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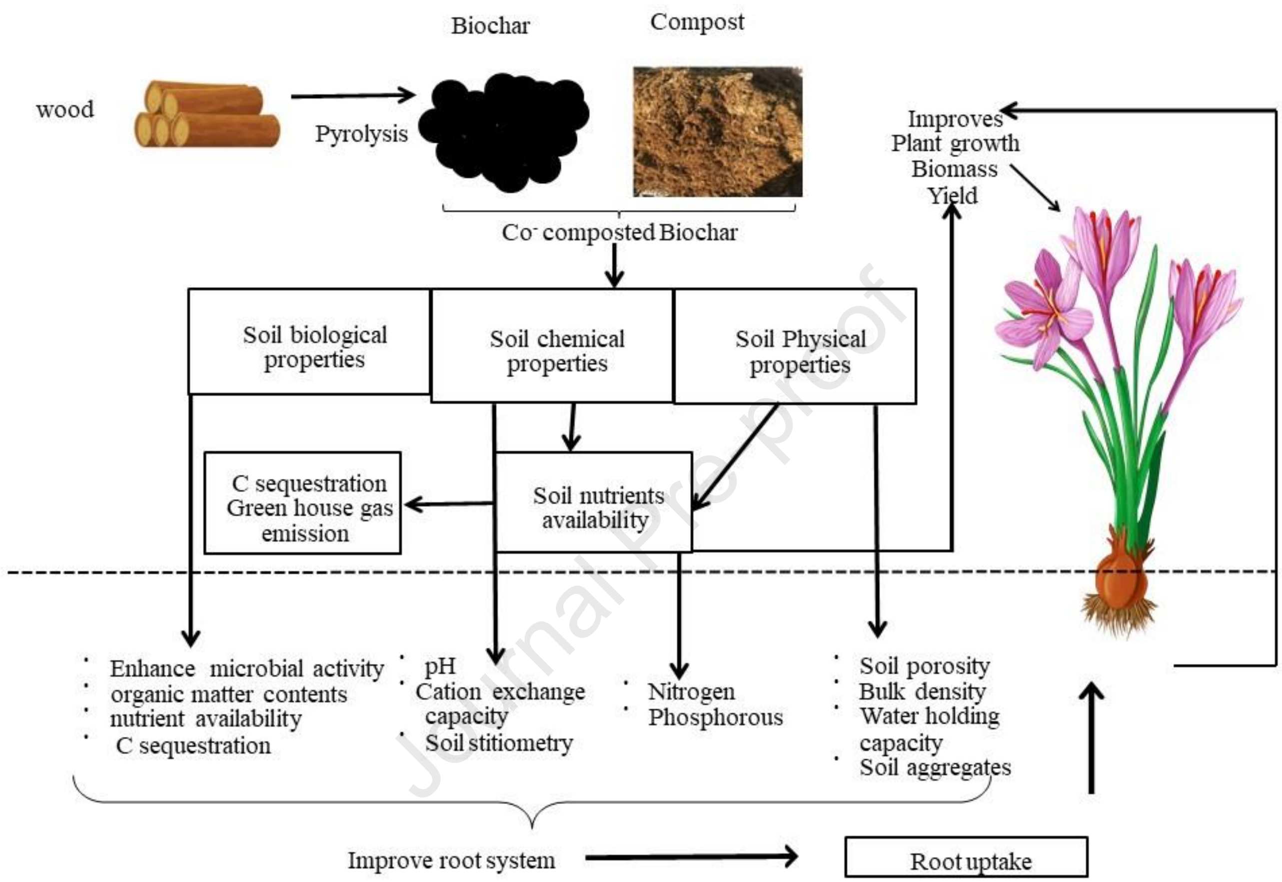

Graphical abstract

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Influence of composted manures and co-composted biochar on growth performance of saffron and soil nutrients under varying electrical conductivity soil conditions: a two-year field study

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Abstract

The stigmas of saffron (*Crocus sativus* L.) are known as "red gold" for being the most expensive spice of the world. This medicinal crop grows well in the regions with cold winter Mediterranean climate. However, salinity can be one of the limiting factors for its cultivation in these regions. Composted manures and their co-compost with wood-derived biochar as fertilizers in saline soil can reduce the salinity stress on saffron. In this study, the composted manures from dairy farms (FYM), sheep and goats (SG) and poultry (PM) and their co-compost with wood-derived biochar (FYM-B, SG-B and PM-B) were amended in non-saline ($EC_{1:2}$ 0.25 dS m^{-1}, SOM; 9.9 g kg^{-1}) and soil with natural slight salinity ($EC_{1:2}$; 1.95 dS m^{-1}, SOM; 30.9 g kg^{-1}) soil for two consecutive years with the total amendment rate of 65 t ha^{-1} for each fertilizer. The saline soil was transported from an agricultural farm (30 km away from research field); whereas, the non-saline soil was not transported and was not cultivated before. The amendment of fertilizers and sowing of corms were conducted at the same time in the mid of August. The stigma yield in saline control soil was significantly lower than non-saline control in both cropping years. In non-saline soil, all fertilizers reduced stigma yield of first-year crop by 14-60% ($P<0.05$). No differences between treatments for the stigma yield of second year crop in non-saline and of first year crop in saline soil were observed. In saline soil, FYM and PM fertilizers increased stigma yield of second year crop by 44% and 41%, respectively ($P<0.05$). The two-year cumulative agronomic efficiencies for nitrogen and phosphorus and the nitrogen use efficiency for leaf biomass were lower under fertilizer treatments than control in non-saline and saline soil. In non-saline soil the PM-B; whereas, in saline soil all fertilizers (except SG) increased the phosphorus use efficiency of leaves ($P<0.05$). The two-year amendment of composted manures and FYM-B in non-saline soil resulted in high uptake of sodium in leaves ($P<0.05$); whereas, such effect was not observed for saline soil. Almost all fertilizers increased ~2-5 fold the concentration of bioavailable phosphorus and ~2-3 fold the concentration of potassium in non-saline and saline soil ($P<0.05$). The positive influence of fertilizers on stigma yield and PUE of leaves of second year crop was observed only for saline soil. Furthermore, contrary to the results for non-saline soil, these fertilizers did not cause an increased uptake of Na in leaves in saline soil. We attribute this effect to the high concentration of SOM and gradual decline in EC (0.94-1.71 dS m^{-1}) over time in saline soil. The gradual improvement in yield (from negative to neutral in non-saline and from neutral to positive in saline soil) was observed over time. Amendment of fertilizers and sowing of corms at same time may be the reason for their negative influence on stigma yield in low SOM-containing non-saline soil.

Keywords: Co-composted biochar, composted manure, nutrient use efficiency, agronomic efficiency, salinity, saffron

1. **Introduction**

Crocus sativus L. (saffron) is a perennial herbaceous plant from Iridaceae family. The dried stigmas of this plant species have many uses for mankind such as it is used as a colouring agent in the textile industry, it is used in perfumes, cosmetics, medicines, foods and confectionery. A corm of this plant species can produce one to four flowers; each flower has only three long orange-color stigmas, 200 to 300 dry stigmas weigh 1 g; therefore, it takes approximately 200,000 flowers to obtain only 1 kg dry stigma [1, 2]. For this reason, saffron is the world's most expensive spice and is therefore known as red gold [3]. The cold climate especially cold-winter Mediterranean and coarse-textured soils (sandy clay, sandy loam, sandy clay loam) are favourable for the cultivation of this crop [4-7].

