Paper

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Abstract

In abiotic stresses, drought is the main problem in agricultural production which inhibits the plants to show off their genetic potential. Maize is not only the cereal crop of the world but also 3rd important cereal crop in Pakistan. Maize is drought-sensitive and affected at each growth and development stage. So, the organic amendment is not only the solution to mitigate the drought stress due to long-lasting moisture availability but also improves the growth, yield, quality, and nutrient uptake with improving soil properties. Therefore, a two-year field experiment during 2018 and 2019 was laid out at Agronomy Research Area, Department of Agronomy, Bahauddin Zakariya University, Multan, Pakistan. Treatments included pre-screened maize hybrids: P-1429 (drought-sensitive) and Dk-6724 (drought-tolerant); pre-optimized levels of each organic fertilizer source (OFS); recommended chemical fertilizer source (CS), 10 t/ha biochar (BC), 10 t/ha farmyard manure (F.M) and 10 t/ha poultry manure (P.M); and irrigation regimes *i.e* normal irrigation (Ck) 100% field capacity and severe drought (SD) 50% field capacity. The Experiment was designed in a randomized complete block design (RCBD) with a split-split plot arrangement and was replicated three times. Irrigation regimes were put in the main plot, organic fertilizer sources were put in the subplot and maize hybrids were put in the sub-sub plot. Different agronomic growth and yield attributes, quality attributes, crop physiology, soil physical properties, nutrient uptake, and activity of antioxidant enzymes were assessed. It resulted that in organic fertilizer sources application, 10 t/ha poultry manure and farmyard manure followed by biochar improved the growth and yield of maize hybrids significantly, under normal irrigation and severe drought. These also improve the quality of maize by improving the nutrient uptake and soil physical properties like increasing the soil porosity and decreasing the soil bulk density during consecutive years 2018 and 2019. It was also noticed that the application of organic fertilizers mitigated the adverse effect of drought by the antioxidant defense system with the production of SOD, POD and CAT.

Keywords: Maize, soil porosity, bulk density, antioxidant activity, organic fertilizer sources, nutrient uptake

1. Introduction

Maize *Zea mays* L. is a cereal crop cultivated worldwide on a large scale and is food for humans, animal feed, and industrial raw material (Khan *et al.*, 2008, Shah et al., 2022). As a food item, it provides different minerals and vitamins, including vitamins B, C, and E (Fekonja *et al*., 2011). Maize is used as processed and in its raw form because it supplies an adequate amount of protein and sugar (Lamphear *et al.*, 2005). In Pakistan, it can be cultivated twice a year during the spring and autumn season. In Punjab, the area of cultivation for maize production is increasing during the spring season due to the movement of formers from cotton cultivation to maize cultivation. The average yield of maize in Punjab during the year 2019-2020 was 9536 kg/ha which was low as compared to others maize production countries. There are several reasons behind the low yield of maize in Punjab, Pakistan. Abiotic stress like drought stress and low soil fertility are the main factors for this low yield.

Climate change is a major cause of high temperatures, more evapotranspiration, and drought stress to all crops especially maize (Hillel and Rosenzweig, 2002). Drought is the biggest challenge worldwide to growing maize crops now a day (Zhang *et al*., 2018). An optimum amount of water is required for the maize crop for successful growth. Drought suppresses crop growth and development, which leads to reduced yields and plant mortality (Aslam *et al*., 2015, Shah et al., 2019). Water deficiency restricts the plant's metabolic activities, leading to biochemical, physiological, and morphological changes in plant processes and growth and development (Djibril *et al*., 2005). Drought stress effect photosynthetic rate and antioxidant activity (Khalid et al., 2021a,b, Hussain and Shah, 2023).

Over the last few decades, a large number of chemical fertilizers have been applied to prevent food shortages worldwide (Savci Serpil, 2012; Sun et al., 2015). The excessive use of chemical fertilizers has led to several soil issues such as nitrogen leaching, soil degradation, soil compaction, soil acidification, and reducing soil organic matter (Horrigan et al., 2002; Nkoa Roger, 2014; Wang et al., 2019). The usage of chemical fertilizers gradually depletes the soil and increases heavy metals which are harmful to soil and human health (Belyaeva *et al*., 2005). To cope with these problems, different strategies are being used. Organic fertilizer sources have the ability to hold more water and are being used to improve soil structure and soil fertility. Organic substances should be used to maintain soil health and fertility (Bolan *et al*., 2003; Lehman et al., 2003). Organic fertilizers act as the best fertilizers for increasing crop yield than chemical fertilizers do by improving soil fertility (Mahmood et al., 2017; Cai et al., 2019). Organic fertilizer sources improve soil fertility and crop productivity (Cai et al., 2019, Wang et al., 2019; Duan et al., 2021). Organic fertilizers are useful for enhancing environmental health and increasing water-holding capacity, decreasing the cost of crop production. Organic fertilizers are a major constituent in sustainable crop production (Adelekan *et al*., 2010).

There are different replacements for inorganic or chemical fertilizers with organic substances like farm-yard manure, poultry manure, and crop residues like biochar (Ibeawuchi et al., 2007). Biochar is obtained from burning organic substances like crop residues, wood, etc. It assists the plants with more amount of carbon (Woolf *et al*., 2010; Sohi, 2012). Fortification of biochar can enhance the productivity of the soil because it helps to maintain soil fertility (Liang et al., 2006; Liu *et al*., 2013). Farmyard manure is being used as an alternative chemical fertilizer to meet the nutritional requirement of crops (Makinde *et al*., 2007; Law et al., 2009). Farmyard manure helps the soil retain water and release nutrients slowly, which increases microbial activity in the soil (Belay *et al*., 2001). Manure can also minimize soil erosion and soil pollution (Singh *et al*., 2016; Zhang *et al*., 2016). Poultry manure is also considered valuable organic fertilizer because of its nature to amend and makes sure the availability of nutrients in the soil (Warren *et al*., 2006). The presence of poultry manure minimizes the wastage of nutrients and helps to incorporate moisture into the soil (Ali *et al*., 2011; Adhikari et al., 2021). Poultry manure has a high amount of carbon which integrates more amount of organic matter into the soil. Therefore, the application of organic fertilizer sources is regarded as a win-win to improve soil fertility and crop production on agricultural land.

