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RESEARCH PAPER

Efficiency of carbon sequestering fertilizers for growth and nutrient acquisition of sunflower (*Helianthus annuus* L.)

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Key Message: This study reveals that application of carbon sequestering fertilizers in combination with inorganic nutrition improved all the growth features of sunflower in the growth medium.

Abstract: The present work explores the assumptions that functionalized biomass derived chars (charcoal) act as carbon sequestering soil amendments to enhance the growth of sunflower. A field study was conducted at College of Agriculture, Sargodha with the aim of investigating the effect of carbon sequestering fertilizers (CSF) on growth, mineral uptake and dry matter contents of sunflower (Hysin-33). Four treatments were applied which were replicated four times using randomized complete block design (RCBD). The treatments include T_1= Control (recommended NPK dose), T_2= T_1 + CSF (Acid treated fly ash) @ 150 kg ha^{-1}, T_3= T_1+CSF (compost powder) @ 150 kg ha^{-1} and T_4= T_1+CSF (Dewaxed press mud) @ 150 kg ha^{-1}. Results revealed that application of recommended doses of NPK fertilizers along with dewaxed filter cake press mud resulted in maximum plant height (254.53 cm), dry weight of achene (133.94 g), stem diameter (13.18 cm), number of achene per head (1715.4), head diameter (30.02 cm), 1000 achene weight (80.57 g), total biomass (1108.4 g), plant nitrogen content (5.11%), plant phosphorus content (0.51%) and plant potassium content (4.67%). Therefore, it can be concluded that application of carbon sequestering fertilizers in combination with inorganic nutrition improved all the growth features of sunflower plants in the growth medium. Among the different types of carbon sequestering fertilizers, press mud performed better than others. Similarly, nutrient concentration of sunflower was also increased by the addition of press mud as CSF.

Keywords: Carbon sequestering fertilizers, Compost, Dewaxed press mud, Sunflower

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Introduction

Sunflower was first introduced in Pakistan as an oilseed crop in early 1970's but its growth in acreage and production is unstable due to various production and socio economic constraints (Arshad et al., 2010). Cotton is the most important source of edible oil in Pakistan that contributes above 65% of domestic production (Economic Survey of Pakistan, 2018-2019), while sunflower is the 2nd major oilseed crop that contributes above 30% of local oilseed production. The sunflower has potential to simply fulfill the future demands of edible oil in Pakistan (Bakht et al., 2010). Sunflower was cultivated on an area of about 264,000 Acres with production of about 142,000 tons seed and 54000 tons of oil during 2018-19, where it is mainly cultivated in cotton belt areas and rice belt areas (Economic Survey of Pakistan, 2018-2019).

Carbon is a vital element of life and present in all living bodies. It is present in different forms, dominantly as biomass of plants, soil organic matter and as a carbon dioxide (CO_2) gas in the atmosphere and also present as dissolved seawater. Addition of soil organic matter into soil is the primary way of accumulation of carbon in the soil system as soil organic matter is the merged combination of carbon containing compounds (Mackenzie & Lerman, 2006; Nguyen et al., 2020). One of the most important natural sources of soil carbon is organic matter of soil (Yao et al., 2019). Carbon fraction of soil also exists as a constituent of mineral soil which favors plant growth and increases yield of crops (Lim et al., 2020). Agricultural practices affect the emission of CO_2 therefore, influences the worldwide enhancement of atmospheric carbon dioxide that requires carbon sequestration even though sustaining dynamic and elevated levels of organic matter (Lal, 2008). Removal of carbon dioxide through the atmosphere and capturing in soil system has several advantages. One important benefit is increased soil carbon fraction. Moreover, enhanced soil and water characteristics, lessened nutrient runoff, decreased soil erosion and improved crop yield achieved as a result of raising the amount of carbon deposited in cultivated soils (Chenu et al., 2019).

Capturing of carbon in soil systems, forest vegetation, oceans and geological formations on a long term basis is called carbon sequestration. Oceans stockpiled maximum globe's carbon while soils hold three folds more carbon than stored in plants and animals that stored almost 75% of carbon pool on terrestrial environment. Thus, soils contribute a key role in satisfying a constant carbon cycle in the world (Lal, 2008; Corbeels et al., 2019). Pakistan's climate is arid to semi-arid that is why our soils have high pH and these soils are deprived in organic fractions and consequently low soil organic carbon fraction. Organic matter in these soils is less than 1%. In order to decrease the dependence on expensive synthetic creations like other states of the world, Pakistani farmers frequently used agro-industrial organic manures for crop production. These nutritional sources are produced from various means (Sabah et al., 2018).