Salinity is one of the important limiting factors for the cultivation of crops in cold-winter Mediterranean deserts [8]. Balochistan is the largest province of Pakistan, it occupies approximately 44% land area of the country. The upland regions such as Quetta, Kalat and Zhob Divisions occupy approximately 50% of the land area of this province. The average summer temperatures of these areas do not reach to 40^{o}C and possess cold-winter Mediterranean climate. On test trial bases, the cultivation of saffron in private and government research farms of these regions has been found successful. Currently, the Balochistan Agricultural Research and Development Center (BARDC), Quetta and the Agricultural Research Institute, Quetta (ARI) have been cultivating saffron for last 14 and 5 years respectively. The per annum production of saffron stigma (on dry weight bases) at BARDC and ARI, on ~0.75 ha land is approximately 500 - 700 g. Currently, these two research institutions are the major producers of saffron in Balochistan. The BARDC produces saffron for commercial purpose and sells dry stigma to PATCO (PARC Agrotech Company) Islamabad, Pakistan. Although, large land area of this province has favourable climatic conditions for the cultivation of saffron, many regions have saline soil including the outskirts of Quetta city. Moreover, the corms of this crop are expensive. Although the cultivation of this crop can benefit farmers financially many times more than other crops, salinity and high-price corms are the factors, this crop has not been considered by farmers of this province for cultivation on large scale.

The utilization of manures and their compost as fertilizers for crop production in agricultural lands is proposed to be an environmental friendly strategy [9, 10]. These fertilizers not only provide nutrients to crops but their use in agricultural lands can also offer substantial help in reducing the pollution caused by their improper and non-utilization [9-10]. Organic fertilizers such as manures are found to increase the yield of saffron [11-13]. Yarami and Sepaskhah [11] reported a significant increase in the yield of saffron stigma in response to the amendment of cow manure at 60 t ha^{-1} rate under salinity stress condition of EC_e 1.1 dS m^{-1}. The application of mineral nitrogen in saline soil was found to reduce the salinity stress on saffron [14]. Organic fertilizers have plant available nutrients [10]. Therefore, the amendment of organic fertilizers can attenuate the salinity stress on saffron [11].

Potassium (K^+) is a major element for plant growth. In saline and sodic soils, excessive sodium (Na^+) in soil solution inhibits the uptake of K^+ by plants as it competes with K^+ through nonselective cation channels and high-affinity K^+ transporters in cell membranes [15, 16]. The high concentration of Na^+ in soil solution turns into a toxic ion for plant growth as its high concentration in cytoplasm inhibits cellular enzymatic activities [15]. Therefore, in saline soils, the optimal K:Na ratio in cells is vital to maintain the normal metabolic activities, which is required for the growth and development of plants [15]. Among the management options for attenuating salinity stress on crops in Mediterranean regions include the use of organic wastes as fertilizers [17-19]. Composted cow dung manure applied at 10 g kg^{-1} soil increased per plant seed production of sunflower by 31%, 36% and 43% under 1.8 dS m^{-1}, 6 dS m^{-1} and 12 dS m^{-1} salinity stress conditions as compared to control [20]. Another organic waste that is frequently reported for its attenuating effect on crops against salinity stress is pyrogenous biomass, known as biochar. However, the positive influence of biochar for salinity stress attenuation can be attained when biochar is applied with other organic wastes or inorganic fertilizers [21-23]. For instance, poultry manure-derived biochar co-composted with the mixture of mature compost, geranium waste and soil, applied at 5 t ha^{-1} and 10 t ha^{-1} rates in saline soil (electrical conductivity of 6.89 dS m^{-1}) at research farm located in El Fayoum province, Cairo, Egypt, increased the fruit yield of eggplant by 24% and 40% respectively as compared to control treatment [21]. The amendment of biochar reduced the uptake of Na^+ in potato and wheat crops and promoted the uptake of K^+ in these crops under salinity stress conditions [24, 25].

In Balochistan, manures from the farms of poultry, cows and buffalos, and sheep and goats are the major biowastes. On the other side, wood of the wild tree *Acacia nilotica* L. is used to make slow pyrolysis biochar on a commercial basis in Sindh Province of Pakistan. This biochar is purchased and used all over the country for barbecue purposes. The leftover broken pieces of this biochar are

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inexpensive (less than 1 US$ per 5 kg). The use of manures and the leftover broken pieces of biochar can be used to make co-composted biochar for agronomic purposes. The use of these biowastes as fertilizers can not only improve the yield of crops but also helps reduce pollution, caused by the non-utilization of these biowastes in this province. The objectives of the present study were to evaluate for two consecutive years in field 1) the influence of high electrical conductivity soil conditions (initial $EC_{1:2}$ before sowing of corms of first year crop was 1.95 dS m^{-1}) on the growth performance of saffron and 2) the influence of composted manures (from poultry, cows and buffalos and sheep and goats) and the co-composts of manures with *Acacia nilotica* wood-derived biochar on the growth performance of saffron and the concentrations of soil nutrients (mineral nitrogen, bioavailable phosphorus and potassium) under high EC and low EC ($EC_{1:2}$ 0.25 dS m^{-1}) soil conditions. In this study, soil with initial $EC_{1:2}$ of 1.95 dS m^{-1} was collected from the agricultural farm of Mulkiyar village, of Quetta district, situated at 30 km distance from the research farm of this study. Although, soils with EC $\geq$ 2 dS m^{-1} are considered as saline (Hopmans et al., 2021), some studies also found that soils with $EC_{1:2}$ of <1.5 negatively influenced the yield of various crops and the biological properties of soil [26-28]. Zhang et al. [27] classified soil $EC_{1:5}$ of as low as ~0.65 dS m^{-1} (equivalent to $EC_{1:2}$; ~1.62 dS m^{-1}) as saline, which affected negatively the yield of cotton at Dafeng Basic Seed Farm, Jiangsu, China. Taking into account the transported soil from Mulkiyar village as slightly saline, following hypotheses were tested in this study; composted manures and their co-compost with biochar improve 1) yield of stigma, agronomic efficiency, uptake of nutrients and nutrient use efficiency of this crop under high and low EC soil conditions, 2) reduce the Na:K ratio in the leaves of saffron under high EC soil conditions and 3) increase the concentration of mineral nitrogen, bioavailable phosphorus and potassium of soil under both EC conditions.

2. Materials and methods

2.1 Study site

The experiment was conducted at the Balochistan Agricultural Research and Development Centre (BARDC), Quetta, Pakistan (66º 57' 20'' E, 30º 11' 39'' N) from 2020 to 2022. Quetta city has a cold-winter Mediterranean climate having dry warm summers and cold rainy winters. Snowfall also occurs in winter. This city receives less than 250 mm of rainfall per year. The rainfall during study period is given in Figure 1.

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2.2. Formation of composted manures and their co-compost with biochar

The feedstock for biochar was the wood of the wild tree *Acacia nilotica* L. This biochar was purchased from the timber market of Quetta city as leftover broken pieces. This biochar is produced on commercial bases in Sindh province (near the city of Karachi), Pakistan. It is produced at 400 – 450 °C in underground kilns, known as "Bhatti" in local language. The manures were obtained from the farms of sheep and goats (SG), dairy cattle (FYM), and poultry (PM). These manures were air-dried and separately put in 200-liter capacity large plastic containers. Meanwhile, these air-dried manures were separately mixed with the finely crushed biochar at a 1:1 ratio. These manure-biochar mixtures (presented as SG-B, FYM-B and PM-B) were separately placed in plastic containers (200-liter capacity). Tap water was added in containers to the amount of complete submersion of manures and manure-biochar mixtures. After thorough mixing with water, they were left in the open air for six months. Water was added in drums every week to avoid drying of fertilizers followed by their thorough mixing with water. The process of composting of manures and co-composting of manures with biochar was started in January. After six months, composts and co-composted biochar fertilizers were left in drums for air-drying. The chemical properties of the composted manures and their co-compost with biochar are provided in Table 1.