Hypothesis: It was hypothesized that organic amendments can be helpful to increase maize productivity by improving the soil structure and also mitigate the adverse effect of drought due to increasing water holding capacity.

2. Materials and methods

2.1. Experimental site and design

The experiment was conducted in 2018 and was repeated in 2019 at Agronomic Research Area, Bahauddin Zakariya University Multan, Punjab, Pakistan. The experiment was laid out on February 1st, 2018, and was repeated on the same date in 2019. An experiment was laid out in Randomized Complete Block Design (RCBD) with a split-split plot arrangement and each treatment was replicated three times. Irrigation regimes were kept in the main plot, organic fertilizer sources were kept in the subplot while maize hybrids were kept in the sub-sub plot.

2.2. Pre-experiment plan

Before this study, a couple of experiments were conducted in 2017 for the screening of drought-sensitive and tolerant maize hybrids under different irrigation regimes. Among the maize hybrids, P-1429 and Dk-6724 were considered as drought-sensitive and tolerant, respectively (Shah et al., 2022). Optimization of levels of organic fertilizer sources *i.e* 0, 5, 10 t/ha (biochar, poultry manure, and farmyard manure) with screened drought-sensitive and tolerant maize hybrids under different irrigation regimes was also done. It resulted that application of 10 t/ha biochar, poultry manure and farmyard manure is more effective as compared control treatment followed by 5t/ha application of biochar, poultry manure and farmyard manure.

2.3. Treatments plan

In this experiment, the efficacy of pre-screened drought-sensitive and tolerant maize hybrids with the pre-optimized level of each organic fertilizer source (recommended chemical fertilizer, biochar, 5 t/ha poultry manure, and 5 t/ha farmyard manure) under different irrigation regimes were optimized. Treatments included maize hybrids: P-1429 (drought-sensitive) and Dk-6724 (drought-tolerant); optimized levels of each organic fertilizer source (OFS); recommended chemical fertilizer (CS), 10 t/ha biochar (BC), 10 t/ha farmyard manure (F.M) and 10 t/ha poultry manure (F.M); and drought stress *i.e* normal irrigation (Ck) 100% field capacity and severe drought (SD) 50% field capacity. Seeds of maize hybrids were collected from Siraj Agro Chemicals, Multan.

2.4. Experimental soil and environment

The experimental soil was sandy clay loam with EC 2.8 dSm^{-1}, pH 7.9, and organic matter 1.02%. Total available nitrogen, phosphorous, and potassium were 0.05%, 9.50 mg/kg and 120 mg/kg, respectively. Maximum and minimum daily temperature and rainfall recorded during the growth period for both years are given in Fig. 1.

2.5. Organic fertilizer sources

Biochar was prepared by the pyrolysis method given by (Qayyum et al., 2015) at the Muhammad Nawaz Sharif University of Agriculture, Multan (MNSUAM). Poultry manure and farmyard manure were collected from Veterinary Cattle Farm, Multan. Physicochemical analyses of organic fertilizer sources are given in Table 1.

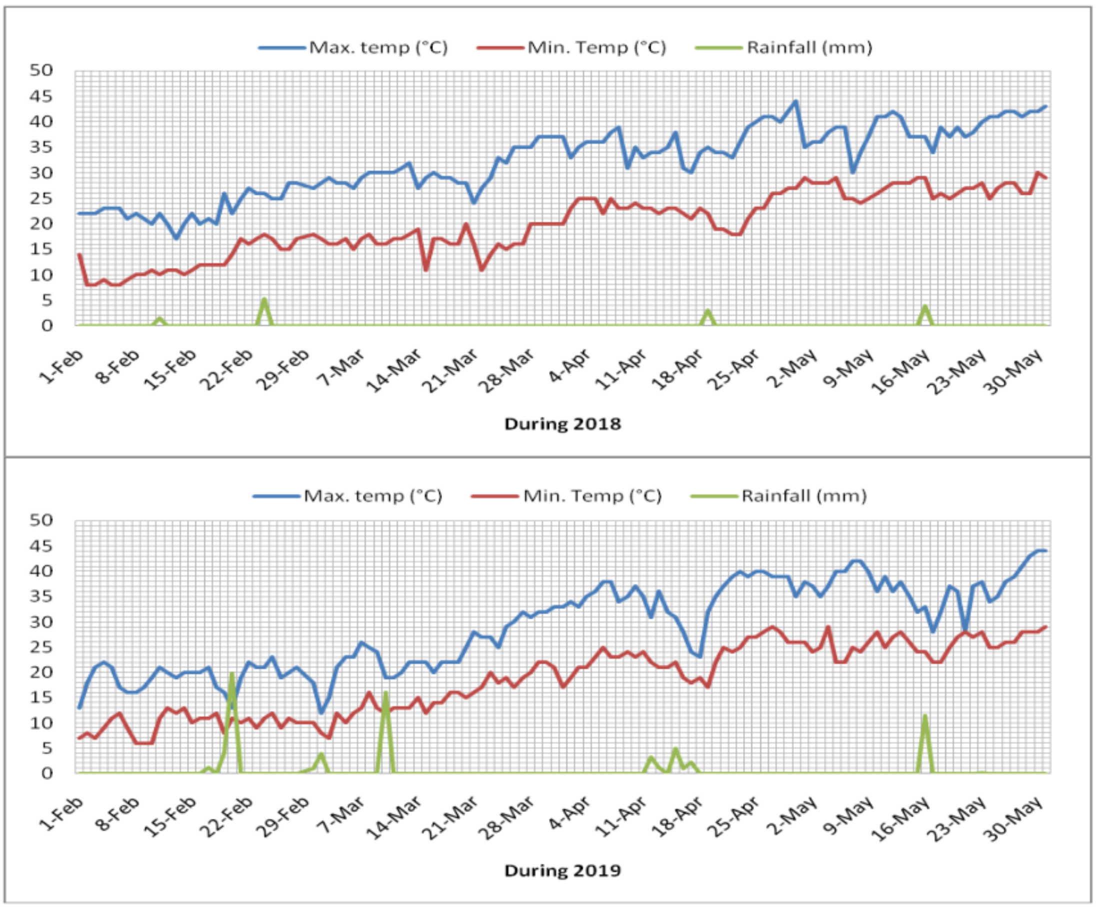


Figure 1. Maximum, minimum, and daily rainfall of experimental location during 2018 and 2019

