Research Article

Effect of Potassium Sources and Soil Calcareous Levels on Sunflower (*Helianthus annuus* L.) Growth at the Early Stage

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Abstract | The arid and semi-arid climate and geology of Pakistan have caused the formation of calcareous soils on many regions. High calcium amount in soil solution suppresses potassium (K) uptake by plants possibly due to K-fixation and variation in cation ratios. Soils in country are thought to be well supplied with K, little or no K fertilizer is applied to majority of the crops, including sunflower. However, recent studies have shown that the sunflower is becoming more responsive and exhibiting superior growth and yield with the addition of K. To determine the impact of K fertilizer sources on the growth and development of sunflower seedlings on artificially established calcareous soils, we carried out a pot study. The experiment included two K sources, sulphate of potash (SoP), and muriate of potash (MoP), and four different lime content levels (<5, 10, 20 and 30%). The results showed that increasing levels of lime decreased growth parameters viz. shoot height, root length, fresh shoot weight, dry shoot weight, fresh root weight, and dry root weight in sunflower seedlings. Similarly, shoot K content was also decreased by 30.44% at increased lime content level (30%) over control, and chlorophyll concentration in leaves declined with increasing% of lime in comparison with the control. Moreover, when compared to the control, SoP application resulted in greater growth parameters, followed by MoP. Further K treatment also increased in K content in shoots and leaf chlorophyll concentration. The shoot K content was increased by 31.14% with SoP and 13.92% with MoP, and chlorophyll concentration by 24.52% with SoP, and 12.06% with MoP compared with the control. The findings concluded that under calcareous soil conditions, K fertilization either in the form of SoP or MoP could more effectively promote sunflower seedling growth.

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Introduction

Calcareous soils are soils that contain calcium carbonate ($CaCO_3$) in one or more on their horizons, with concentrations ranging from a few to 95% (Weil and Brady, 2017). High amount of $CaCO_3$ affect the physicochemical characteristics of soil, reducing crop productivity due to high soil pH,

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low nutrient availability and cycling, and reduced microbial activity (Taalab *et al.*, 2019; Babar *et al.*, 2022; Narayanasamy *et al.*, 2023; Wang *et al.*, 2023). The fixation of K and variation in basic cation ratios limit the concentration of K in the soil solution for plant uptake (Wakeel *et al.*, 2017). With the increasing global population demands of agriculture foods are growing and further widening is the gap between agricultural output and food demand, calling for the implementation of smart practices like increased fertilizer use efficiency to lessen the impact of calcareous soils on crop output (Abbasi *et al.*, 2022; Naorem *et al.*, 2023).

Calcareous soils cover roughly about 1.5 billion acres or 30 percent of world land surface, mainly in the arid and semi-arid areas (Leytem and Mikkelsen, 2005; Taalab *et al.*, 2019). Generally, calcareous soils more extensively present in Asian, African, European and American continents, and countries including USA, Iran, Iraq, Jordan, Oman, Lebanon, Sudan, Egypt, Afghanistan, Cyprus, Libya, Qatar, Saudi Arabia, Sudan, Somalia, Bulgaria, Turkey, Syria, India, Bangladesh and Pakistan (FAO, 1973). These soil types are most prevalent in Pakistan's arid and semi-arid regions (Rashid, 2005; Wakeel *et al.*, 2017). Most of the areas in lower Sindh are also reported as moderately to strongly calcareous in nature (Chohan *et al.*, 2015; Talpur *et al.*, 2016).

Potassium is known as a vital plant nutrient that contributes to sustainability by aiding in the development of plants, enhancing agricultural yield and quality, and enhancing soil health (Wakeel *et al.*, 2017). Potassium plays important roles in photosynthesis, ionic equilibrium, protein synthesis, nutrient translocation, stomatal regulation, water usage, and enzyme activation for the formation of ATP, starch in grains, sugar translocation, photosynthesis, and protein synthesis (Wolde, 2016). There are several ways in which plants can benefit from it, including the improvement in water utilization efficiency, and the increased resistance to biotic and abiotic stressors (Das *et al.*, 2022). K is a crucial macronutrient and osmotically active substance that aids plants in adjusting to reduce water potential during drought stress (Bukhsh *et al.*, 2012). It is possible for plants lacking sufficient potassium to experience stunted growth, low yields, and increased vulnerability to pests and diseases (Das *et al.*, 2022). We might be able to help maintain and protect natural resources for future generations by adopting sustainable agriculture practices that encourage potassium usage.