2.3. Experimental design and treatment

In this trial, saline soil was transported from an agricultural farm in Mulkiyar village, Balochistan, Pakistan. This agricultural farm is at approximately 30 km distance of the research farm of this study and is under the similar climatic condition as of Quetta city. This soil was collected from 0-20 cm depth and had natural $EC_{1:2}$ of 1.95 dS m^{-1}. The research trial on saline soil was not conducted in the agricultural farm at Mulkiyar village due to security reasons (possible vandalism of experiment by local people). The non-saline soil was not transported, and the non-cultivated area of the study site was prepared for this experiment. The non-saline soil and saline soil were Haplic Yermosols (Brown Chernozem), calcareous silt loam. The properties of the non-saline soil and saline soil are given in our published report [29]. Briefly, the non-saline soil had pH; 7.9, $EC_{1:2}$; 0.25 dS m^{-1}, soil organic matter (SOM); 9.9 g kg^{-1}, 500 g kg^{-1} silt, and 50 g kg^{-1} clay. The slightly saline soil had pH; 7.23, $EC_{1:2}$; 1.95 dS m^{-1}, total dissolve salts; 812 ppm, SOM: 30.9 g kg^{-1}, 475 g kg^{-1} silt, and 50 g kg^{-1} clay. Saline soil was spread over the soil surface as approximately 10 inches thick layer before the establishment of plots for experiment purposes. Twenty-one plots of 1×1m size were established on non-saline soil and the same number of plots were made on saline soil. A buffer of ~0.25m was made between plots using bricks to avoid lateral movement of water between plots. The study trial was conducted using a randomized complete block design (RCBD) with three replications of each treatment (Supplementary Figure 1). The treatments were (1) control (no fertilizer amendment), (2) composted manure from sheep and goat (SG), (3) composted manure from cow and buffalo (FYM), (4) composted manure from poultry (PM), (5) co-composted biochar with SG (SG-B), (6) co-composted biochar with FYM (FYM-B), and (7) co-composted biochar with PM (PM-B). During the first sampling year, 1.5 kg (15 t ha $^{-1}$) of these fertilizers were added to plots. As this amendment rate of fertilizers did not increase the yield of saffron stigma of the first-year crop, we increased the amount of fertilizers for the second-year crop to 5 kg per plot (50 t ha ^{1}) (Table 3). Each plot received the same fertilizer as of previous year. Fertilizers were added in the first week of August. After the addition of fertilizers, they were mixed in soil up to a depth of 10 cm.

2.4. Cultivation of Saffron

Saffron corms were obtained from the BARDC Quetta. Those corms were imported from Iran. The corms were treated with fungicide (Mexal, 72% WP, chemical composition; Mancozeb 640 g kg $^{-1}$ (64% w/w), Metalaxyl, 80 g kg $^{-1}$ (8% w/w)) for approximately 30 minutes before planting to avoid fungal infection. Inside each plot, four rows were made, and within each row, four corms with a distance of 25 cm were placed in 5-6 inches deep pits (Supplementary figure 2). There were sixteen corms in each plot. After the planting of corms, the plots were irrigated immediately. Later on, plots were irrigated once or twice per week.

2.5. Harvest of stigmas and estimation of the agronomic efficiency ratio

For the first-year crop, corms started germination in October 18, 2020, and flower emergence was recorded in October 28, 2020. The flowering period lasted for 19 days and was completed in November 23, 2020. Leaf emergence for the second-year crop began in October 8, 2021. Flower emergence began in October 20, 2021, lasted for 18 days, and ended in November 12, 2021. Saffron flowers were hand-picked daily, the stigmas were separated manually, and their fresh weight was recorded.

The agronomic efficiency ratio (AE) based on the two-year cumulative saffron stigma yield was calculated according to Baligar et al. [30] and is presented below.

$$AE\ (control\ treatment) = \frac{Two\ years\ cumulative\ yield\ of\ control\ treatment}{Nitrogen\ (or\ bioavailable\ phosphorus\ in\ soil)} \quad \text{……………………..} \quad (1)$$

$$AE\ (fertilizer\ treatments) = \frac{Yield\ under\ fertilizer\ treatment - yield\ under\ control\ treatment}{Nitrogen\ (or\ bioavailable\ phosphorus\ in\ organic\ fertilizers\ applied)}\ (2)$$

2.6. Nutrient Analysis and Nutrient Use Efficiency of Saffron

After the completion of vegetative growth of the second-year crop (end of March), leaves were harvested from each plot. Leaves were oven-dried at 60°C for 48h. The dry biomass of leaves from each plot was recorded. The leaves were ground to homogeneous powder and sent to the Pakistan Agricultural Research Council (PARC) Islamabad for analysis of nitrogen and phosphorus. The concentrations of sodium (Na) and potassium (K) in leaves of saffron were analysed following the protocol of Estefan et al. (2013).

The nitrogen or phosphorus use efficiency was calculated according to Baligar et al. [30] as;

$$NUE\ (N, P, Na\ and\ K) = \frac{leaf\ biomass}{N\ (or\ P, Na\ or\ K)\ in\ leaf\ tissue} \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

2.7. Soil sampling and analysis of chemical properties

After two years of cropping and harvesting of leaves, in April 2022, soil samples were collected from the centre of each plot from 0-10 cm depth. Subsequently, the samples were air-dried and sieved through a 2-mm mesh sieve. The air-dried soil samples were analyzed for pH, EC (soil samples were prepared as the mixture of soil and water at 1:2 soil:water ratio), and concentration of sodium (Na), potassium (K), mineral nitrogen and Olsen phosphorus. The protocols described by Estefan et al. (2013) were followed for the chemical analysis of soil samples. All soil chemical analyses were performed in the Soil Analysis Laboratory, Agricultural Research Institute (ARI), Quetta, Balochistan, Pakistan.

2.8. Statistical analysis

Data sets were analyzed for the normality test using the D′Agostino-Pearson K^2 test. Data sets of the concentration of nitrogen and phosphorus in leaves were log and square root transformed respectively before analysis. The values in tables and figures are based on non-transformed data. The data for an annual fresh yield of stigma were subjected to three-way analyses of variance (ANOVA) under a randomised complete block (RCB) design; where the factors were treatments, soil (non-saline and saline) and years of cropping. The data for two years of cumulative yield of stigma, concentration of nitrogen and phosphorus in leaves, nitrogen and phosphorus use

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efficiency of leaves and the concentration of mineral nitrogen and Olsen phosphorus in non-saline and saline soil were subjected to two-way ANOVA under RCB design; where, factors were fertilizers and soil (non-saline and saline). The differences between treatments were measured using the least significance difference test (LSD). Since the data of agronomic efficiency were not normally distributed and the variations within the data set were huge, a comparison between data sets was made using the non-parametric Kruskall-Wallis Test. The treatments with overlapping range values were not significantly different, whereas, the treatments with non-overlapping values were significantly different. CoSTAT and Microsoft Excel were used for statistical analysis.

3. Results

3.1. Stigma fresh weight

In non-saline soil, compared to control treatment, amendment of all fertilizers significantly decreased the yield of fresh stigma by 15% – 49% ($P \leq 0.05$; Table 1). For first-year crop grown in non-saline soil, the stigma yield was lower in the PM-B treatment than in all other treatments ($P \leq 0.05$; Table 2). The difference between treatments was non-significant for the first-year crop grown in saline soil and the second-year crop grown in non-saline soil ($P \leq 0.05$; Table 4). For the second-year crop of saline soil, amendments of FYM and PM fertilizers considerably increased yield compared with the control by 44% and 41% ($P \leq 0.05$; Table 2). No difference in fresh stigma yield was observed between saline and non-saline soil for a given treatment except SG treatment. The yield of first-year crop in non-saline soil under SG treatment was significantly higher than in saline soil by 32% ($P \leq 0.05$; Table 2). The two-year cumulative fresh yield of stigma in non-saline soil showed that FYM, PM, and FYM-B reduced the yield compared with the control treatment ($P<0.05$; Table 2). However, for saline soil, no differences between treatments were observed (Table 2). The fertilizer × soil type (non-saline and saline) interaction was significant ($P<0.05$) for two years and for cumulative of two years data of saffron stigma fresh yield. The stigma fresh yield was significantly lower in saline than in non-saline soil ($P<0.05$). All fertilizer treatments reduced the agronomic efficiency ratio (AE) for nitrogen and phosphorus (Figure 2).