Table 1. Physicochemical analyses of experimental organic fertilizer sources used during 2018 and 2019

Organic fertilizer sources	Total OC (%)		C: N		D.M (%)		Total N (%)		Total P (mg/kg)		Total K (mg/kg)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
P.M	20.8	20.7	19.8	20.2	78.5	78.5	1.69	1.76	0.64	0.66	1.05	1.07
F.M	16.9	17.2	18.8	19.0	64.9	65.5	1.29	1.28	0.39	0.39	0.69	0.74
Biochar	23.1	23.0	19.9	20.2	62.0	62.4	1.12	1.11	0.45	0.47	0.60	0.60

P.M = Pollutary manure; F.M = Farmyard manure; D.M = Dry matter; OC = Organic carbon; N = Nitrogen; P = Phosphorus; K = Potassium

2.6. Sowing methods and seed treatment

The experiment was laid out in direction of east-west. The size of each experimental plot was 3×5 meters. Sowing was done with the dibbling method and plant-to-plant 18 cm and row-to-row distance of 70 cm was maintained to attain a plant population of 32000 per acre. Before sowing seeds were treated with (Imidacloprid 70WC), Thiamethoxam 70WC) @ 5g/kg, and Thiophanate @ 2g/kg seed to prevent stem borer and disease attack.

2.7. Crop husbandry

A recommended dose of N:P: K (120:100:80) was applied according to the designed treatments. Urea (46% nitrogen) and diammonium phosphate (18% nitrogen+46% P_2O_2) fertilizers were used as a source of chemical fertilizers source. The required amount of phosphorus and potassium was applied at the time of sowing while the required amount of nitrogen was applied in three splits. The half dose was applied at the time of sowing and half of the remaining was applied at the V8 stage and half was applied at silking stage. All other agronomic practices were kept unchanged for all the treatments during the growth period. Water holding capacity was maintained during the entire growth period by using the cut-throat flume and tensiometer. Plants were harvested at physiological maturity for data collection.

2.8. Data collection

Data regarding yield attributes like plant height (cm), stem diameter (cm), cob length(cm), number of grains rows, number of grains per row, number of grains per cob, 1000-grain weight (g), grain yield (t/ha), and biological yield (t/ha); quality parameters like grain protein content (%) and oil content (%); and nutrients like nitrogen, phosphorus and potassium uptake (t/ha) was measure at physiological maturity. Ten plants from each experimental plot were tagged before for collected collection. Quality traits like grain oil content and grain protein content (Anonymous, 1990); and nutrient uptake like nitrogen (Wolf, 1982), phosphorus (Richards et al. 1954), and potassium (Ryan et al., 2001) were measured by pre-described methods. The chlorophyll contents index was measured with the help of a SPAD meter (SPAS-502). Soil physical properties like soil density and total porosity were measured by following (Blake and Hartge, 1986) and (Brady and Weil, 1998). An antioxidant activity like superoxide dismutase (SOD) contents were determined by following the protocol of Beauchamp and Fridovich (Beauchamp & Fridovich, 1971), catalase (CAT) was assayed by following Aebi (Aebi, 1984), peroxidase (POS) was determined by Sakharov and Ardila (Sakharov & Ardila, 1999).

2.9. Statistical analysis

All collected data were analyzed for analysis of variance by using Statistix 9.1 statistical software. Three-way ANOVA was applied for the significance level. The maize traits showing a significant difference ($P \leq 0.05$) were further analyzed through the least significant difference (LSD) test for comparing the difference among the treatment means. R studio and Microsoft Excel were used to prepare graphs.

Table 2. The influence of organic fertilizers and irrigations on the growth and yield of maize hybrids in 2018 and 2019

Treatments			Plant Height (cm)		Stem diameter (cm)		Grain rows per cob		Number of grains per row		Number of grains per cob	
Drought	Hybrids	O.F.S	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
CK	DK-6724	CS	186.3 d-f	190.1 d-f	1.84 d-g	1.94 c-f	16.30 c-e	17.20 c-f	34.23 cd	36.17 cd	557.6 cd	622.1 c-e
CK	DK-6724	BC	190.7 cd	196.3 c-e	1.90 d-f	2.00 c-e	16.60 c	17.37 c-e	34.67 c	36.47 cd	576.9 cd	633.2 c-e
CK	Dk-6724	FM	211.0 b	217.7 b	2.30 a	2.24 b	18.13 b	19.07 b	38.33 b	40.47 b	695.3 b	773.4 b
CK	DK-6724	PM	229.7 a	235.5 a	2.15 b	2.42 a	19.70 a	20.47 a	41.33 a	42.80 a	835.3 a	875.9 a
CK	P-1429	CS	182.2 fg	186.2 fg	1.82 e-g	1.91 eg	15.97 d-f	16.63 fg	32.83 e	35.47 de	524.0 d-f	590.4 d-f
CK	P-1429	BC	188.8 c-e	194.2 c-f	1.87 d-g	1.98 c-e	16.40 c-e	17.13 c-f	33.97 cd	36.33 cd	556.6 c-e	623.3 c-e
CK	P-1429	FM	192.8 c	198.8 c	1.94 cd	2.02 c	16.73 c	17.43 c-e	34.67 c	37.33 c	581.1 c	652.2 c
CK	P-1429	PM	211.8 b	217.3 b	2.03 c	2.22 b	18.40 b	19.00 b	38.13 b	39.93 b	701.5 b	758.9 b
SD	Dk-6724	CS	152.0 i	154.3 i	1.52 j	1.61 h	13.83 h	14.47 h	27.37 g	29.57 g	378.3 g	427.8 h
SD	Dk-6724	BC	173.1 h	178.2 gh	1.66 h	1.83 g	15.20 g	16.23 g	31.20 f	33.47 f	473.9 f	543.8 fg
SD	Dk-6724	FM	183.3 e-g	188.8 ef	1.80 fg	1.95 c-f	15.90 ef	17.03 d-f	33.00 de	35.37 de	524.6 c-f	602.6 c-e
SD	DK-6724	PM	191.8 cd	197.3 cd	1.93 cd	2.01 cd	16.50 cd	17.43 cd	34.50 c	37.00 cd	570.2 cd	645.2 cd
SD	P-1429	CS	150.1 i	153.5 i	1.55 ij	1.56 h	13.27 i	14.37 h	27.03 g	28.73 g	358.9 g	413.7 h
SD	P-1429	BC	172.0 h	177.2 h	1.65 hi	1.85 fg	15.20 g	16.20 g	30.97 f	32.83 f	470.8 f	532.8 g
SD	P-1429	FM	179.8 g	187.0 f	1.78 g	1.92 d-g	15.57 fg	16.77 ef	32.33 e	34.47 ef	503.7 ef	578.8 e-g
SD	P-1429	PM	191.0 cd	196.5 c-e	1.92 de	2.00 c-e	16.30 c-e	17.63 c	34.37 c	36.57 cd	560.9 cd	646.3 cd