Besides several other issues (high pH, low N, P and organic matter), the problem of K availability and uptake by plants in calcareous soils has extensively been noticed and reported in the world mainly due to antagonistic relationship with other basic cations i.e., Na^+, Ca^{2+} and Mg^{2+} present in such soils (Ertiftik and Zengin, 2015; Narayanasamy *et al.*, 2023). The majority of the K in plant tissue is absorbed by roots from the soil solution as a monovalent cation, and the rate of absorption is controlled by environmental and plant factors (Jan and Hussan, 2022). Even though K is typically abundant in calcareous soils, a large amount of soil K is nevertheless unavailable to plants due to imbalances between available Ca^{2+}, Mg^{2+}, and K ions that may result in K deficit through competitive uptake interactions (Weil and Brady, 2017).

Exhaustively cultivated calcareous soils in Pakistan generally get insufficient and or no inputs of K fertilizer despite the fact, plants absorb K significantly (Wakeel *et al.*, 2017). The K status of the soil may possible be adversely affected by intensive farming without K application over time due to the potential mining of indigenous K reserves (Das *et al.*, 2018). Generally, the growers apply fertilizers without following recommended sources, rates, methods and time of application. To some extent the growers apply nitrogenous and phosphatic fertilizers on large scale, however they regret to apply K fertilizers to their field crops with a general perception that K is adequate and enough for field crops to be grown on their soils (Chajjro *et al.*, 2013; Wakeel *et al.*, 2017).

The objective of this research was to assess the impact of potassium fertilizer sources on the growth and development of sunflower seedlings on artificially established calcareous soils with range of $CaCO_3$ levels. Two K sources namely SoP, and MoP were tested in four different artificially prepared $CaCO_3$ levels (<5, 10, 20 and 30%). A successful source of K could improve sunflower seedling growth in high calcareous soils.

Materials and Methods

In order to select the effective K source to improve sunflower growth in developed calcareous soils at early stage this trial was carried out in a wire-house of the Department of Soil Science, SAU, Tandojam, Pakistan under natural sunlight. The growth period was 25th February 2018 to 6th April 2018. The average maximum temperature during the experiment was between 28.6 and 39.5°C, the average lowest temperature was between 20.6 and 28.5°C, and the average relative humidity was between 31 and 49%. In plastic pots measuring 24 cm in diameter and 28 cm deep, five kilograms of soil material was placed. Using 70% of the field capacity of soil in plastic pots, all plants were irrigated every day with tap water.

Preparation of calcareous soil

The technique described by Osman *et al.* (1978) was used to artificially prepare calcareous soils. The soil used in the experiment (Table 1) was taken from the field of Latif farm. Four $CaCO_3$ levels established for the study were <5, 10, 20, and 30%. The soil of each treatment was taken and properly incorporated with the necessary ratios of pure $CaCO_3$. A steady weight of 5 kg was maintained using sand. In order to achieve equilibrium, the artificial calcareous soils were repeatedly wet and dried. The soil of each treatment was placed in 5 kg plastic pots with drainage holes at bottom. The pots were placed in the wire-house.

Experimental details

A factorial (two factors) Complete Randomized Design (CRD) with four repeats was used for the experiment. In addition to control, treatments consisted of four $CaCO_3$ levels (Slightly calcareous = <5%, moderately calcareous=10%, strongly calcareous = 20% and very strongly calcareous = 30%) and two K fertilizer sources (SoP and MoP).

Plant material and growth conditions

A local sunflower cultivar HO-1 was used in the study. The seed was obtained from Oil Seed Research Institute, Tandojam. Seed was initially surface sterilized with 5% Sodium hypochlorite (NaOCl) solution to improve the seed germination and to prevent the growth of certain microbial contaminants. In each pot, nine sunflower achene were sowed at equally spaced and roughly two centimetres deep. After two weeks of emergence, plants were thinned to obtain five seedlings of almost uniform size in each pot. Regular irrigation with tap water was given to the plants.