3.2. Nutrient Uptake and nutrient use efficiency of saffron leaves

In non-saline soil, the SG-B increased, whereas PM-B decreased the concentration of nitrogen in saffron leaves compared with the control treatment by ~8% ($P<0.05$; Table 3). Compared with the control, all treatments (except SG) increased the concentration of phosphorus in saffron leaves by 62% - 43% in non-saline soil; whereas in saline soil, only PM-B increased the concentration of phosphorus by 40% - 64% compared with all other treatments ($P<0.05$; Table 3). The fertilizer treatment × soil (non-saline and saline) interaction for the concentration of nitrogen and crude protein was non-significant ($P<0.05$). However, fertilizer treatment × soil (non-saline and saline) interaction for the concentration of phosphorus was significant ($P<0.05$) and the concentration of phosphorus in leaves of non-saline soil was significantly higher than the leaves of saline soil ($P<0.05$).

For the crop grown in non-saline soil, a significant difference in nitrogen use efficiency was observed between the SG and FYM-B treatments only. The NUE of leaves was lower in the SG treatment than in the FYM-B treatment ($P<0.05$; Figure 2). No difference between treatments for NUE was observed for crops grown in saline soil (Figure 2). The results for PUE were also not consistent in non-saline and saline soil. For non-saline soil, all treatments except SG increased PUE compared with the control ($P<0.05$; Figure 2). In saline soil, only PM-B fertilizer increased the PUE of leaves compared with all other treatments ($P<0.05$); whereas no difference between other treatments in this regard was observed (Figure 2).

For the plants grown in non-saline soil, the concentration of Na in plant tissues was significantly lower in the control treatment than in SG, FYM, PM and FYM-B treatments ($P<0.05$; Table 3). No difference between treatments was observed for saline soil regarding the concentration of Na in the leaves of saffron (Table 3). Likewise; for a given treatment, no difference was observed between crop grown in saline versus crop grown in non-saline soil about the concentration of Na in leaves (Table 3).

Regarding the concentration of K in the leaves of saffron, no difference between control and fertilizer treatments was observed for both saline and non-saline soil (Table 3). Furthermore, except for the plants grown under control, SG-B and PM-B treatments in saline soil, which showed a significantly higher concentration of K than the plants grown in non-saline soil under the same treatments, no difference between non-saline versus non-saline soil was observed for other treatments (Table 3).

3.5. Chemical properties of the soil

The pH of soil was not different between treatments for both non-saline soil and saline soil; however, the pH of non-saline soil was significantly higher than the pH of saline soil ($P<0.05$;

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Table 5). The non-saline soil under PM treatment had approximately 2 – 4 times higher EC than all other treatments except FYM ($P<0.05$; Table 5). For saline soil, FYM-B treatment reduced EC than control by 31% ($P<0.05$; Table 5). The soil x treatment interaction was significant; non-saline soil under control, SG, SG-B and PM-B treatments had significantly lower EC than saline soil under the same treatments ($P<0.05$; Table 5). No difference between treatments was observed for the concentration of Na in non-saline soil; however, in saline soil, SG-B significantly increased the concentration of Na than SG ($P<0.05$; Table 5). The concentration of Na was significantly higher in saline than non-saline soil under all treatments ($P<0.05$; Table 5).

For the non-saline soil, all treatments significantly increased the concentration of K in soil by 47 to 65% than control ($P<0.05$; Table 5); however, no difference between composted fertilizers and their co-compost with biochar was observed (Table 5). For the saline soil, as was observed for non-saline soil, all fertilizer treatments significantly increased the concentration of K than control by 44 to 69% ($P<0.05$; Table 5). However, contrary to the results of non-saline soil, the co-compost of SG and FYM with biochar further increased the concentration of K than these composted manures ($P<0.05$; Table 5).

No difference between treatments was observed for the concentration of mineral nitrogen in non-saline soil. However, for saline soil, except SG and FYM, all other treatments significantly improved the nitrogen concentration in soil compared to the control ($P<0.05$; Table 5). All treatments, except SG, significantly increased the concentration of Olsen phosphorus than control in non-saline and saline soil ($P<0.05$; Table 5). Compared with simple manure compost, amendments of co-composted biochar with FYM and SG significantly increased the concentration of P in non-saline and saline soil ($P<0.05$; Table 5). The highest concentration of P was observed for PM treatment in non-saline and saline soil. The fertilizer treatment × soil (non-saline and saline) interaction for nitrogen was significant but for phosphorus, this interaction was non-significant ($P<0.05$). The non-saline soil had a significantly higher concentration of nitrogen than saline soil ($P<0.05$).

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4. Discussion

4.1. Fresh yield of saffron stigma and agronomic efficiency influenced by organic amendments

A significantly lower yield of saffron stigma under saline control than non-saline control treatment for the first and the second year crop was observed. Although the EC of saline soil was further reduced over time (from 1.95 dS m^{-1} before sowing of corms of first year crop to 1.36 dS m^{-1} when the leaves of second year crop were harvested), the reduction in fresh yield under saline soil indicates that saffron yield was sensitive to high EC soil conditions. Our results are in agreement with the findings of Yarami and Sepaskhah [11], who found significant reduction in stigma yield of saffron under ECe of 1:1 dS m^{-1}. However, the amendment of fertilizers for two consecutive years attenuated high EC stress on this crop, which resulted in a significant increase in the yield under FYM and PM treatments than control. Furthermore, no differences in stigma yield under fertilizer treatments between non-saline soil and saline soil were observed. This indicates that these organic fertilizers played a substantial role in attenuating the high soil EC stress on saffron. Our results are in agreement of the findings of Yarami and Sepaskhah [11] and Hashemi et al. [14] that organic (manure) and synthetic fertilizers reduce the salinity stress in saffron.

Over two years of amendment of organic fertilizers, non-consistent results were observed over space (non-saline and saline soil) and time (years). Unexpectedly, the first-year crop was grown in non-saline soil, and compared with the control, a significant reduction in saffron fresh stigma yield was observed when organic fertilizers were amended. The reduction in yield was 14% to 60%. Furthermore, the amendment of poultry manure co-composted with biochar (PM-B) resulted in the lowest yield of all treatments, including the control. However, when these fertilizers were amended the following year, no reduction was observed, and the results were non-significant for yield. Over two-year cumulative yield also showed a significant reduction in yield for FYM, PM, and FYM-B treatments compared with the control treatment by 27, 26.7 and 39%, respectively. In contrast, crops grown in saline soil showed no significant difference in stigma fresh yield between treatments for the first-year crop. Interestingly, for the second-year crop, these fertilizers i.e., FYM and PM significantly increased yield by 44% and 41%, respectively compared with the control, whereas no difference between organic fertilizer treatments was observed. For the second-year crop, no difference between treatments was observed. Likewise, no difference in over two-year cumulative fresh stigma yield was observed. The agronomic efficiency ratio (based on over two-year cumulative yield and the total N or P applied to soil from fertilizers) of saffron leaves for both

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nitrogen and phosphorus was significantly lower under fertilizers than under control treatments in non-saline soil and saline soil. We attribute this result to the non-significant or lower stigma yield (FYM, PM and FYM-B) under fertilizer treatments in non-saline soil and non-significant effect of fertilizers on stigma yield in saline soil.