Ck=control, O.F.S= organic fertilizer sources, CS= chemical source, BC= biochar, FM= farmyard manure, PM= poultry manure; Means not sharing the same letters for each trait significantly differs at $P \leq 0.05$.

Table 3. Impact of organic fertilizer supplies and irrigation systems on growth and yield traits of maize hybrids during the years 2018 and 2019

Treatments			Cob Length (cm)		Leaf area index		1000-grain weight (g)		Grain yield (t/ha)		Biological yield (t/ha)	
Drought	Hybrids	F.S	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Ck	DK-6724	CS	17.77 d-f	18.30 c-e	4.36 e-g	4.45 e-g	289.5 cd	297.4 c-e	7.68 ef	8.46 c-f	14.48 d-g	15.64 d-g
Ck	DK-6724	BC	18.37 cd	18.67 c-e	4.72 cd	4.82 cd	291.6 cd	302.0 cd	8.15 cd	8.52 c-f	15.32 cd	16.26 c-e
Ck	Dk-6724	FM	20.23 b	20.67 b	5.41 a	5.52 a	324.0 b	334.4 b	9.44 a	9.77 b	17.67 a	18.03 b
Ck	Dk-6724	PM	21.93 a	22.47 a	5.06 b	5.17 b	342.5 a	352.8 a	8.86 b	10.31 a	16.31 b	19.62 a
Ck	P-1429	CS	17.30 fg	17.93 d-f	4.33 fg	4.42 fg	283.8 de	291.8 de	7.58 f	8.14 e-g	13.99 fg	15.37 f-h
Ck	P-1429	BC	17.93 c-e	18.47 c-e	4.45 e-g	4.54 e-g	290.7 cd	299.6 c-e	7.79 d-f	8.56 c-f	14.38 e-g	16.08 c-e
Ck	P-1429	FM	18.43 c	18.83 c	4.62 c-e	4.71 c-e	298.7 c	308.0 c	8.08 c-e	8.79 c	14.92 c-e	16.41 cd
Ck	P-1429	PM	20.13 b	20.73 b	4.84 bc	4.94 bc	319.6 b	329.4 b	8.48 bc	9.52 b	15.64 bc	18.03 b
SD	Dk-6724	CS	14.83 j	15.50 g	3.71 hi	3.79 j	236.5 g	243.2 g	6.49 gh	6.69 h	11.99 h	13.31 i
SD	DK-6724	BC	16.47 hi	17.23 f	3.96 h	4.07 hi	267.9 f	276.2 f	6.92 g	7.76 g	12.78 h	14.75 h
SD	Dk-6724	FM	17.43 e-g	18.53 c-e	4.30 g	4.38 g	282.9 de	291.7 de	7.52 f	8.27 d-f	13.88 g	15.81 d-f
SD	DK-6724	PM	18.20 cd	18.40 c-e	4.60 c-e	4.65 d-f	296.1 cd	305.3 cd	8.05 de	8.75 cd	14.85 c-f	16.64 c
SD	P-1429	CS	14.27 k	15.13 g	3.69 i	3.76 j	230.0 g	236.3 g	6.45 h	6.48 h	11.90 h	12.85 i
SD	P-1429	BC	16.37 i	16.97 f	3.93 hi	4.01 ij	262.8 f	271.9 f	6.87 gh	7.73 g	12.69 h	14.83 gh
SD	P-1429	FM	17.07 gh	17.73 ef	4.24 g	4.32 gh	275.7 ef	285.9 ef	7.42 f	8.07 fg	13.68 g	15.49 e-g
SD	P-1429	PM	18.17 cd	18.80 cd	4.58 d-f	4.67 d-f	292.7 cd	300.7 c-e	8.02 de	8.62 c-e	14.81 c-f	16.47 cd

Ck=control, F.S= Fertilizer sources, CS= chemical fertilizer source, BC= biochar, FM= farmyard manure, PM= poultry manure; Means not sharing the same letters for each trait significantly differed at P≤ 0.05.

3. Results

3.1. Growth and yield attributes

Results regarding the interactive effect of organic fertilizer sources and irrigation regimes between the drought-sensitive and tolerant maize hybrids showed a significant difference in both years 2018 and 2019 (Table 2 and Table 3).

