 0.63 | 0.24 | 167 | 58 |
| MK-8 | 0.76 | 0.75 | 328 | 347 | 249 | 261 | 0.95 | 0.30 | 235 | 77 |
| MK-9 | 0.82 | 0.78 | 358 | 338 | 292 | 263 | 0.70 | 0.27 | 205 | 70 |
| NIA-Sunder | 0.79 | 0.76 | 342 | 356 | 267 | 270 | 0.75 | 0.25 | 199 | 68 |
| $HSD_{0.05}$, P | - | | - | | - | | 0.07 | | 2.12 | |
| $HSD_{0.05}$, G | 0.08 | | 23.75 | | 24.82 | | 0.07 | | 29.87 | |
| $HSD_{0.05}$, P×G | - | | - | | 39.74 | | 0.12 | | - | |

$HSD_{0.05}$ = Honestly Significant Difference at 5% probability level, P = phosphorus levels, G = genotypes, P × G = interaction between phosphorus levels and genotypes

Phosphorus rates could not produce significant effects on P utilization efficiency (PUtE), though, genotypes and G × P interactions significantly ($P < 0.05$) influenced PUtE (Table 1). Under low P treatment, the PUtE ranged from 207 to 292 kg grain yield $kg^{-1}$ total P uptake, whereas under high P treatment, it ranged from 226 to 270 kg grain yield $kg^{-1}$ total P uptake (Table 5). Averaging across P rates, the genotype MK-9 was highly efficient in P utilization, while MK-6 showed the lowest PUtE (Table 5). Phosphorus acquisition efficiency (PAE) and P use efficiency (PUE) were significantly ($P < 0.05$) affected by P rates, genotypes and G × P interactions (Table 1). The PAE decreased by 78% under high P treatment. It varied between 1.19 and 1.79 kg total P uptake $kg^{-1}$ P supply under no/zero P application, and between 0.28 and 0.38 kg total P uptake $kg^{-1}$ P supply in P treated soil (Table 5). Genotype MK-8 showed the highest PAE, while MK-7 and MK-3 showed the lowest PAE when evaluated across both P levels. It is interesting to note that with P deprivation, more variations in PUtE and PAE were seen among wheat genotypes. When P @ 110 kg $P_2O_5$ $ha^{-1}$ was given to the soil, phosphorus use efficiency (PUE), the product of PUtE and PAE, dropped from 378 to 81 kg grain yield $kg^{-1}$ P supply (79% decrease). Table 5 shows that its ranges were 289-446 kg grain yield $kg^{-1}$ P supply at low P and 67-101 kg grain yield $kg^{-1}$ P supply at high P. MK-8 and MK-4 had the highest PUE when averaging across P levels, while MK-3 and MK-7 had the lowest PUE.

Table 6 displays the relative significance of the P use efficiency components: acquisition and utilization, based on the methodology of Moll et al. (1982). According to the data, 83.1 and 16.6% of the genotypic variability for PUE at low P treatment was explained by PAE and PUtE, respectively. PUtE accounts for 37.6% of the variability in P use efficiency seen in P fertilized soil, while PAE contributed 62.9% of this variability. The correlation coefficients and the ratio of the variability found between PUE and its constituents, PAE and PUtE,

(Table 6) provide more insight into these interactions. In P deficient circumstances, the high correlation between PAE and PUE (r = 0.751) and their substantial standard deviation ratio (1.107) account for 83.1% of the variability in PUE. Due to a lower correlation (r = 0.221) between these two variables and a smaller variability for PUtE (0.751), PUtE at low soil P only explained 16.6% of the variability found in PUE. Similar pattern was noted at the high P level.