Fertilizer application

The suggested dose (140-70 NP kg ha^{-1}) of urea and diammonium phosphate was used, two sources of K, sulphate of potash (SoP) and muriate of potash (MoP), were also applied at the rate of 70 kg ha^{-1} at the start of the experiment.

Table 1: *Selected physico-chemical properties of the soil used in the pots.*

Parameters	Unit	Values	Categorizations	Reference
Sand	%	30	Medium texture	Bouyoucos method (1962)
Silt	%	24		
Clay	%	46		
Texture class (USDA)		Silty clay		
EC_e	(dS m^{-1})	1.67	Non saline	FAO (USDA)
pH		7.54	Slightly to Mildly alkaline	Rayment and Lyons (2011)
Organic matter content	%	0.65	Low	FAO (1980)
Lime content	%	4.98	Slightly-calcareous	Sahai (2004)
Exchangeable (NH_4OAc)	mg kg^{-1}	99	Low	Estefan *et al.* (2013)
Phosphorus (AB-DTPA)	mg kg^{-1}	1.02	Low	Estefan *et al.* (2013)
Nitrogen	%	0.030	Low	Estefan *et al.* (2013)
Soluble Ca	meq L^{-1}	2.70	-	-
Soluble Mg	meq L^{-1}	1.05	-	-
Soluble K	meq L^{-1}	0.42	-	-
K activity ratios	([K+])/√([Ca2+]+[Mg2+])	0.21	-	Basak (2007)
	$([K^+])/\sqrt{([Mg^{2+}])}$	0.41	-	Basak (2007)
	$([K^+])/\sqrt{([Ca^{2+}])}$	0.25	-	Basak (2007)

Seedling growth measurement and analysis
Forty days after emergence two plant samples were uprooted from the pots and used to record the growth parameters using standard procedures.

Root and shoot weight
Shoots were separated from roots and weighted immediately using an electronic balance for fresh weight. Samples were dried at 70°C for 48 hours to attain constant weight. After being cooled to room temperature, their dry weight was measured using an electronic scale.

Measurement of chlorophyll concentration
Fresh leaf samples of sunflower plants were collected. Each sample, which weighed 0.5 g, was cut into minute pieces and homogenised with 80% (v/v) acetone in a pre-cooled mortar and pestle. The Centrifuging of the extract at 3,000 rpm was done for fifteen minutes, prepared up to 25 mL using 80% (v/v) acetone. Using a spectrophotometer (Hitachi-220 Japan), the supernatant's absorbance was measured at wavelengths of 645, 663, and 480 nm. The concentrations of chlorophylls a and b were calculated using Arnon's (1949) formulae.

Measurement of K concentration
The K concentration were analysed by the method as suggested by Estefan *et al.* (2013). The plant tissue samples were washed with distilled water before drying. Each sample remained 48 hours in an oven set at 70 °C. The plant tissue samples were dried, and then powdered in a grinder. Dry ash techniques were used to analyze the K concentration in sunflower plant tissue. Each ground sample weighed 1.0 g, and it was ashed in a muffle furnace for five hours at 550°C. The substance was then dissolved in 2 N HCl, and then made up to a volume of 100 mL using distilled water. The material was then diluted and used for K analyses with a flame photometer (Jenway PFP-7).

Statistical analysis
The data on the growth parameters, chlorophyll concentration and shoot K concentration were analyzed using Minitab® Ver. 17 for analysis of variance (ANOVA). Parameters means were compared at p <0.05.

Results and Discussion

Shoot height
The results of shoot height of sunflower seedlings as influenced by K fertilizer sources on calcareous soils are presented in Table 2. Overall, the both sources of K fertilizer on shoot height were highly significant (p<0.05). Maximum shoot height was obtained with SoP followed by MoP as compared to control. The results exhibited that the effect of $CaCO_3$ levels on shoot height were also highly significant (p<0.05). Shoot height at $CaCO_3$ level (30%) were significantly less than $CaCO_3$ level <5, 10 and 20%. The effect of interaction of sources x $CaCO_3$ levels for shoot height was statistically non-significant (p<0.05). However, as compared to $CaCO_3$ levels shoot height at $CaCO_3$ level (30%) was less than $CaCO_3$ level <5, 10 and 20%. The results concluded that the application of SoP gained greater shoot height (16.33 cm) and $CaCO_3$ level (30%) had minimum (12.83 cm) shoot height on individual basis.