Organic fertilizer sources (CS, B, FM, and PM) showed a significant effect on plant height, stem diameter, cob length, grain rows per cob, number of grains per row, and number of grains per cob between the maize hybrids under normal and drought stress. Maximum Plant height (229.7 and 235.5 cm), stem diameter (2.15 and 2.42 cm), cob length (21.93 and 22.47 cm), grain rows per cob (19.70 and 20.47), number of grains per row (41.33 and 42.80) and number of grains per cob (835.3 and 875.9) was observed with PM application (PM) under 100% FC (Ck) in drought-tolerant maize hybrid (Dk-6824) during 2018 and 2019, respectively. While the minimum plant height (150.1 and 153.5 cm), stem diameter (1.55 and 1.56 cm), cob length (14.27 and 15.13 cm), grain rows per cob (13.27 and 14.37), number of grains per row (27.03 and 28.73) and number of grains per cob (358.9 and 413.7) was noted with chemical fertilizer sources (CS) under 50% FC (SD) in drought-sensitive maize hybrid (P-1429) during 2018 and 2019, respectively. Results showed that organic sources application increased the growth of drought-sensitive maize hybrid (P-1429) and make it statistically par with organic fertilizer sources in drought-tolerant maize hybrid (Dk-6724) under the same irrigation regimes during 2018 and 2019 (Table 2). Results also showed that the application of organic fertilizer sources under severe drought (SD) mitigated the drought stress when it was compared with normal irrigation (Ck) during 2018 and 2019 (Table 2).

Concerning the influence of organic fertilizer sources on cob length, leaf area index (LAI), 1000-grain weight, grain yield, and biological yield, the maximum cob length (21.93 and 22.47 cm), leaf area index (5.41 and 5.52 cm^2), 1000-grain weight (342.5 and 352.8 g), grain yield (9.44 t/ha and 9.77 t/ha) and biological yield (17.67 t/ha and 19.62 t/ha) was noted with PM and FM application under 100% FC (CK) in drought-tolerant maize hybrid (Dk-6724) during 2018 and 2019, respectively. While the minimum cob length (14.27 and 15.13 cm), leaf area index (15.13 and 3.69 cm^2), 1000 grain weight (230.0 and 236.3 g), grain yield (6.45 t/ha and 6.48 t/ha), and biological yield (11.90 t/ha and 12.85 t/ha) was recorded with chemical fertilizer sources (CS) under 50% FC (SD) in drought-sensitive maize hybrids (P-1429) during 2018 and 2019 (Table 3). Results regarding 1000-grain weight showed that organic sources application mitigated the drought stress in P-1429 and also under (SD) treatment and make it statistically as par Dk-6724 and under (Ck) treatment during 2018 and 2019. Results regarding the grain yield showed that the application of chemical fertilizers sources (CS) and farmyard manure application in Dk-6724 were statistically as par biochar application (BC) and farmyard manure application (FM), respectively in P-1429 under the same irrigation regimes (SD) during 2018. In 2019, the statistical value for grain yield of P-1429 with poultry manure application (PM) under (Ck) and biochar application (BC) under (SD) was statistically as par grain yield in Dk-6724 with farmyard manure application (PM) under (Ck) and biochar application (BC) under (Ck), respectively. Application of FM in Dk-6724 under SD removed the adverse effect of drought and made it statistically as par P-1429 with (CS) application under Ck treatment during 2019. Application of CS, BC, and FM in P-1429 for biological yield mitigated the drought effect and made it statistically as par Dk-6724 under the same irrigation during 2018. The same mitigated effect was observed in 2019.

3.2. Quality traits

Quality parameters like oil content and grain protein content showed that organic fertilizer sources significantly improved the quality of maize hybrids under drought stress during both years. The maximum oil content (4.42 and 4.47%) was noted in Dk-6724 with farmyard manure application under normal irrigation while the minimum (2.98 and 3.00%) oil content was noted in P-1429 with CS under severe drought (CS) during the 2018 and 2019, respectively. Alike, oil content and maximum protein content (8.04 and 8.35%) were got in Dk-6724 with farmyard manure under normal irrigation while the minimum protein content (5.41 and 5.91%) was got in P-1429 with CS application under severe drought (Fig. 3.1). A dramatic effect of organic fertilizer sources was shown on drought-sensitive maize hybrid when it was compared with Dk-6724 under normal and drought stress. Oil and grain protein content percentage was improved when organic fertilizer sources were applied under drought stress as compared to normal irrigation. Results also showed that organic fertilizer showed improved oil and protein content when organic fertilizer sources were applied to drought-sensitive maize hybrid P-1429 (Fig. 2).

3.3. Nutrient uptake

Results regarding the effect of organic fertilizer sources on nutrient uptake of maize hybrids under drought stress were also significant. Organic sources showed a significant effect on irrigation regimes and maize hybrids. DK-6724 uptake the maximum nitrogen (131.8 and 141.1 kg/ha) with poultry manure application under control irrigation while P-1429 uptake the minimum nitrogen (88.2 and 95.2 kg/ha) with CS application under severe drought during 2018 and 2019, respectively. Similarly, nitrogen uptake, maximum phosphorus (27.3 and 28.0 kg/ha), and potassium uptake (40.2 and 42.8 kg/ha) were also noted in the same treatment as nitrogen uptake during 2018 and 2019, respectively. Results also showed that organic sources application improved the nutrient uptake under severe drought stress when it was compared with control irrigation. Organic sources application also improved the nutrient uptake in P-1429 which resulted in a non-significant effect between the hybrids. Among the organic fertilizer sources, the maximum uptake was shown in poultry manure followed by farmyard manure and biochar. Drought stress dramatically decreased nutrient uptake (Fig. 2).