The PUtE of the genotypes was also decomposed into two components: quotient of P utilization (QPUt) and P harvest index (PHI). Wheat genotypes exhibited more variability for QPUt than PHI which was confirmed by the higher ratio of standard deviation of QPUt and PUtE at both low and high P environments (Table 6). The QPUt accounted for the largest fraction of the variability observed in the genotypes for PUtE at low P (72.5%) and at high P environments (111.2%), due to a higher correlation coefficient of QPUt with PUtE and also to a larger ratio of standard deviation between QPUt and this trait (Table 6).

Table 6. Relative contribution of the components traits ($X_i$) to the variation of resultant trait (Y) according to Moll et al. (1982).

| Resultant trait (Y) | Component trait ($X_i$) | Low P | | | High P | | |
|---|---|---|---|---|---|---|---|
| | | Contribution of $X_i$ to Y | $r_{xiy}$ | $Sx_i/S_y$ | Contribution of $X_i$ to Y | $r_{xiy}$ | $Sx_i/S_y$ |
| P use efficiency | P utilization efficiency | 0.166 | 0.221 | 0.751 | 0.377 | 0.715 | 0.526 |
| | P acquisition efficiency | 0.831 | 0.751 | 1.107 | 0.629 | 0.864 | 0.729 |
| P utilization efficiency | Quotient of P utilization | 0.725 | 0.798 | 0.908 | 1.112 | 0.754 | 1.476 |
| | P harvest index | 0.258 | 0.431 | 0.598 | -0.130 | -0.121 | 1.079 |

$r_{xiy}$ is the coefficient of correlation between the components trait ($X_i$) and the resultant trait (Y), while $Sx_i/S_y$ is the ratio between standard deviation of $X_i$ and Y.

## Discussion

Selection of crop genotypes that adapt well to situations of contrasting P availability is an efficacious strategy for sustainable P use. A genotype is considered ideal if it yields higher under P deficiency and responds well to P application (van de Wiel et al., 2016). The primary goal of evaluating germplasm under low P conditions is to increase PAE, and genotypes chosen in this manner frequently have low yield potential and P fertilization responsiveness. High input conditions are ideal for expressing yield potential (Sandaña, 2016). Therefore, selection under various P supply conditions can lead to improvements in both PAE and PUtE in the given species. This purpose is effectively covered by the current study.

Grain yield of wheat genotypes varied significantly at both P levels. Genotypes MK-3 and MK-4 with PSF > 10% were highly responsive to P fertilization (Table 3). However, grain yield of MK-8 was not affected by P deficiency as its phosphorus stress factor was less than 1. Such genotypes have the ability to sustain growth and development even in low P conditions (Abbas et al., 2018a). According to Yaseen and Malhi (2009b), modern wheat cultivars can yield more than their predecessors, even though P application rates are lower. As demonstrated by their high grain and total P uptake under low P treatment, genotypes like MK-8, which are less sensitive to P deprivation, translocate more P towards grain (Table 3). Our claim was reinforced by the notable positive correlation between grain yield and both grain P absorption ($r > 0.73$, $P < 0.001$) and total P uptake ($r > 0.72$, $P < 0.001$) at both P levels.

By choosing genotypes with greater P utilization quotient (QPUt) and P harvest index (PHI), grain output can be increased through higher PUtE (Sandaña and Pinochet, 2014). QPUt corresponds exactly to the reciprocal of the grain P concentration and is equal to the grain yield divided by the quantity of P absorbed in the grain (grain yield multiplied by grain P concentration). The P utilization efficiency, therefore, increases with decreasing grain P concentration (Parentoni and Souza Júnior, 2008). Selection of wheat genotypes with low grain P concentration will support sustainable land usage (Korkmaz et al., 2009). In this experimentation, grain P concentration was negatively related with PUtE at low P ($r = -0.53$, $P < 0.01$) and high P ($r = -0.45$, $P < 0.05$) which infers that selecting for lower grain P concentration may help in evolving cultivars with increased PUtE (Gemenet et al., 2015). However, there is a limit to the approach of P concentration reduction in grain. For nutritional purposes and seed vigor, the grain must have a minimal amount of P (White and Veneklaas, 2012). Increased P translocation into the grains - the PHI- can increase P utilization efficiency without lowering grain P content. Our research findings demonstrated that wheat grain at both P levels gathered more than 73% of the total P (Table 4), indicating a narrow space for breeding for greater PHI. If P absorption efficiency is not increased, selecting for high grain production under these conditions will further lower grain P concentration due to the dilution effect (Rose et al., 2011). Because variations in the P harvest index appear to have little bearing on the PUtE of the wheat genotypes under varying P conditions, selection strategies aimed at increasing wheat P utilization efficiency in alkaline calcareous soils should concentrate on lowering grain P concentration (Yaseen and Malhi, 2009a).