In Asia incorporation of organic matter to agricultural soils was generally practiced for decades but this trend moved towards chemical fertilizers because of the intensive cropping and business oriented agriculture. These synthetic fertilizers were utilized in such huge quantities that these deteriorate soil health. Systematic addition of organic matter for example sugar industry organic wastes, animal wastes and residues of crops are the supreme significance in sustaining soil productivity, tilth and efficiency of cultivated soils (Solaimalai et al., 2001; Liu et al., 2019).

Acid treated fly ash is an organic product of the sugarcane industry. It is fine material in powder form produced as a byproduct of burning of coal in electric generation power plants. This is produced as waste material in the course of sugar production. Once sugarcane is crumpled and juice is obtained, the left behind flesh (bagasse) can be utilized for generating electricity. The substance which is left behind is fly ash that has no use and poses a major environmental problem. According to an estimate approximately two million tons of this kind of waste is generated each year from sugar mills in Pakistan (Nasir & Qureshi, 1999). Fly ash is used as organic fertilizers for crop production that is becoming popular among the farming community. This carbon sequestering material is a significant organic byproduct of sugar mills and a good source of fertilizer nutrients such as phosphorus, potassium, calcium, magnesium, sulfur, copper, iron, zinc etc. (Totawat et al., 2002).

Pakistan is a country which is producing a huge amount of agricultural waste. All these waste materials are rich sources of carbon. Major agricultural wastes are coming from the sugarcane industry in different forms such as compost, fly ash, press mud or filter cake etc. All such waste material contains carbon which is captured into the soil otherwise carbon returns to the environment in CO_2 form and causes pollution. All sugar mill organic waste products (filter cake, compost and fly ash) added nutrients to the soil system (Dotaniya et al., 2016). Organic rich press mud contains a significant amount of organic matter contents that enhance basic cations of soil. Press mud contains a significant amount of organic matter content that improves basic cations of soil. It also improves carbon, nitrogen, sulfur and phosphorus content in organic forms whereas fly ash mainly improves basic cations and anions such as carbonates and silicate (Curtin et al., 1998). .

The addition of compost enriched with nutrients improves the total soil organic carbon and nutrient contents (Pinamonti, 1998) and boosted maize crop growth (Atuanya et al., 2012). Carbon rich compost is an agronomically valuable, environmentally harmless and comparatively inexpensive source of organic improvement that boosts soil microbial activity and improves crop growth (Raviv, 2005; Hepperly et al., 2009). Present study was designed to explore the effect of carbon sequestering fertilizers on growth and mineral acquisition of sunflower.

Material and Methods

Experiment location and treatments

The plot (physio-chemical properties given in Table 1) was selected from the University research area for conducting research this trial. The seeds of sunflower that were used in this research trail were taken from the company ICI of Pakistan. The genotype of the sunflower was Hysun-33 hybrid. All the organic wastes used as carbon sequestering fertilizers for growing sunflower i.e., acid treated fly ash, compost powder and Dewaxed press mud were collected from Madina Sugar Industry, Faisalabad, Pakistan. Composition of these organic materials is given in Table 2. All the fertilizers were applied according to the experimental treatment plan. Half of the treatments were mixed with soil at the time of seed bed preparation for the purpose of sequestering carbon into the soil system. While, remaining half of the treatments were given after 25 days of crop emergence. Nitrogen and phosphorus were applied through urea and diammonium phosphate (DAP) fertilizers. Half of the nitrogenous fertilizer applied at planting time while the remaining half was given when sunflower head formation started. However, all the suggested phosphatic and potassium fertilizers were applied as a basal dose at planting time of crop. The study consisted of four treatments each of which was repeated four times. Treatments include:

T_1= Control (Recommended N, P & K fertilizers)
T_2= T_1+ CSF (Acid treated fly ash) @ 150 kg ha^{-1}
T_3= T_1+ CSF (compost powder) @ 250 kg ha^{-1}
T_4= T_1+ CSF (Dewaxed press mud) @ 150 kg ha^{-1}

Sample preparation and analysis

Plants samples were dried in an oven (Binder, ED 115, Germany) at 65 ^{o}C till constant weight. After oven-drying size reduction was made by using a grinding mill (Polymix, CH-6014, Kinematica AG, Switzerland) having 2 mm sieve. Blue color method was followed for estimation of P (Olsen, 1954) using spectrophotometer (Shimadzu, UV-1201, Kyoto, Japan). The organic carbon from soil sample was estimated by loss on ignition (L.O.I) method by using electric muffle furnace (Daihan lab Tech, LEF- 130 S, Seoul, Korea). After wet digestion of plant samples with acid mixture (HNO_3+ $HClO_4$ 1: 2), flame photometer was used to measure plant potassium.