Table 2: *Effect of K sources and soil calcareous levels on shoot height and root length of sunflower at early growth stage.*

Source	$CaCO_3$ (%)									
	Shoot height (cm)					Root length (cm)				
	<5	10	20	30	Means	<5	10	20	30	Means
without K	15.69	14.90	14.06	11.93	14.14[b]	5.48	5.18	4.72	4.13	4.88[b]
SoP	18.24	17.56	15.56	13.97	16.33[a]	6.60	6.33	5.54	5.01	5.87[a]
MoP	17.51	17.06	15.91	12.58	15.76[a]	6.09	5.90	5.47	4.34	5.45[a]
Means	17.14[a]	16.51[ab]	15.18[b]	12.83[c]	-	6.05[a]	5.80[ab]	5.25[b]	4.49[c]	-
		K sources	CCL	K sources x CCL						
Shoot height (cm)	SED	0.463	0.534	0.925						
	LSD	0.781***	0.902***	NS						
Root length (cm)	SED	0.193	0.223	0.386						
	LSD	0.326***	0.377***	NS						

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Root length

The data on how K fertilizer sources affect the length of sunflower roots on calcareous soils are presented in Table 2. Overall, the both source of K fertilizer on root length were highly significant (p<0.05). In comparison to control, SoP followed by MoP produced the greatest root length. The results showed that the effect of $CaCO_3$ levels on root length were also highly significant (p<0.05). Root length at $CaCO_3$ level (30%) were significantly less than $CaCO_3$ level <5, 10 and 20%. The effect of interaction of sources x $CaCO_3$ levels for root length was statistically non-significant (p<0.05). However, compared to $CaCO_3$ levels root length at $CaCO_3$ level (30%) was less than $CaCO_3$ level <5, 10 and 20%. The results concluded that the application of SoP gained greater root length (5.87 cm) and $CaCO_3$ level (30%) had minimum (4.49 cm) root length on individual basis. However, treatment combination of source SoP x $CaCO_3$ level <5% had more (6.60 cm) root length.

Fresh shoot weight

The data on how two K fertilizer sources on calcareous soils affected the fresh shoot weight of sunflower is shown in Table 3. The effect of SoP and MoP sources of K fertilizer on fresh shoot weight were highly significant (p<0.05). As compared to the control, SoP and then MoP yielded the highest fresh shoot weight. The findings demonstrated that $CaCO_3$ levels had a highly significant (p<0.05) impact on fresh shoot weight. Fresh shoot weight at $CaCO_3$ level (30%) were significantly less than $CaCO_3$ level <5, 10 and 20%. The statistics showed that the interaction between sources and $CaCO_3$ levels had no significant (p <0.05) influence on fresh shoot weight. However, compared to $CaCO_3$ levels fresh shoot weight at $CaCO_3$ level (30%) was less than $CaCO_3$ level <5, 10 and 20%. The results concluded that the application of SoP gained greater fresh shoot weight (8.00) g and $CaCO_3$ level (30%) had minimum (5.69 g) fresh shoot weight on individual basis. However, treatment combination of source SoP x $CaCO_3$ level <5% had more (9.32 g) fresh shoot weight.

Dry shoot weight

The result pertaining of dry shoot weight of sunflower (Table 3) indicated that the effect of K sources and $CaCO_3$ levels was highly significant (p<0.05), but the interaction of sources x $CaCO_3$ levels was non-significant at (p<0.05). Dry shoot weight decreased with increasing $CaCO_3$ levels. Maximum dry shoot weight was observed in $CaCO_3$ level <5 and 10%. However dry shoot weight was decreased by 28.84% over $CaCO_3$ level <5% in $CaCO_3$ level 30%. In case of sources greater dry shoot weight observed in SoP and MoP while lower dry shoot weight was found in control. Between sources under different $CaCO_3$ levels results further indicated that the greater shoot weight (1.22 g) was observed in SoP at $CaCO_3$ level <5% and lowest was observed in control at $CaCO_3$ level 30%.