Important genetic variability in PAE was observed in the present study (Table 5). The PAE had strong positive relationship with total P uptake ($r > 0.90$, $P < 0.001$), and the total P uptake was related to grain ($r > 0.72$, $P < 0.001$) and total yield ($r > 0.50$, $P < 0.05$) at both P levels. Thus, PAE can be improved by selecting genotypes with higher grain and/or total yield (Yaseen and Malhi, 2009b). Differential P uptake by wheat genotypes having comparable yield indicates important genotypic differences in PAE (Table 4). Wheat genotypes with greater PAE (e.g. MK-8) under both P conditions require lower soil P threshold values for fertilizer response than genotypes with low PAE (MK-3 and MK-7) (Irfan et al., 2018). In low input cropping systems, cultivating genotypes with high PAE would significantly boost productivity. Conversely, in high input systems, these genotypes would lessen the wasteful use of P fertilizers and environmental issues related to P losses to water bodies (Manschadi et al., 2014; Ruark et al., 2014). The improved P acquisition by crop can be attributed to several mechanisms, i.e. root structural and architectural modifications (Niu et al., 2013), up-regulation of high-affinity root P transporters (Amtmann and Armengaud, 2009), mycorrhizal associations (Smith and Read, 2010), and enhanced carboxylate exudations into rhizosphere (White et al., 2013). Root characteristics were not examined in this investigation. Thus, more research on PAE and associated root properties can help choose cultivars with better qualities related to uptake of P.

Our research shows that when it comes to determining grain yield and PUE in wheat genotypes, PAE is more important than PUtE. According to our findings, PAE had a two-fold greater significance at high P conditions and an approximately five-fold greater significance at low P conditions in explaining the genetic variability for PUE (Table 6). Our results were consistent with those of Manske et al. (2001), who found that P acquisition in low and high P acidic soil accounted for > 85% of the variability in wheat PUE. The findings of Parentoni and Souza Júnior (2008) also substantiate our results. Contrarily, McDonald et al. (2015) reported higher contribution of P utilisation to the genetic variability in grain yield of wheat genotypes grown under diverse soil and environmental conditions. These contrasting results indicate the influence of soil type, P status and environmental conditions (Parentoni and Souza Júnior, 2008; Wang et al., 2010). Therefore, mechanisms associated to P acquisition efficiency rather than P internal utilization should receive more focus in physiological research on P use efficiency of the test genotypes in our study (Rose and Wissuwa, 2012). Future breeding initiatives should prioritize root structural and architectural traits due to the paramount significance of P acquisition in high P-fixing alkaline calcareous soil conditions. The data reported in this study show that there exist sufficient variations among wheat genotypes for PUE which can be exploited for wheat improvement. Moreover, it was revealed that MK-4 and MK-8 were the best wheat genotypes in terms of PUE under contrasting P availabilities.