Standard solution of potassium chloride was made. Standard and graph readings evaluated against instrument reading to find out the plant potassium concentration (Jones et al., 1991):

$$\% \text{ K} = \frac{\text{K (ppm)}}{10000} \times \frac{\text{df}}{10000}$$

Data regarding plant growth parameters like plant height, stem diameter, head diameter, number of grains per head, weight of achene per plant, 1000 achene weight and total biomass weight were recorded using standard procedures.

Table 1 Soil characteristics of experimental area (pre-analysis)

Parameters	Unit	Fly ash
pH_s		8.2
EC_e	dSm^{-1}	1.27
Soil organic matter	%	0.28
Soil organic Carbon	%	0.16
Available potassium	ppm	280
Available phosphorus	ppm	9
Ca^{+2}+ Mg^{+2}	$mmol_eL^{-1}$	3.2
Sand	%	45.2
Silt	%	26.7

Table 2 Chemical properties of fly ash and press mud

Parameters	Unit	Fly ash	Press mud
pH		7.8	9.2
Total nitrogen	%	2.33	0.085
Total phosphorus	%	1.26	0.048
Total potassium	%	0.7	0.33
Organic matter	%	20-25	Nil
Total organic carbon	%	43.2	0.36
C: N ratio	%	18.54	4.29

Statistical analysis

After compilation of data regarding growth and nutrient acquisition parameter statistical evaluation was performed by calculating Analysis of Variance (ANOVA) by using computer software Statistix 8.1. The least significant difference test (LSD) was used for the comparison of means.

Results

Plant height (cm)

Plant height is a major growth factor of sunflower plants. Results regarding effect of carbon sequestering fertilizers (CSF) on sunflower plant height indicated that plant height increased significantly by the addition of all treatments over control (Fig. 1). Minimum plant height was recorded in T_1 (control) receiving recommended doses of NPK fertilizers with numerical value of 175.5 cm that was reached to maximum value of 254.53 cm in T_4 receiving recommended doses of NPK along with dewaxed filter cake pressmud @ 150 kg ha^{-1}. Treatment T_4 was followed by T_3 where (Recommended NPK fertilizers + Carbon sequestering fertilizers (C) @ 250 kg ha^{-1}) (220.56 cm). Data regarding means differences was found statistically significant.

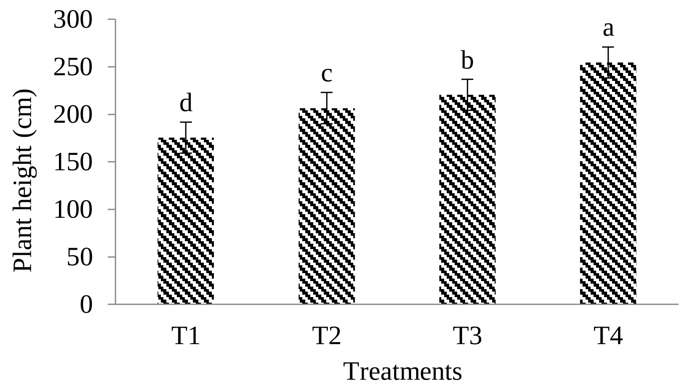

Fig. 1 Effect of CSF on plant height (cm) in sunflower

Dry weight of achene per plant (g)

Dry weight of achene $plant^{-1}$ of sunflower was also considerably increased by application of carbon sequestering fertilizers (CSF). Differences among various treatments were significant statistically. Maximum dry weight of achene $plant^{-1}$ was noted in T_4 (Recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1}) which exhibited 133.94 g dry achene weight (Fig. 2). Treatment T_3 (Recommended NPK fertilizers + Carbon sequestering fertilizers (C) @ 250 kg ha^{-1}) remained next to T_4 (Recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1}) in dry achene weight (126.50 g). The noted value of dry weight of achene for treatment T_2 (Recommended NPK fertilizers + Carbon sequestering fertilizers (FA) @ 150 kg ha^{-1}). The lowest weight of achene (108.63 g) was observed in control (T_1).