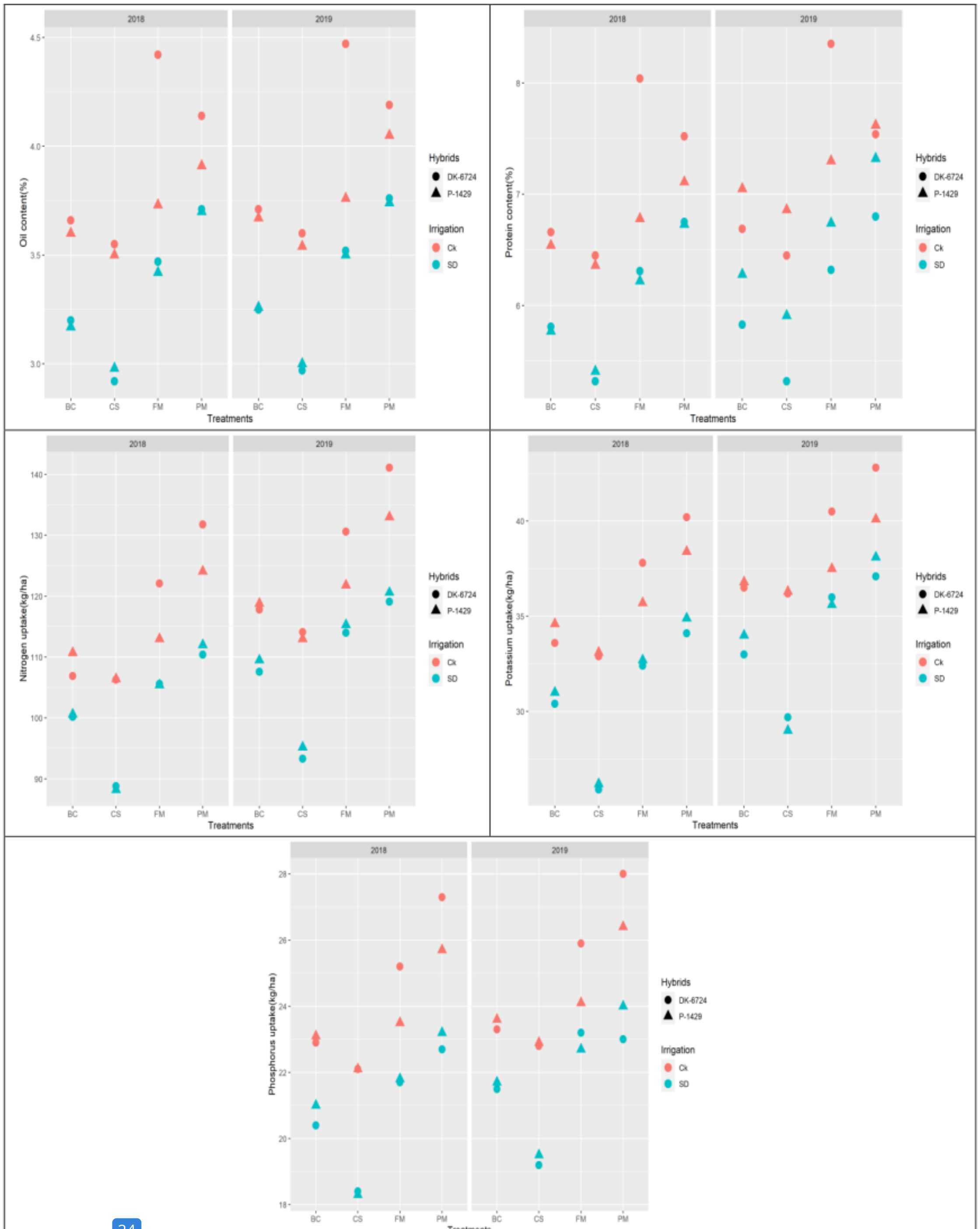


Figure 2. Effect of organic fertilizer sources and irrigation regimes on the quality and nutrient uptake between the maize hybrids during 2018 and 2019

3.4. Leaf chlorophyll contents

The application of organic fertilizer sources and irrigation regimes showed a significant effect on leaf chlorophyll contents between the maize hybrids during 2018 and 2019. Among the organic fertilizer sources, the application of poultry manure showed the maximum leaf chlorophyll contents followed by farmyard and biochar application when it was compared with chemical fertilizer application during both years. High leaf chlorophyll contents were noted under drought stress when it was compared with chemical fertilizer under 50% FC. While maize hybrids showed a non-significant effect with the application of organic fertilizer sources and irrigation regimes for leaf chlorophyll contents (fig. 3).

3.5. Soil properties

Results for soil analysis also showed that the application of organic fertilizer sources significantly improved the soil properties like soil bulk density and soil porosity. Soil bulk density is an important parameter for crop nutrition and irrigation management. The interactive effect of organic fertilizer sources and irrigation regimes with maize hybrids was non-significant for soil bulk density during both years. The main effect of organic fertilizer sources and irrigation regimes was significant. Maximum soil bulk density (1.50 and 1.49 g cm^{-3}) was measured in chemical fertilizer application while minimum soil bulk density (1.39 g cm^{-3}) was measured in poultry manure application during 2018 and 2019, respectively. Between the irrigation regimes, maximum soil bulk density (1.42 and 1.41 g cm^{-3}) was noted in 50% FC, and minimum soil bulk density (1.45 and 1.44 g cm^{-3}) was noted in drought stress (100% FC). It was noticed in a two-year field experiment that with the application of organic fertilizer sources, soil bulk density decreased during 2018 as compared to 2019. The application of organic fertilizer sources also affected the soil porosity significantly. Maximum soil porosity was measured in DK-6724 with the application of poultry manure under 100% FC while the minimum soil porosity was measured in P-1429 with chemical fertilizer application under 50% FC (Fig. 4).

3.6. Antioxidant activity

Antioxidant activity was affected significantly by the application of organic fertilizer sources and irrigation regimes during 2018 and 2019. Maximum SOD, POD, and CAT values were recorded in DK-6724 with the application of poultry manure application under 100% FC. Minimum antioxidant activity was noted in P-1429 with chemical fertilizer under severe drought. Poultry manure and farmyard manure showed low SOD values under 100% FC than biochar and chemical fertilizer applications at 100% FC. The same pattern was noted under severe drought stress (50% FC). POD values also differed significantly with the application of organic fertilizer sources and irrigation regimes. The decline in POS values was noticed in chemical fertilizer and biochar application than in poultry manure and farmyard manure application under normal irrigation (100% FC) and severe drought (50% FC). The same pattern for CAT was also noticed. Maximum CAT was measured in DK-6724 with poultry manure application under 100% FC than P-1429 with the application of chemical fertilizer under severe drought (Fig. 5).