Fresh root weight

Data regarding fresh root weight of sunflower as influenced by different $CaCO_3$ level and K fertilizer sources are shown in Table 4. The findings showed that the impact of $CaCO_3$ levels and K sources was highly significant (p<0.05) for fresh root weight. However, $CaCO_3$ levels x K sources interaction was non-significant at (p<0.05). Fresh root weight of

Table 3: *Effect of K sources and soil calcareous levels on fresh shoot weight and dry shoot weight of sunflower at early growth stage.*

Source	$CaCO_3$ (%)									
	Fresh shoot weight (g)					Dry shoot weight (g)				
	<5	10	20	30	Means	<5	10	20	30	Means
without K	6.72	6.52	6.15	5.26	6.16^b	0.88	0.85	0.80	0.68	0.80^b
SoP	9.32	8.87	7.54	6.27	8.00^a	1.22	1.13	1.00	0.82	1.04^a
MoP	7.87	7.50	7.01	5.55	6.98^b	1.03	0.98	0.91	0.73	0.91^b
Means	7.97^a	7.63^a	6.90^a	5.69^b	-	1.04^a	0.98^a	0.90^a	0.74^b	-
		K sources	CCL	K sources x CCL						
Fresh shoot weight	SED	0.399	0.460	0.797						
	LSD	0.673***	0.777***	NS						
Dry shoot weight	SED	0.049	0.057	0.098						
	LSD	0.083***	0.096***	NS						

Table 4: *Effect of K sources and soil calcareous levels on fresh root weight and dry root weight of sunflower at early growth stage.*

Source	$CaCO_3$ (%)									
	Fresh root weight (g)					Dry root weight (g)				
	<5	10	20	30	Means	<5	10	20	30	Means
without K	0.64	0.58	0.54	0.44	0.55[b]	0.30	0.25	0.21	0.18	0.23[c]
SoP	0.75	0.69	0.60	0.53	0.64[a]	0.33	0.29	0.25	0.21	0.27[a]
MoP	0.70	0.65	0.60	0.46	0.60[a]	0.32	0.28	0.24	0.18	0.25[b]
Means	0.70[a]	0.64[b]	0.58[c]	0.48[d]	-	0.32[a]	0.27[b]	0.23[c]	0.19[d]	-
		K sources	CCL	K sources x CCL						
Fresh root weight	SED	0.018	0.021	0.037						
	LSD	0.031***	0.036***	NS						
Dry root weight	SED	0.006	0.006	0.011						

Table 5: *Effect of K sources and soil calcareous levels on chlorophyll a and chlorophyll b concentration of sunflower at early growth stage.*

Source	$CaCO_3$ (%)									
	Chlorophyll a concentration (mg g^{-1} fw)					Chlorophyll b concentration (mg g^{-1} fw)				
	<5	10	20	30	Means	<5	10	20	30	Means
without K	0.988	0.824	0.739	0.587	0.785[b]	0.534	0.416	0.369	0.264	0.396c
SoP	1.252	1.074	0.882	0.700	0.977[a]	0.937	0.786	0.660	0.434	0.704[a]
MoP	1.105	0.928	0.828	0.656	0.879[b]	0.708	0.545	0.439	0.324	0.504[b]
Means	1.115[a]	0.942[b]	0.816[c]	0.648[d]	-	0.727[a]	0.582[b]	0.489[b]	0.341[c]	-
		K sources	CCL	K sources x CCL						
Chlorophyll a concentration	SED	0.040	0.047	0.081						
	LSD	0.068***	0.079***	NS						
Chlorophyll b concentration	SED	0.031	0.035	0.061						

sunflower was high (0.64 g) in SoP source of K and less (0.55 g) in control. In K sources under different $CaCO_3$ levels greater fresh root weight was found in SoP at $CaCO_3$ level <5% while less (0.44) in case of control at $CaCO_3$ level 30%. In overall $CaCO_3$ levels, fresh shoot weight decreased with increasing $CaCO_3$%. Between sources highest fresh shoot weight (0.64 g) was observed in SoP followed by MoP (0.60 g) and the control (0.55 g).