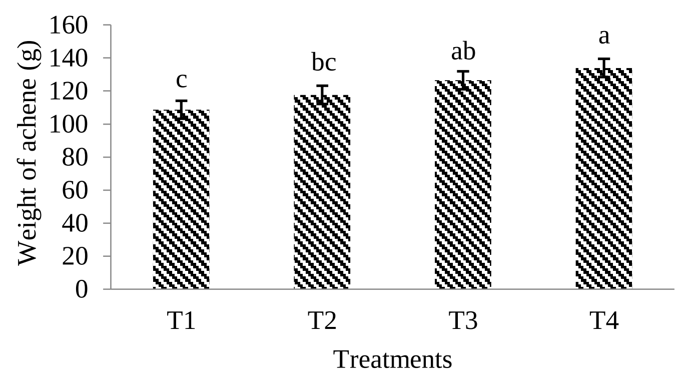

Fig. 2 Effect of CSF on dry weight of achene (g) in sunflower

Stem diameter (cm)

Data regarding stem diameter reflected that variations between different carbon sequestering fertilizer (CSF) treatments relating to stem diameter were statistically significant. Highest stem diameter with value of 13.18 cm was noticed in T_4 receiving recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1} followed by T_3 where recommended NPK fertilizers were applied along with Carbon sequestering fertilizers (C) @ 250 kg ha^{-1} (Fig. 3). On the other hand, minimum stem diameter was recorded in treatment T_1 (recommended doses of NPK) with numerical value of 8.72 cm.

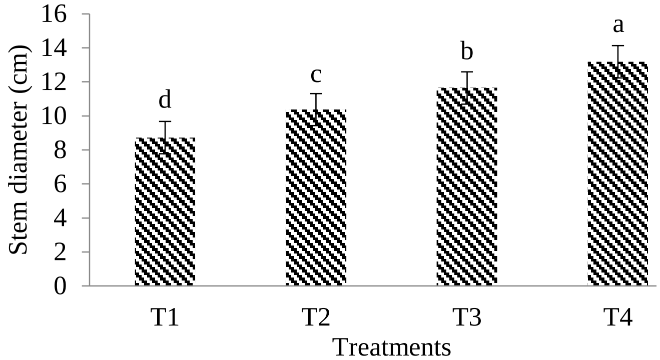

Fig. 3 Effect of CSF on stem diameter (cm) in sunflower

Number of achene per head of sunflower

Number of achene per head of sunflower per plant was significantly enhanced by the application of carbon sequestering fertilizers (CSF) when evaluated with sole application of mineral fertilizer treatment T_1 (Fig. 4). Highest number of achene per head (1751.4) was recorded in T_4 (Recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1}). While the minimum number of achene per head of sunflower was found in control treatment (T_1) receiving sole application of chemical fertilizers at recommended rate (NPK) with numerical value of 1381.

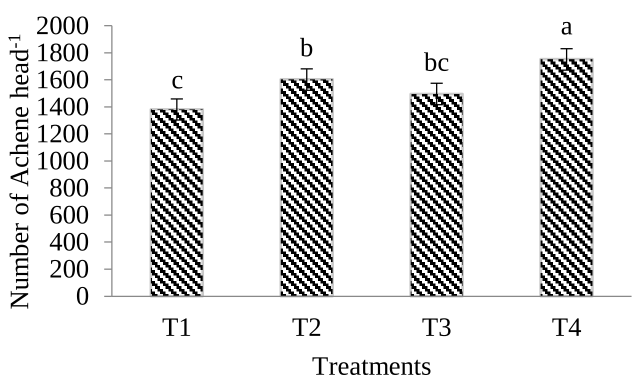

Fig. 4 Effect of CSF on number of achene per head in sunflower

Head diameter of sunflower (cm)

Data regarding sunflower head diameter (Fig. 5) indicated that the diameter of sunflower head gradually enhanced with application of different sorts of carbon sequestering fertilizer treatments (CSF). Results of various CSF treatments with regard to head diameter of sunflower were significant in terms of statistics. Lowest head diameter (22.82 cm) was found in treatment T_1 (control) that reached to the highest head diameter (30.02 cm) in T_4 (Recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1}).