## Conclusion

The current study showed that when several genotypes were cultivated in field conditions with both low and high P supplies, there was significant genetic variability among wheat genotypes for PUE, PAE, PUtE, and the related characteristics. It was shown that the genotypes MK-4 and MK-8 were the best fits for soils with different levels of P availability. Furthermore, the PAE of wheat genotypes was primarily responsible for PUE discrepancies. By choosing genotypes with lower grain P concentration, it is possible to boost P utilization efficiency by placing more weight on the quotient of utilization than the P harvest index. These results highlight the necessity of screening vast genetic pools on various soil types with variable P supply. This will provide a window of opportunity for conventional breeding to increase PUE in wheat production systems. Furthermore, by modifying P fertilization in accordance with cultivar sensitivity to P deprivation (tolerant vs. sensitive genotypes), this information will be helpful for P management, which will ultimately lower production costs and fertilizer requirements especially in P-limited alkaline calcareous soils.

## References

Abbas, M., Irfan, M., Shah, J.A., 2018a. Differential performance of wheat genotypes for grain yield, phosphorus uptake and utilization at low and high phosphorus: Evaluation of PUE in wheat genotypes. *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences* 55(2): 55-64.

Abbas, M., Shah, J.A., Irfan, M., Memon, M.Y., 2018b. Remobilization and utilization of phosphorus in wheat cultivars under induced phosphorus deficiency. *Journal of Plant Nutrition* 41(12): 1522-1533.