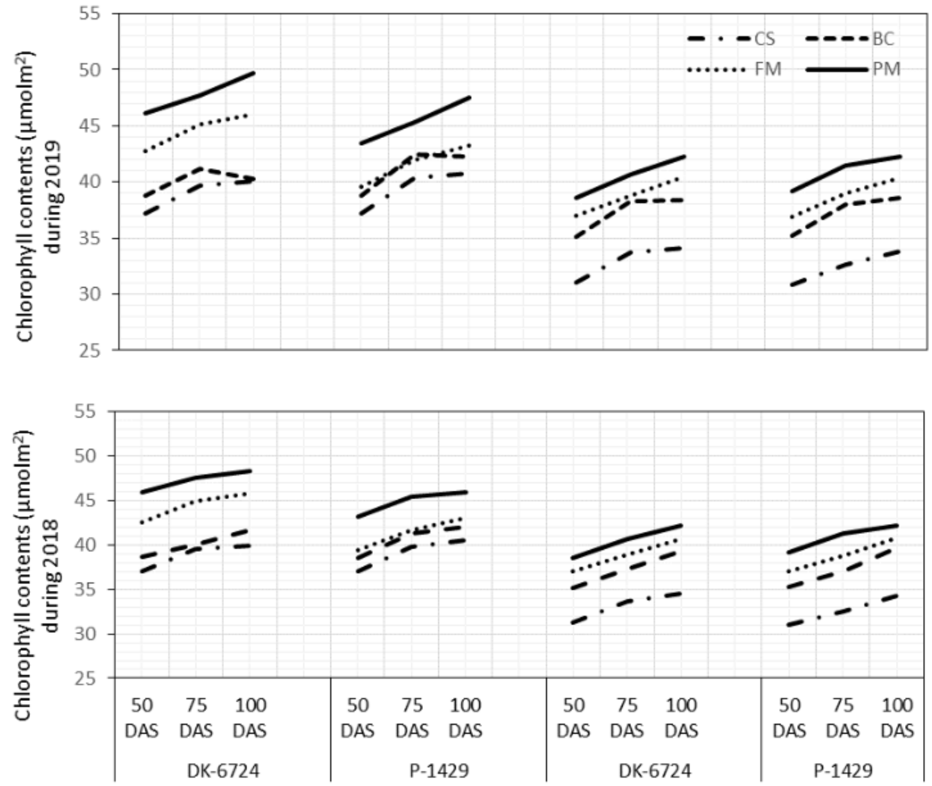
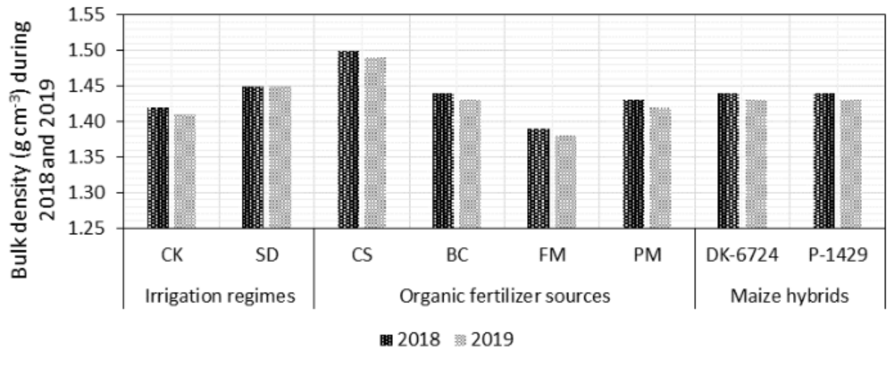


Fig. 3. Effect of organic fertilizer sources and irrigation regimes on leaf chlorophyll contents between the maize hybrids at different growing stages during 2018 and 2019.



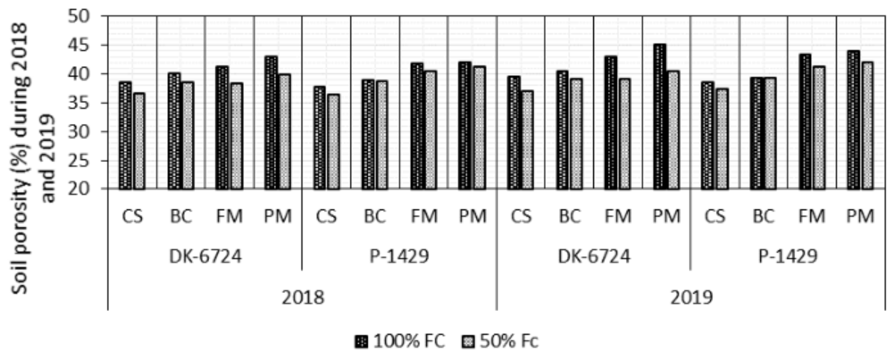


Fig. 4. Effect of organic fertilizer sources and irrigation regimes on soil properties between the maize hybrids during 2018 and 2019