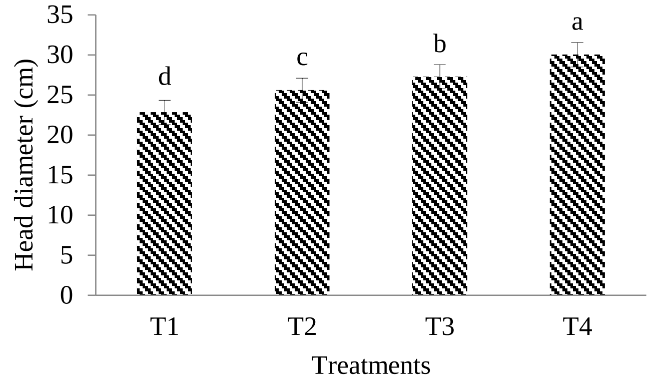

Fig. 5 Effect of CSF on head diameter (cm) in sunflower

1000 achene weight (g)

Results regarding thousands achene weight of sunflower depicted that achene weight considerably enhanced with application of carbon sequestering fertilizers (CSF) (Fig. 6). Minimum thousand achene weight (66.295 g) was found in T_1 (recommended NPK) while maximum thousand achene weight (80.570 g) was observed in T_4 (Recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1}).

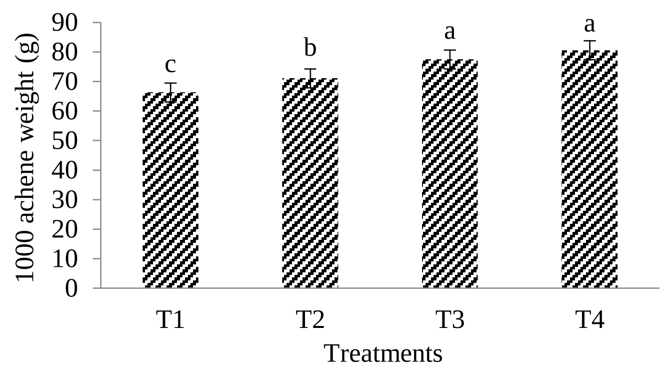

Fig. 6 Effect of CSF on 1000 achene weight (g) in sunflower

Total biomass (g)

Statistics indicated that differences between various carbon sequestering fertilizer (CSF) treatments relating to total biomass weight of sunflower plants were significant statistically (Fig. 7). Application of chemical fertilizer at recommended rate (T1) resulted in minimum total biomass weight (992.5 g) of sunflower. Contrary, highest biomass weight (1108.4 g) was observed in T_4 (Recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1}).

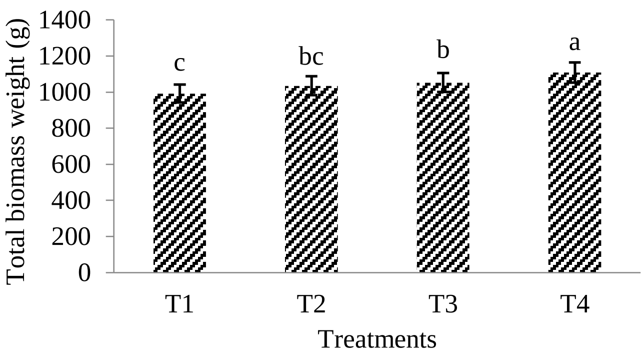

Fig. 7 Effect of CSF on total biomass (g) in sunflower

Plant nitrogen content (%)

Results revealed that application of recommended NPK and Carbon sequestering fertilizers considerably enhanced the plant nitrogen (N) concentration (Fig. 8). Maximum plant nitrogen (N) concentration (5.1106%) was analyzed in T_4 (Recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1}). Conversely, minimum N concentration (3.2825%) was observed for treatment T_2 (Recommended NPK fertilizers + Carbon sequestering fertilizers (FA) @ 150 kg ha^{-1}). It can be concluded from the data that combining application of carbon sequestering fertilizers (CSF) and NPK fertilizers improved the concentration of plant available nitrogen.