Our results are not consistent with the general findings that the amendment of biochar-based fertilizers improves the yield of crops, including saffron, and improves the agronomic efficiency of crops [32-34]. The extensive review of Agegnehu et al. [33] and Sánchez-Monedero et al. [34] suggested that composted manures, a mixture of biochar with compost, or manure co-composted with biochar tend to increase soil fertility and crop yield more than when only biochar is applied to the soil. However, we did not observe a positive influence of these composted manures or their co-composting with biochar on the yield of saffron in non-saline soil. Empirical evidence shows that paper mill-derived biochar produced at low production temperatures (300-400 °C) reduced the yield of corn but had no negative influence on the same crop when this feedstock was pyrolyzed at higher production temperatures (>450^{o}C) [35]. Another study showed that biochar produced from paper mills reduced the yield of radish and wheat in calcarosol, which had low soil organic matter (20.3 g kg^{-1} soil) but improved the yield of soybean and radish in ferrosol, which had a higher concentration of organic matter (36 g kg^{-1} soil) [36]. The biochar used in our study was slow pyrolyzed at 400-450 °C and the soil organic matter of non-saline soil was many times lower than saline soil (9.9 g kg^{-1} soil in non-saline soil and 30.9 g kg^{-1} in saline soil). The low production temperature of wood-derived biochar and the difference in the concentration of soil organic matter in non-saline versus saline soil may explain the reduced yield of saffron compared with the control in non-saline soil, which showed reduced yield in response to the amendment of organic fertilizers. The extensive literature review by Gul and Whalen [37] also suggests that the positive influence of biochar-based fertilizers is generally observed in soils with high organic matter concentrations. The other reason for the reduced yield in the non-saline soil of the first-year crop could be that we applied fertilizers to the soil and sowed the corms at the same time. Empirical evidences suggest that organic fertilizers increase soil fertility when they are amended few months before sowing of crops [38]. This will allow nutrients from the organic fertilizers to get released in soil. Van Es et al. [38] found that the timing of application of dairy manure in soil had a significant influence on soil fertility in the order of fall > spring. Moreover, the results were consistent for two different soils; Stafford loamy sand and Muskellunge clay loam. Because organic fertilizers capture

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nutrients and act as slow-release fertilizers [39], in non-saline soil, which had a low concentration of soil organic matter, the application of organic fertilizers (and the sowing of corms at the same time) might had caused temporary nutrient limitation to saffron. This might had resulted in a reduced yield of saffron stigma.

4.2. Nutrient uptake by leaves and nutrient use efficiency of leaves

We analysed nitrogen and phosphorus concentrations in leaves of the second-year crop when leaves were mature (in March 2022 when leaves stopped further growth and about to senescence in April). The results showed that two years of consecutive amendment of SG-B in non-saline soil, whereas FYM-B and PM-B in saline soil, increased nitrogen uptake than control by 8%, 12%, and 16% respectively. The PM-B treatment showed reduced N uptake compared with the control and SG-B in non-saline soil by 7% and 15.5%, respectively. No difference in nitrogen use efficiency (NUE) between fertilizers and control treatment was observed for the crop grown in non-saline soil. Interestingly, no difference in the concentration of mineral nitrogen in soil was observed between treatments for experiments conducted in non-saline soil.

For saline soil, the results are not similar to those observed for non-saline soil. PM, FYM-B, and PM-B significantly increased the uptake of N compared with the control treatment by 13, 11.7 and 16%, respectively. In contrast, FYM reduced N uptake more than control, PM, FYM-B and PM-B by 5, 18, 16 and 20%, respectively. No difference in NUE between the treatments was observed. Interestingly, these treatments, i.e. PM, FYM-B, and PM-B, also increased the concentration of mineral nitrogen in the soil compared with the control and FYM treatments. However, this increase in N was not reflected in the NUE of plants grown in soil amended with these fertilizers (Figure 2).

Regarding the uptake of phosphorus, all treatments except SG increased P uptake than control by 44% - 57%. On the other hand, SG treatment reduced N uptake more than all other treatments by 30% - 73%. For saline soil, as observed for N uptake, the results are not similar to those was observed for non-saline soil (Figure 2). In saline soil, only PM-B increased the uptake of P more than all other treatments by 2-3-fold. The concentration of Olsen phosphorus in soil was 2 to 6-fold higher in response to the amendment of fertilizers than in the control, except for SG fertilizer, which did not increase Olsen P concentration than in the control in both non-saline soil and saline soil. Interestingly, the amendment of co-composted biochar significantly increased the concentration of Olsen P than when simple manures were amended (SG versus SG-B, FYM versus

FYM-B, PM versus PM-B). Furthermore, the results for Olsen P were consistent in both non-saline soil and saline soil. All treatments except SG (which showed reduced PUE), increased the PUE of leaves compared with the control in non-saline soil. SG treatment also did not increase bioavailable P concentration in non-saline and saline soil and reduced the uptake of P in leaves in non-saline soil. In saline soil, only PM-B fertilizers improved the PUE of leaves compared with all other treatments (Figure 2).

The concentration of K in leaf tissues of saffron was not different between treatments in both non-saline soil and saline soil. Similarly, no difference between treatments was observed regarding the concentration of Na in the leaf tissues of saffron for saline soil. However, significantly higher concentration of Na was found in saffron leaves grown in non-saline soil under all the composted fertilizer treatments i.e. SG, FYM, PM and co-composted fertilizer treatment FYM-B. This high concentration of Na in leaf tissues also caused the significantly lower K:Na ratio in leaves (except for FYM treatment). The Na and K are important nutrients of plants. However, under high concentration of Na in soil solution due to high salinity or sodicity, reduces the uptake of K by plants [15]. Furthermore, high uptake of Na results in a lower cellular K:Na ratio, which reduces the cellular metabolic activities and in return negatively influences the growth and yield of crops [15]. Although the uptake of Na was higher and the K:Na ratio was lower in the leaves of saffron under these fertilizer treatments in non-saline soil, this factor however did not reduce the yield of saffron of second year crop. Unfortunately, we do not have data of the first year crop, when all fertilizer treatments significantly reduced the yield of saffron stigma, which in return resulted in the reduction in the two years combined yield of stigma. We hypothesize that these fertilizers might had cause the similar effect of higher Na uptake and lower K: Na ratio in leaves of first year crop. This may be the reason that the yield of saffron stigma of first year crop and the cumulative yield of two years crop in non-saline soil was significantly lower under composted fertilizer treatments i.e. SG and FYM and co-composted treatment FYM-B than control treatment. This negative influence of these fertilizers was however not observed in non-saline soil. This is apparent from our study that organic amendments caused high uptake of Na by saffron plants in non-saline soil, which had low concentration of SOM (9.9 g kg^{-1} soil). In the saline soil, these amendments however did not cause the same effect on the uptake of Na by leaves of saffron. The possible reason might be the concentration of SOM, which was three times higher in saline (30.9 g kg^{-1})

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than in non-saline soil. This high concentration of residual SOM in saline soil, might have resulted in the normal uptake of Na and K by leaves of saffron.