Dry root weight

Statistical analysis of data for sunflower dry root weight presented in Table 4 showed that the effect of $CaCO_3$ levels as well as K sources differed significantly (p<0.05), while interaction of $CaCO_3$ levels x K sources interaction was non-significant at (p<0.05). Greater dry root weight (0.27 g) was significantly produced from SoP followed by MoP (0.25 g) as compared to control which produced (0.23 g). with respect to $CaCO_3$ levels, $CaCO_3$ <5% attained larger dry root weight (0.32 g) then decreased by 14.49%, 26.77% and 40.35 in $CaCO_3$ 10%, 20% and 30%, respectively. Between sources under different $CaCO_3$ levels results further indicated that the greater dry root weight (0.33 g) was observed in SoP at $CaCO_3$ level <5% and lowest was observed in control at $CaCO_3$ level 30%.

Chlorophyll concentration

Tables 5, 6 summarize the results of the influence different $CaCO_3$ level and K fertilizer sources on chlorophyll a, b and total concentration of sunflower seedlings. With increasing percentages of $CaCO_3$, chlorophyll a, b and total concentration decreased progressively (p<0.05) in comparison to controls. Significant increases of the chlorophyll a, b and total concentration of sunflower seedlings (p<0.05) were detected in both the sources of K. The primary leaves of sunflower were significantly affected by $CaCO_3$ levels, which resulted in a decline of chlorophyll a, b and total concentration. Presence of 30% $CaCO_3$ levels resulted in a significant decrease of chlorophyll (a, b and total). Beyond that concentration, decrease of chlorophyll a, b concentration was observed with elevated concentration level of $CaCO_3$. When sunflower leaves were exposed to 30% $CaCO_3$ levels, the amount of chlorophyll a, b reached a minimum value. Chlorophyll concentration of seedlings produced from $CaCO_3$ levels with 10, 20 and 30% $CaCO_3$ were decreased by 15.54, 26.80 and 41.92%, respectively, compared to the $CaCO_3$ level (<5%) seedlings (p<0.05). $CaCO_3$ stress caused a significant reduction in chlorophyll a and b concentration of the sunflower seedlings. Application of potash in the form of SoP improved the Chlorophyll concentration by 24.52% and 12.06% with MoP compared with the control.

Shoot K concentration

K concentration in shoot of sunflower seedlings as influenced by different $CaCO_3$ level and K fertilizer sources are shown in Table 6. The results indicated the effect of $CaCO_3$ levels and K sources was highly significant (p<0.05), but the interaction of $CaCO_3$ levels x K sources was non-significant at (p<0.05). There was a decreasing trend in K accumulation in shoots by increasing $CaCO_3$ levels. Maximum K was observed in where level of $CaCO_3$ was <5%. However, K accumulation was decreased by 30.44% over $CaCO_3$ <5% in $CaCO_3$ 30%. The effect of sources for K concentration in shoot was significant (p<0.05). Application of K sources caused increase in shoot K content. The shoot K content was increased by 31.14% with SoP and 13.92% with MoP compared with the control.

In this study, two K fertilizer sources SoP and MoP were tested by conducting pot experiment. This study was to find out the effective K source under different levels of $CaCO_3$ (<5, 10, 20, and 30%) which improved sunflower growth at early stage. The results revealed that both sources of K fertilizer significantly enhanced the growth, chlorophyll content, and shoot K concentration parameters of sunflower seedlings grown in pots with varying levels of calcareousness. Regardless of the two sources of K fertilizer, K application increased shoot height, root length, fresh and dry shoot weight, fresh and dry root weight, Chlorophyll concentration and shoot K concentration. Potassium used as SoP demonstrated a greater improvement in growth parameters, chlorophyll concentration and shoot K concentration in sunflower seedlings. Comparatively, potassium applied as MoP performed lower in growth and other parameters. These results are related to the earlier findings of Zhang *et al.* (2017) in which it was found that addition of potassium fertilizer enhanced the chlorophyll concentration in leaves of *Brassica oleracea*. These results are also in accordance with those provided by Kapourchal *et al.* (2011) and Arshadullah *et al.* (2014) but results are contradictory to those Ayub *et al.* (1999) and Bakht *et al.* (2010). The inconsistent results could have been caused by variations in the $CaCO_3$ levels or chloride (Cl^-) contents of the soil (Hussain *et al.*, 2015).