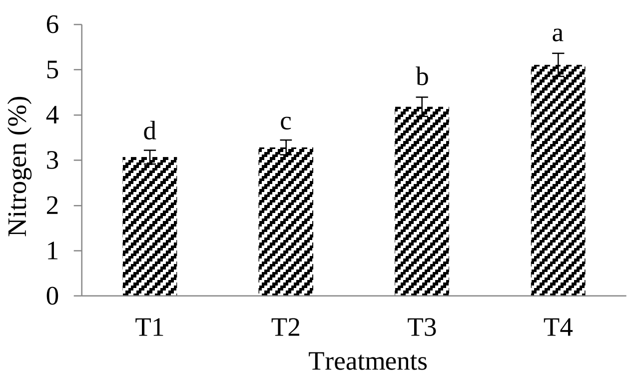

Fig. 8 Effect of CSF on nitrogen content (%) in sunflower

Plant phosphorus content (%)

Data regarding plant phosphorus concentration showed that significant increase in plant available phosphorus concentration was observed by all the treatments (Fig. 9). Highest plant phosphorus (0.5083%) was noted in T_4 (Recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1}). Treatment T_3 (Recommended NPK fertilizers + Carbon sequestering fertilizers (C) @ 250 kg ha^{-1}) proved adjacent to T_4. It has been shown by results that the application of carbon sequestering fertilizers along with NPK significantly enhanced the plant phosphorus concentration.

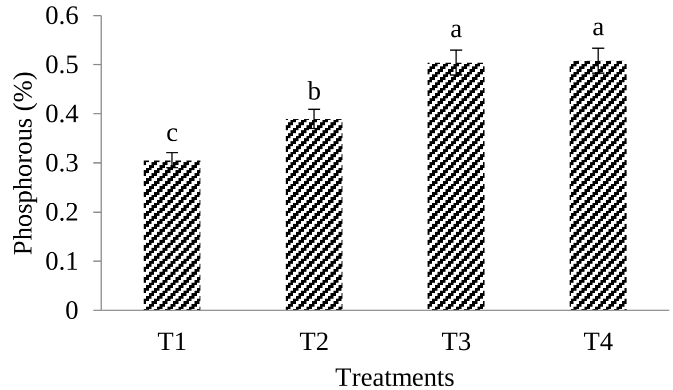

Fig. 9 Effect of CSF on leaf P content (%) in sunflower

Plant potassium content (%)

Results related to plant available potassium (K^+) showed significant increase in plant available potassium by all treatments of carbon sequestering fertilizers (Fig. 10). Maximum potassium 4.66% was observed in T_4 (Recommended NPK fertilizers + Carbon sequestering fertilizers (PM) @ 150 kg ha^{-1}). It was followed by treatment T_3 (Recommended NPK fertilizers + Carbon sequestering fertilizers (C) @ 250 kg ha^{-1}) which represent 3.87% potassium concentration in plants and proved significant in terms of statistics. The values of potassium concentration for treatments T_2 (Recommended NPK fertilizers + Carbon sequestering fertilizers (FA) @ 150 kg ha^{-1}) as well as T_1 (Recommended rate of NPK) were 3.56 and 3.11%, respectively. It has been clear from the data that the carbon sequestering fertilizers (CSF) considerably increased the plant available potassium concentration.