Amtmann, A., Armengaud, P., 2009. Effects of N, P, K and S on metabolism: new knowledge gained from multi-level analysis. *Current Opinion in Plant Biology* 12(3): 275-283.
Baker, A., Ceasar, S.A., Palmer, A.J., Paterson, J.B., Qi, W., Muench, S.P., Baldwin, S.A., 2015. Replace, reuse, recycle: improving the sustainable use of phosphorus by plants. *Journal of Experimental Botany* 66(12): 3523-3540.
Bayuelo-Jiménez, J.S., Ochoa-Cadavid, I., 2014. Phosphorus acquisition and internal utilization efficiency among maize landraces from the central Mexican highlands. *Field Crops Research* 156: 123-134.
Beebe, S.E., Rojas-Pierce, M., Yan, X., Blair, M.W., Pedraza, F., Munoz, F., Tohme, J., Lynch, J.P., 2006. Quantitative trait loci for root architecture traits correlated with phosphorus acquisition in common bean. *Crop Science* 46(1): 413-423.
Byrne, S.L., Foito, A., Hedley, P.E., Morris, J.A., Stewart, D., Barth, S., 2011. Early response mechanisms of perennial ryegrass (Lolium perenne) to phosphorus deficiency. *Annals of Botany* 107(2): 243-254.
Chapman, H.D., Pratt, F.P., 1961. Ammonium vandate-molybdate method for determination of phosphorus. In: Methods of analysis for soils, plants and waters. Division of Agricultural Sciences, University of California, pp. 184-203.
Cordell, D., Drangert, J.O., White, S., 2009. The story of phosphorus: global food security and food for thought. *Global Environmental Change* 19(2): 292-305.
Gemenet, D.C., Hash, C.T., Sanogo, M.D., Sy, O., Zangre, R.G., Leiser, W.L., Haussmann, B.I., 2015. Phosphorus uptake and utilization efficiency in West African pearl millet inbred lines. *Field Crops Research* 171: 54-66.
Gill, H.S., Singh, A., Sethi, S.K., Behl, R.K., 2004. Phosphorus uptake and use efficiency in different varieties of bread wheat (Triticum aestivum L). *Archives of Agronomy and Soil Science* 50(6): 563-572.
Gomez, K.A., Gomez, A.A., 1984. Statistical procedures for agricultural research. John Wiley & Sons, New York. 657p.
Government of Pakistan, 2022. Pakistan Economic Survey 2021-22. Ministry of Finance, Islamabad, Pakistan.
Irfan, M., Abbas, M., Shah, J.A. and Memon, M.Y., 2018. Internal and external phosphorus requirements for optimum grain yield are associated with P-utilization efficiency of wheat cultivars. *Communications in Soil Science and Plant Analysis* 49(22): 2843-2853.
Karthikeyan, A.S., Jain, A., Nagarajan, V.K., Sinilal, B., Sahi, S.V., Raghothama, K.G., 2014. Arabidopsis thaliana mutant lpsi reveals impairment in the root responses to local phosphate availability. *Plant Physiology and Biochemistry* 77: 60-72.
Kochian, L.V., 2012. Rooting for more phosphorus. *Nature* 488(7412): 466-467.
Korkmaz, K., İbrikçi, H., Karnez, E., Buyuk, G., Ryan, J., Ulger, A.C., Oguz, H., 2009. Phosphorus use efficiency of wheat genotypes grown in calcareous soils. *Journal of Plant Nutrition* 32(12): 2094-2106.
Lambers, H., Cawthray, G.R., Giavalisco, P., Kuo, J., Laliberté, E., Pearse, S.J., Scheible, W.R., Stitt, M., Teste, F., Turner, B.L., 2012. Proteaceae from severely phosphorus-impoverished soils extensively replace phospholipids with galactolipids and sulfolipids during leaf development to achieve a high photosynthetic phosphorus-use-efficiency. *New Phytologist* 196(4): 1098-1108.
Liu, H., Shi, Z., Ma, F., Xu, Y., Han, G., Zhang, J., Liu, D., An, D., 2022. Identification and validation of plant height, spike length and spike compactness loci in common wheat (Triticum aestivum L.). *BMC Plant Biology* 22(1): 568.
Manschadi, A.M., Kaul, H.P., Vollmann, J., Eitzinger, J., Wenzel, W., 2014. Developing phosphorus-efficient crop varieties - an interdisciplinary research framework. *Field Crops Research* 162: 87-98.
Manske, G.G.B., Ortiz-Monasterio, J.I., Van Ginkel, M., Gonzalez, R.M., Fischer, R.A., Rajaram, S., Vlek, P.L.G., 2001. Importance of P uptake efficiency versus P utilization for wheat yield in acid and calcareous soils in Mexico. *European Journal of Agronomy* 14(4): 261-274.
Marschner, H. 2012. Marschner's mineral nutrition of higher plants. 3rd edition. Academic Press, Elsevier. 672p.
McDonald, G., Bovill, W., Taylor, J., Wheeler, R., 2015. Responses to phosphorus among wheat genotypes. *Crop and Pasture Science* 66(5): 430-444.
Memon, K.S., 2005. Soil & fertilizer phosphorus. In: Soil Science. Bashir, A. Bantel, R., (Eds.). National Book Foundation, Islamabad, Pakistan. pp. 291-316.
Miller, R.O., 1998. Nitric-perchloric acid wet digestion in an open vessel. In: Handbook of reference methods for plant analysis. Kalra, Y.P. (Ed.). CRC Press, Washington D.C., USA. pp. 57-61.
Moll, R.H., Kamprath, E.J., Jackson, W.A., 1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. *Agronomy Journal* 74(3): 562-564.
NFDC, 2019-2020. National Fertilizer Development Center (NFDC). Crop Wise Usage of Fertilizer. Ministry of National Food Security and Research, Government of Pakistan, Islamabad. Available at [Access date: 16.08.2023]: http://www.nfdc.gov.pk/
Niu, Y.F., Chai, R.S., Jin, G.L., Wang, H., Tang, C.X., Zhang, Y.S., 2013. Responses of root architecture development to low phosphorus availability: a review. *Annals of Botany* 112(2): 391-408.
Olsen, S.R., 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate, Circular No. 939. US Department of Agriculture, Washington, D.C. USA. 19p.
Panigrahy, M., Rao, D.N., Sarla, N., 2009. Molecular mechanisms in response to phosphate starvation in rice. *Biotechnology Advances* 27(4): 389-397.
Parentoni, S.N., Souza Júnior, C.L.D., 2008. Phosphorus acquisition and internal utilization efficiency in tropical maize genotypes. *Pesquisa Agropecuária Brasileira* 43: 893-901.
Rose, T.J. and Wissuwa, M., 2012. Rethinking internal phosphorus utilization efficiency: a new approach is needed to improve PUE in grain crops. *Advances in Agronomy* 116: 185-217.