4.3. Influence of fertilizers on the chemical properties of soil

The consecutive two-year amendment of organic fertilizers did not influence the pH of the soil. However, in non-saline soil, the PM fertilizer increased and in saline soil, the FYM-B fertilizer decreased EC significantly by 45 and 31% respectively. Not only that FYM-B reduce the EC in saline soil, but it also caused the highest increase (39%) in the concentration of soil mineral N. Next to the PM fertilizer, this fertilizer also caused the highest increase in the concentration of bioavailable P and K by 75% and 60% respectively in saline soil. We attribute this positive influence of FYM-B fertilizer on soil nutrients to its influence in the reduction of EC of saline soil, which might have promoted the microbial processes involved in the biochemical cycling of these nutrients. Unfortunately, due to time and funding limitations, we could not test our hypothesis in this regard; however, there is ample empirical evidence that suggests that biochar co-composted with manures or mixed with manures improves microbial processes and the concentration of bioavailable nutrients in saline soils [40-42]. The highest positive influence on soil nutrients specifically P and K was observed for PM fertilizer in both non-saline soil and saline soil. In non-saline soil, this fertilizer did not increase the concentration of mineral N but caused an approximately 44-fold increase in the concentration of P and a 22-fold increase in the concentration of K in the soil. Likewise, all fertilizers increased many fold the concentration of P and K than control treatment in both non-saline soil and saline soil. Our results agree with other published reports that the amendment of co-composted biochar and composted manures increases the concentration of bioavailable nutrients [41, 43].

5. Conclusions

The results of present study suggest that high EC soil condition significantly reduced the stigma yield of saffron. Although, over time the high EC of soil further dropped down to 1.36 dS m^{-1} in control plot, stigma yield was significantly lower in saline control than non-saline control plot. This suggests that saffron was sensitive to high EC soil conditions. As hypothesized, the two-year continuous amendment of composted manures PM and FYM increased significantly the stigma yield than control treatment in saline soil. This finding suggests that these fertilizers attenuated the high EC soil conditions on saffron. In the non-saline soil, which had a very low concentration of SOM (9.9 g kg^{-1} soil), fresh amendment (amended at the same time as corms were sowed) of these fertilizers significantly reduced stigma yields than control treatment. The second-year amendment, however, did not reduce yield and caused a non-significant influence on yield than control. In saline soil, which had approximately three times higher concentration of SOM (30.9 g kg^{-1} soil), the first-year amendment of these fertilizers did not increase yield but the second-year amendment of composted PM and FYM fertilizers increased the yield by 41%. This indicates that the positive influence of these amendments appeared with time when they were amended continuously. In non-saline soil, composted manures and FYM-B significantly increased the uptake of Na and reduced the K:Na ratio in leaves of second-year crop. This may be the reason for the reduction in the two-year cumulative yield of saffron stigma to control treatment. Furthermore, in non-saline soil, organic fertilizers did not increase the agronomic efficiency and nutrient use efficiency of leaves for nitrogen and phosphorus, except PM-B fertilizer, which increased the PUE of leaves than control. However, in saline soil, all organic amendments significantly increased the PUE of leaves than control. Our study shows that in the infertile soil with low SOM concentration, fresh amendment of these fertilizers may cause high uptake of Na by crops and may affect negatively the yield of crops. Despite these findings, organic fertilizers increased many fold the concentrations of bioavailable P and K in both non-saline soil and saline soil. Based on our findings, we recommend that these fertilizers may be amended at least for three consecutive years to check if their positive influence appears over time on saffron. We recommend that these fertilizers need to be amended few months before the sowing of corms.

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Table 1: The pH, ash (%),total nitrogen (N), total phosphorus (P), total sodium (Na), total potassium (K) in fertilizers, two years amendment rate of fertilizers, and the total amount of N, P, Na and K input in soil from the fertilizers that were amended in soil for two consecutive years.

Treatment	pH	Ash (%)	Total N in fertilizer (mg kg^{-1})	Total P in fertilizer (mg kg^{-1})	Total Na in fertilizer (mg kg^{-1})	Total K in fertilizer (mg kg^{-1})	Fertilizer input (t ha^{-1})	Total N input in soil from fertilizer (kg ha^{-1})*	Total P input in soil from fertilizer (kg ha^{-1})*	Total Na input in soil from fertilizer (kg ha^{-1})*	Total K input in soil from fertilizer (kg ha^{-1})*
SG	8.400	28.50	5.166	2.188	15.64	17.88	65.00	0.336	0.142	1.016	1.162
FYM	7.880	8.490	6.940	3.831	17.39	14.22	65.00	0.451	0.249	1.130	0.924
PM	7.960	78.90	14.89	7.829	11.42	13.30	65.00	0.968	0.509	0.742	0.864
SG-B	8.090	17.60	5.100	3.402	13.75	13.40	65.00	0.331	0.221	0.893	0.871
FYM-B	7.810	21.80	1.360	1.366	10.69	12.79	65.00	0.088	0.088	0.694	0.831
PM-B	8.370	75.30	3.097	1.907	13.75	8.830	65.00	0.201	0.124	0.893	0.574

*values are calculated following formula;

Total N (or P, Na or K) in fertilizers added in soil = Amount of fertilizer applied in soil × concentration of N (or P, Na or K) present in fertilizer/1000

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Table 2: Mean (±SD) fresh weight of stigmas (g m^{-2})

	First-year crop		Second-year crop		Two years cumulative- yield	
Treatments	**Non-saline soil**	**Saline soil**	**Non-saline soil**	**Saline soil**	**Non-saline soil**	**Saline soil**
Control	1.04 ± 0.21^{a}	0.76 ± 0.30	1.65 ± 0.25*	0.73 ± 0.19^{b}	2.69 ± 0.46^{a}*	1.48 ± 0.45
SG	0.79 ± 0.08^{b}*	0.54 ± 0.06	1.18 ± 0.43	0.99 ± 0.30^{ab}	1.96 ± 0.42^{b}	1.53 ± 0.30
FYM	0.70 ± 0.11^{b}	0.63 ± 0.27	1.27 ± 0.25	1.30 ± 0.37^{a}	1.97 ± 0.34^{b}	1.94 ± 0.64
PM	0.77 ± 0.13^{b}	0.70 ± 0.16	1.32 ± 0.47	1.24 ± 0.33^{a}	2.38 ± 0.92^{ab}	1.17 ± 0.34
SG-B	0.89 ± 0.36^{b}*	0.44 ± 0.11	1.49 ± 0.56	0.73 ± 0.24^{ab}	2.34 ± 1.16^{ab}	1.77 ± 0.63
FYM-B	0.74 ± 0.07^{b}	0.64 ± 0.19	1.60 ± 1.10	1.13 ± 0.45^{ab}	1.63 ± 0.51^{b}	1.62 ± 0.46
PM-B	0.42 ± 0.12^{c}*	0.65 ± 0.13	1.21 ± 0.64	0.96 ± 0.34^{ab}	2.08 ± 0.57^{ab}	1.94 ± 0.48

Values within columns with different uppercase letters are significantly different ($P \leq 0.05$). * indicates significant difference between non-saline versus saline soil for a given treatment ($P<0.05$). Columns with values without letters indicate no significant difference between treatments.