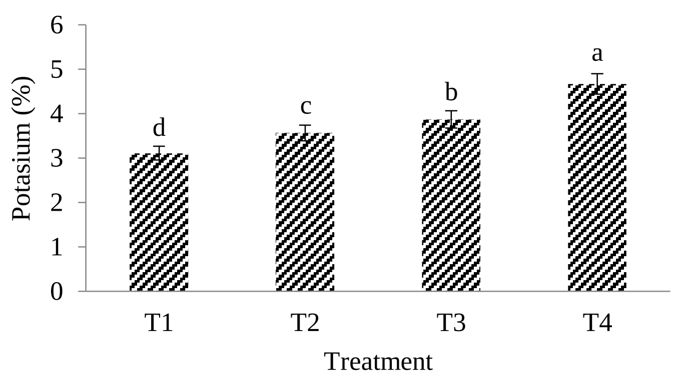

Fig. 10 Effect of CSF on leaf K content (%) in sunflower

Discussion

Application of carbon sequestering fertilizers (CSF) considerably enhanced the soil NPK status. Although chemical fertilizers are a good source of plant essential nutrients, it is a known fact now that integrated application of organic and mineral plant nutritional sources performed better in terms of enhancing plant growth though improvement of soil physicochemical properties and nutrient availability in growth media. Production of crop plants is influenced by several variables such as seed related, field related, water related and nutrition related factors. To achieve agriculture productivity in adverse soil conditions by role of organic matter incorporation, various possibilities are reported in literature such as green manure, animal manure mixing, application of agro industrial organic wastes such as press mud, fly ash and compost etc. (Sabah et al., 2018; Nguyen et al., 2019). Among the organic means of crop nutrition, filter cake or press mud have a distinctive position as the by-product organic waste of the sugarcane industry which is soft, spongy, amorphous and brownish material. Many scientists reported that press mud can be utilized as valuable organic manure due to high content of organic carbon in its chemical composition (Nehra & Hooda, 2002; Jamil et al., 2008; Kumar & Chopra, 2016). Filter cake is an organic waste which is capable of providing ample quantity of plant nutrients to soil because of its significant effect on physicochemical properties of soil such as water retaining capacity, texture, structure, aeration and soil organic fraction (Rakkiyappan et al., 2001). Press mud or sugarcane filter cake (SFC) contains sufficient amount of macro and micro mineral nutrients (Dotaniya et al., 2016) such as phosphorus, potassium, calcium, magnesium and sulfur which are 1.27%, 1.81%, 2.40% 1.29% and 2.61% respectively along with minor nutrients for example iron-2042 ppm, zinc- 36.5 ppm and copper- 22.6 ppm (Reddy, 2002).

Acid treated fly ash is an organic product of the sugarcane industry. This is produced as waste material in the course of sugar production. Once sugarcane is crumpled and juice is obtained, the left behind flesh (bagasse) can be utilized for generating electricity. The substance which is left behind is fly ash that has no use and poses a major environmental problem. According to an estimate approximately two million tons of this kind of waste is generated each year from sugar mills in Pakistan (Nasir & Qureshi, 1999). Fly ash used as organic fertilizers for crop production becomes a well-known practice nowadays. Carbon contains fly ash when used in different ratios which improves several soil physical, chemical and biological characteristics like pH, structure, texture, density, porosity, water retaining ability of soil (Totawat et al., 2002; Karwal & Kaushik, 2020). According to Razzaq (2001) organic matter fraction and health of soils increased on a sustained basis when sugarcane filter cake is applied along with chemical fertilizers in crop production. This increased organic matter level of soil ultimately improved soil physicochemical properties of growth media and subsequently increased plant growth as well as nutrient acquisition by plants.

Application of carbon sequestering fertilizers (CSF) considerably enhanced soil NPK status as well as it has a huge capacity to increase growth performance and mineral contents of various crops which in turn produced greater yield of crops. Due to the application of carbon sequestering fertilizers (CSF) to soil system highest N (5.11%), P (0.5083%) and K (4.66%) uptake was recorded. These observations are in accordance with findings of Bokhtiar et al. (2000); Poonkodi & Angayarkanni (2001); Patil & Bhilare (2001); Nehra & Hooda (2002); Sarir et al. (2005); Korai et al. (2014); Demelash et al. (2014); Arif et al. (2017). Elsayad et al. (2008) also suggested that press mud contains adequate levels of organic matter, NPK and essential micronutrients for crop growth. Efficiency and productiveness of cultivated soils can also be enhanced through this material. Yield of several crops including maize and millet considerably increases when sugarcane filter cake is incorporated into the soils (Singh et al., 2005; Chattha et al., 2019). Therefore, systematic addition of sugarcane organic wastes such as filter cake, compost, and fly ash and crop residues has the greatest significance in agricultural production. That helps in improvement of soil tilth, fertility and act as a soil conditioner (Solaimalai et al., 2001).

Conclusion

Application of carbon sequestering fertilizers (press mud, fly ash & compost) in combination with mineral nutrition enhanced all growth characters of sunflower plants in the growth medium. Among the different types of carbon sequestering fertilizers (press mud, fly ash & compost) press mud proved superior to others. It was concluded that application of sugar industry organic wastes as carbon sequestering fertilizers substantially enhanced growth, yield and nutrient acquisition by sunflower. Additionally, efficient management of agricultural wastes is also achieved in a safe way and also up gradation of soil carbon fraction and nutrient content of growth media.

Authors Contributions: M.S. conducted the research experiments. M.A.T. supervised the research study. N.-S. contributed in drafting and statistical analysis. G.S. co-supervised the research study and technically assisted at every step.

Conflict of Interest: The authors declare that they have no conflict of interest.

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