The findings also demonstrated that increasing $CaCO_3$ level in the soil decreased the growth parameters, chlorophyll concentration and shoot K concentration in sunflower seedlings. Higher the values for all the growth parameters, chlorophyll and shoot K concentration parameters recorded at slightly calcareous level <5% $CaCO_3$ level and lowest at strongly calcareous level of 30% $CaCO_3$. High calcium levels in the soil solution may decrease K uptake by

Table 6: *Effect of K sources and soil calcareous levels on total chlorophyll concentration and shoot K concentration of sunflower at early growth stage.*

Source										
	$CaCO_3$ (%)									
	Total chlorophyll concentration (mg g^{-1} fw)					Shoot K concentration (%)				
	<5	10	20	30	Means	<5	10	20	30	Means
without K	1.620	1.287	1.137	0.876	1.230^b	2.80	2.67	2.49	2.09	2.5^b
SoP	2.053	1.678	1.357	1.045	1.533^a	3.88	3.59	3.14	2.56	3.29^a
MoP	1.811	1.451	1.274	0.981	1.379^{ab}	3.26	3.08	2.85	2.25	2.86^b
Means	1.828^a	1.472^b	1.256^c	0.967^d	-	3.31^a	3.12^{ab}	2.83^b	2.30^c	-
		K sources	CCL	K sources x CCL						
Total chlorophyll concentration	SED	0.066	0.076	0.132						
	LSD	0.112***	0.129***	NS						
Shoot K concentration	SED	0.059	0.084	0.119						
	LSD	0.123***	0.139***	NS						

the crop (Wakeel *et al.*, 2017). Chohan *et al.* (2015) indicated that high amount of lime can be one of the major factors responsible for lowering K availability in these soils. Generally, low soil K availability limits plant growth and decreases sunflower yield (Li *et al.*, 2014). $CaCO_3$ in soil solution disturbs soil properties associated to the growth of plant including availability of plant nutrient, soil crusting and soil water relations (Wahba *et al.*, 2019). Plants in calcareous soils experience reduced K availability, which causes much more severe problems than K deficiencies (Alghamdi *et al.*, 2023). The K requirement of a sunflower crop and the need for fertilizer K may vary significantly depending on soil and climatic conditions (Li *et al.*, 2018). Though it may not be the always same for all crops, the uptake of K by crops is also considerable affected by other cations (Amo *et al.*, 2023).

This study was conducted in an artificial environment which may not accurately represent natural conditions. A limited sample size, a single cultivar of sunflower seedlings, and fertilizer nutrient K source, artificially prepared calcareous soils may have contributed to the results of the study. There may have been an absence of consideration of the interactions between soil nutrients, weather conditions, pests and diseases, or the potential long-term effects on the soil and environment that may have been overlooked in this study. A further limitation of the study may be that it was conducted over a short period of time and was not replicated in other places. In future studies, the sample size could be increased, investigate the interaction between K fertilizers with nitrogen, phosphorus, and micronutrients such as boron, to use zinc in a broader range of calcareous soil types, environmental factors could be taken into account, and multiple cultivars of sunflower seeds may be used. Moreover, research studies could be conducted over a longer period of time to gain a better understanding of the potential fertilizer K effects on sunflower seedlings under various calcareous soil conditions.

Conclusions and Recommendations

It is concluded that under calcareous soil conditions, potassium fertilization either in the form of SoP or MoP could more effectively promote sunflower seedling growth. Application of SoP in calcareous soils is recommended for better early growth. It would be evaluated further to confirm our findings.

Novelty Statement

The findings of study confirmed that increasing the $CaCO_3$ level in the soil decreased the growth parameters, chlorophyll concentration, and shoot K concentration in sunflower seedlings. The results showed that both SoP and MoP K fertilizer sources improved the growth, chlorophyll content, and shoot K concentration parameters of sunflower seedlings grown in pots with varying levels of calcareousness in the soil.

Author's Contribution

Abdul Aleem Memon: Conceived the idea, designed the study, did chemical analysis, wrote abstract, introduction, methodology, data collection, data entry in minitab and analysis, results and discussion, conclusion, and references.
Inayatullah Rajpar: Conceptualization, designed the study, supervision, elaborated the intellectual content and modifies the manuscript.
Ghulam Murtza Jamro: Conceptualization, designed the study, supervision, elaborated the intellectual content and, reviewed, proof reading, manuscript revision, plagiarism check.
Javeed Shah: Reviewed proof reading, manuscript revision and modify the manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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