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Table 3: Mean (±SD) concentration of nitrogen and phosphorus, sodium and potassium in the leaves of saffron from the second-year crop

	Nitrogen (mg g^{-1} leaves)		**Phosphorus (mg g^{-1} leaves)**		**Sodium (mg g^{-1} leaves)**		**Potassium (mg g^{-1} leaves)**	
Treatments	**Non-saline soil**	**Saline soil**	**Non-saline soil**	**Saline soil**	**Non-saline soil**	**Saline soil**	**Non-saline soil**	**Saline soil**
Control	25.4 ± 0.58^{b}*	23.2 ± 0.38^{b}	0.294 ± 0.009^{a}*	0.335 ± 0.007^{a}	0.83 ± 0.34^{b}	1.23 ± 0.34	9.61 ± 1.06^{ab}	11.2 ± 0.77^{ab}*
SG	24.7 ± 0.89^{bc}	24.8 ± 3.73^{abc}	0.306 ± 0.018^{a}*	0.230 ± 0.008^{c}	1.97 ± 0.23^{a}	0.77 ± 0.80	10.9 ± 0.69^{a}	11.2 ± 0.90^{ab}
FYM	24.6 ± 0.85^{bc}*	22.1 ± 0.41^{c}	0.150 ± 0.004^{d}*	0.276 ± 0.011^{b}	1.84 ± 0.52^{a}	1.37 ± 0.90	9.17 ± 1.15^{ab}	12.3 ± 1.78^{ab}
PM	24.7 ± 2.53^{abc}	26.8 ± 1.00^{a}	0.177 ± 0.011^{bc}*	0.341 ± 0.011^{a}	2.17 ± 0.50^{a}	1.43 ± 1.11	10.4 ± 0.98^{ab}	11.8 ± 0.67^{a}
SG-B	27.7 ± 1.41^{a}	21.7 ± 4.84^{abc}	0.178 ± 0.010^{b}*	0.277 ± 0.009^{b}	2.11 ± 0.10^{ab}	1.57 ± 0.30	9.55 ± 0.29^{b}	11.8 ± 1.12^{ab}*
FYM-B	24.5 ± 1.15^{b}*	26.3 ± 0.13^{a}	0.165 ± 0.067^{c}*	0.332 ± 0.006^{a}	1.97 ± 0.41^{a}	1.43 ± 0.34	9.36 ± 0.90^{ab}	10.3 ± 0.55^{b}
PM-B	23.4 ± 0.98^{c}*	27.6 ± 1.00^{a}	0.128 ± 0.032^{e}	0.136 ± 0.470^{d}	1.37 ± 0.30^{ab}	1.37 ± 0.30	9.93 ± 0.11^{b}	10.8 ± 0.48^{ab}*

Values within columns with different uppercase letters are significantly different ($P \leq 0.05$). * indicates significant difference between non-saline versus saline soil for a given treatment ($P<0.05$). Columns with values without letters indicate no significant difference between treatments.

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Table 4: Mean (±SD) the K:Na ratio, sodium use efficiency (NaUE) and potassium use efficiency (KUE) of saffron leaves grown in non-saline soil and saline soil under various treatments

	K:Na		NaUE		KUE	
Treatments	**Non-saline soil**	**Saline soil**	**Non-saline soil**	**Saline soil**	**Non-saline soil**	**Saline soil**
Control	13.9 ± 8.86[a]	9.79 ± 4.01	19.4 ± 10.3[a]	13.6 ± 4.58	1.45 ± 0.25	1.43 ± 0.35
SG	5.83 ± 1.06[b]	109.0 ± 169.4	6.91 ± 1.87[bc]	119.6 ± 183.5	1.18 ± 0.25	1.10 ± 0.30
FYM	5.45 ± 2.53[abc]	14.2 ± 13.08	10.6 ± 6.12[abc]	17.3 ± 8.50	1.87 ± 0.22	1.55 ± 0.59
PM	4.95 ± 1.08[bc]	19.7 ± 23.40	6.02 ± 1.69[c]	25.5 ± 26.3	1.23 ± 0.36	1.47 ± 0.36
SG-B	5.58 ± 3.39[abc]	7.45 ± 2.18	7.58 ± 4.16[abc]	11.1 ± 2.76	1.41 ± 0.24	1.53 ± 0.45
FYM-B	4.90 ± 1.17[c]	7.44 ± 1.78	6.34 ± 0.64[c]	11.2 ± 2.24	1.35 ± 0.41	1.53 ± 0.16
PM-B	7.51 ± 1.86[ab]	8.26 ± 2.30	10.3 ± 2.40[ab]	14.3 ± 6.76	1.39 ± 0.26	1.69 ± 0.54

Values within columns with different uppercase letters are significantly different ($P \leq 0.05$). * indicates significant difference between non-saline versus saline soil for a given treatment ($P<0.05$). Columns with values without letters indicate no significant difference between treatments.

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Table 5. Mean ± standard deviation of pH, electrical conductivity (EC; dS m^{-1}), sodium (Na; mg kg^{-1} soil) and potassium (K; mg kg^{-1} soil) of soil samples taken after harvest of leaves of second year crop in April 2022.

Treatment	pH		EC		N		P		Na		K	
	Non-saline soil	Saline soil	Non-saline soil	Saline soil	Non-saline soil	Saline soil	Non-saline soil	Saline soil	Non-saline soil	Saline soil	Non-saline soil	Saline soil
Control	8.7 ± 0.18*	8.2 ± 0.08	0.87 ± 0.16^{b}*	1.36 ± 0.17^{a}	0.55 ± 0.12	0.37 ± 0.09^{d}	1.81 ± 0.91^{e}	1.92 ± 0.62^{e}	171 ± 21.9*	247.3 ± 13.6^{ab}	78.9 ± 5.36^{d}	75.1 ± 7.35^{e}
SG	8.7 ± 0.08*	8.1 ± 0.17	0.44 ± 0.25^{b}*	1.33 ± 0.29^{ab}	0.57 ± 0.16	0.40 ± 0.07^{cd}	2.43 ± 0.32^{e}	2.91 ± 0.57^{e}	189 ± 7*	240.3 ± 8.08^{b}	169.5 ± 11.68^{c}*	134.4 ± 7.02^{d}
FYM	8.6 ± 0.20*	8.2 ± 0.04	1.4 ± 0.43^{ab}	1.31 ± 0.41^{ab}	0.65 ± 0.17	0.39 ± 0.02^{d}	5.28 ± 1.09^{d}	5.51 ± 0.64^{d}	181 ± 14.7*	242.3 ± 12.5^{ab}	223.1 ± 14.34^{a}*	142.2 ± 8.83^{d}
PM	8.4 ± 0.25*	8.2 ± 0.14	1.58 ± 0.18^{a}	1.51 ± 0.28^{a}	0.58 ± 0.05	0.61 ± 0.12^{ab}	10.5 1.01^{a}*	9.05 0.13^{a}	180 ± 14.1*	250.6 ± 20.8^{ab}	173.4 ± 34.7^{ab}	239.6 ± 19.0^{a}
SG-B	8.5 ± 0.08*	8.2 ± 0.05	0.63 ± 0.07^{b}*	1.71 ± 0.53^{a}	0.65 ± 0.09	0.51 ± 0.06^{bc}	5.96 ± 1.11^{c}	6.88 ± 0.75^{c}	164.6 ± 20.2*	259.6 ± 5.13^{a}	150.0 ± 27.86^{bc}	153.9 ± 7.60^{c}
FYM-B	8.6 ± 0.08*	8.2 ± 0.14	0.8 ± 0.17^{b}	0.94 ± 0.16^{b}	0.56 ± 0.02	0.61 ± 0.02^{a}	7.63 ± 0.75^{b}	7.57 ± 0.27^{b}	172 ± 16.8*	242 ± 11.3^{ab}	215.3 ± 61.6^{abc}	186.1 ± 3.51^{b}
PM-B	8.6 ± 0.19*	8.3 ± 0.16	0.79 ± 0.05^{b}*	1.34 ± 0.50^{ab}	0.62 ± 0.11	0.47 ± 0.08^{ab}	9.49 ± 1.01^{a}*	7.48 ± 0.42^{b}	177.6 ± 12.8*	247.3 ± 14.5^{ab}	192.9 ± 18.5^{ab}	198.7 ± 19.1^{a}

Values within columns with different uppercase letters are significantly different ($P \leq 0.05$). * indicates significant difference between non-saline versus saline soil for a given treatment ($P<0.05$). Columns with values without letters indicate no significant difference between treatments.