Rose, T.J., Rose, M.T., Pariasca-Tanaka, J., Heuer, S., Wissuwa, M., 2011. The frustration with utilization: why have improvements in internal phosphorus utilization efficiency in crops remained so elusive?. *Frontiers in Plant Science* 2: 73.

Ruark, M.D., Kelling, K.A., Good, L.W., 2014. Environmental concerns of phosphorus management in potato production. *American Journal of Potato Research* 91(2): 132-144.

Sandaña, P., Pinochet, D., 2014. Grain yield and phosphorus use efficiency of wheat and pea in a high yielding environment. *Journal of Soil Science and Plant Nutrition* 14(4): 973-986.

Sandaña, P., 2016. Phosphorus uptake and utilization efficiency in response to potato genotype and phosphorus availability. *European Journal of Agronomy* 76: 95-106.

Smith, S.E., Read, D.J., 2010. Mycorrhizal Symbiosis. Academic Press, 787p.

Sulpice, R., Ishihara, H., Schlereth, A., Cawthray, G.R., Encke, B., Giavalisco, P., Ivakov, A., Arrivault, S., Jost, R., Krohn, N., Kuo, J., aliberté, E., Pearse, S.J., Raven, J.A., Scheible, W.R., Teste, F., Veneklaas, E.J., Stitt, M., Lambers, H., 2014. Low levels of ribosomal RNA partly account for the very high photosynthetic phosphorus-use efficiency of Proteaceae species. *Plant, Cell & Environment* 37(6): 1276-1298.

Thornton, M.K., Novy, R.G., Stark, J.C., 2014. Improving phosphorus use efficiency in the future. *American Journal of Potato Research* 91(2): 175-179.

Valle, S.R., Pinochet, D., Calderini, D.F., 2011. Uptake and use efficiency of N, P, K, Ca and Al by Al-sensitive and Al-tolerant cultivars of wheat under a wide range of soil Al concentrations. *Field Crops Research* 121(3): 392-400.

Van de Wiel, C.C.M., van der Linden, C.G., Scholten, O.E., 2016. Improving phosphorus use efficiency in agriculture: opportunities for breeding. *Euphytica* 207(1): 1-22.

Wang, X., Shen, J., Liao, H., 2010. Acquisition or utilization, which is more critical for enhancing phosphorus efficiency in modern crops?. *Plant Science* 179(4): 302-306.

White, P.J., Veneklaas, E.J., 2012. Nature and nurture: the importance of seed phosphorus content. *Plant and Soil* 357(1): 1-8.

White, P.J., George, T.S., Gregory, P.J., Bengough, A.G., Hallett, P.D., McKenzie, B.M., 2013. Matching roots to their environment. *Annals of Botany* 112(2): 207-222.

Yang, H., Chen, R., Chen, Y., Li, H., Wei, T., Xie, W. and Fan, G., 2022. Agronomic and physiological traits associated with genetic improvement of phosphorus use efficiency of wheat grown in a purple lithomorphic soil. *The Crop Journal* 10(4): 1151-1164.

Yaseen, M., Malhi, S.S., 2009a. Variation in yield, phosphorus uptake, and physiological efficiency of wheat genotypes at adequate and stress phosphorus levels in soil. *Communications in Soil Science and Plant Analysis* 40(19-20): 3104-3120.

Yaseen, M., Malhi, S.S., 2009b. Differential growth performance of 15 wheat genotypes for grain yield and phosphorus uptake on a low phosphorus soil without and with applied phosphorus fertilizer. *Journal of Plant Nutrition* 32(6): 1015-1043.