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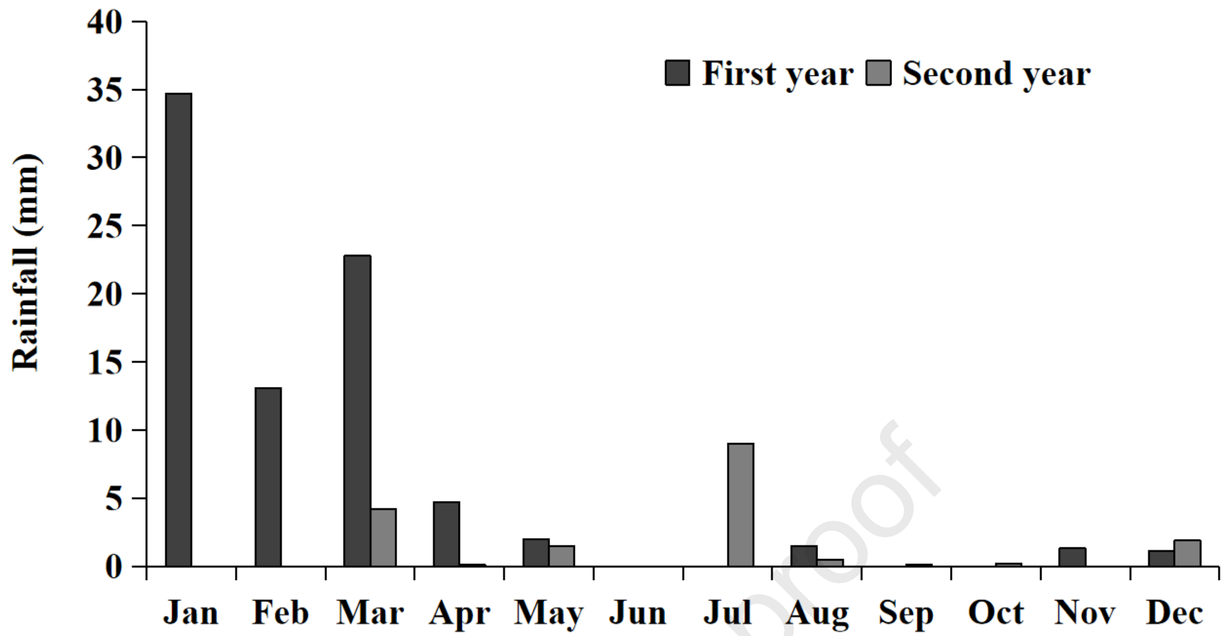

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535 **Figure 1:** Rainfall during the study period. Data obtained from https://www.worldweatheronline.com.

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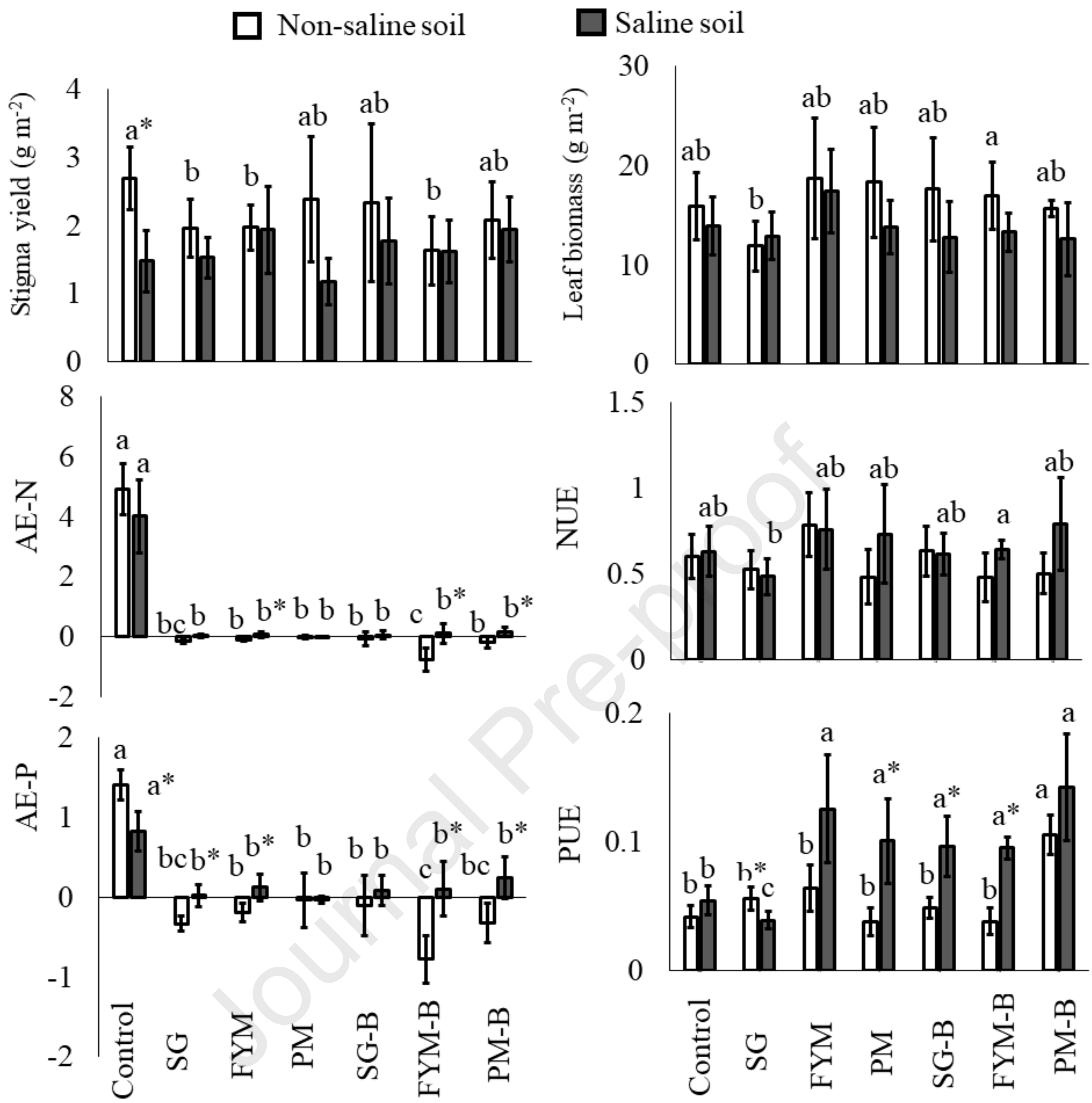

Figure 2: Mean (± SD) of stigma yield (cumulative yield of two years of cropping), leaf biomass, agronomic efficiency ratio of stigma fresh yield for nitrogen (AE-N) and phosphorus (AE-P), nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE) of saffron leaves. Within soil type, bars with different letters indicate a significant difference at $P<0.05$. * indicates a significant difference between non-saline versus saline soil for a given treatment ($P<0.05$).

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Highlights

- Soil with electrical conductivity of $EC_{1:2}$; 1.95 dS m^{-1} reduced the stigma yield of saffron.
- In soil with $EC_{1:2}$; 0.25 dS m^{-1}, with low concentration of organic matter (9.9 g kg^{-1} soil), composted manures and their co-compost with biochar reduced stigma yield of saffron of first year crop.
- In soil with low EC level, composted manures and co-composted biochar increased the concentration of sodium and reduced the K:Na ratio in leaves.
- Positive effect of fertilizers was observed for the second year crop in the soil with high EC and high concentration of organic matter.
- Two years of fertilizer amendment increased significantly the concentration of bioavailable phosphorus and potassium.

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Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Shagufta Qasim reports equipment, drugs, or supplies and writing assistance were provided by Agricultural Research Institute, Quetta, Pakistan. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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