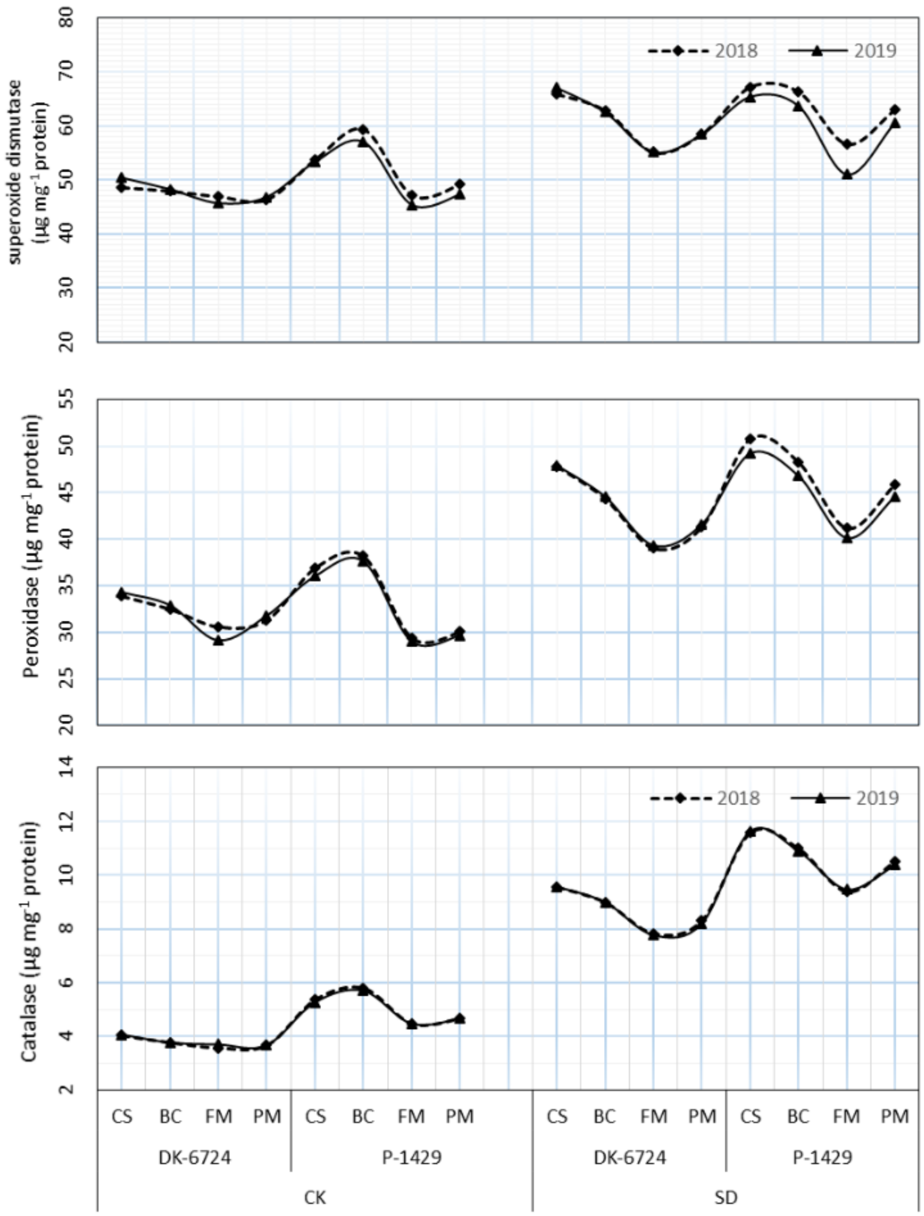


Fig. 5. Effect of organic fertilizer sources and irrigation regimes on antioxidant activity between the maize hybrids during 2018 and 2019

4. Discussion

4.1. Growth and yield

Our results revealed that plant growth, yield and yield components increased with the application of organic sources when compared with chemical fertilizer sources (Table 2 and 3). Nutrient uptake affected crop physiology and increased the leaf chlorophyll content which ultimately improved the maize crop growth. Our results were as par previous findings. In maize, the application of manures, i.e., PM and FM tend to promote higher plant height (Iqbal et al., 2013; Mohsin et al., 2012; Gul et al., 2021). Poultry manure application compared to farmyard manure enhanced the LAI (Amanullah and Khalid 2015). In maize, the length and diameter of the cob have a crucial role in yield. Grains per ear and grain size both affect maize yield, which is significantly influenced by these two factors. The improvement in crop growth increased the yield attributes of maize. For maize to grow its cobs and kernels, nitrogen is a must. Cob and kernel development in maize necessitates the presence of nitrogen. Organic manure application helped to raise the number of grains per cob (Khan et al., 2008; AG et al., 2017). The application of organic manure enhanced the growth, grain yield, and yield components (Khaliq et al., 2004; Khan et al., 2008; Khalid et al., 2016). Many researchers (Khanzada and Arif 2000; Ali et al., 2011; Khan et al., 2008; Udom and Bello 2009, Hadayatullah et al., 2013) reported that poultry manure significantly increased the grain yield in maize and biological yield (Iqbal et al., 2013; Sharma et al., 2019).

Among the abiotic stresses, drought is the major limiting factor for the growth and productivity of many field crops. Although (Zhang et al., 2014; Edreira et al., 2014; Fahad et al., 2016). In this experiment, drought stress reduced the plant height, stem diameter, and leaf area of both drought-sensitive and drought-tolerant maize hybrids, leading to a reduction in yield and other related traits (Tables 2 and 3). This stress treatment had a more severe effect on drought-sensitive maize hybrid as compared to drought-tolerant maize hybrid. Several previous studies have shown that drought stress can negatively impact the growth and yield of various cereal crops (Rollins et al., 2013; Hu et al., 2015; Elazab et al., 2016).

4.2. Quality attributes

Our results showed that maize hybrids were significantly affected by drought stress and organic sources application. Drought stress decreased the oil content and protein content while organic fertilizer sources improved the quality of maize hybrids (Fig. 2). Poultry manure and farmyard manure application increased the protein and oil content compared to biochar and chemical fertilizers. Our findings were supported by past research. It has been shown that protein content is substantially impacted by nitrogen content that is present in sufficient quantities in organic sources, especially in poultry manure and farmyard manure. The rise in protein levels may be related to an increase in leaf N content, rapidly converted to protein during grain growth and then transported to grain for protein synthesis (Nagavani and Subbian, 2014). Aldal'in (2017) resulted that oil content increased with the application of poultry manure. The application of poultry manure is more profitable than other organic fertilizer sources regarding the quality parameters of maize (Triboi et al. (2000); Awad et al., 2014).

4.3. Nutrient uptake

Results regarding nutrient uptake showed that maximum N, P, and K were measured in poultry manure and farmyard manure as compared to biochar and chemical fertilizer under normal and drought stress (Fig. 2). Manure study shows that poultry manure is more nutrient-dense than other manure. Hirzel et al. (2007); Waniyo et al. (2013); Liu et al. (2010) and Soro et al. (2015) support our results; they concluded that N, P, and K uptake increase with increasing nutrient concentration from organic fertilizer sources amendment in soil. These results were also confirmed by some researchers (Patidar & Mali (2002); Rao & Shaktawat (2002). So, it is clear that in maize, maximum N, P, and K uptake was observed in poultry manure application (Fahad et al., 2011; Sarwar et al. 2012; Das et al. 2013) because it is reasonable that poultry manure application increased the soil nitrogen content (Garg and Bahla et al., 2011; Aldal'in, 2017; Aziz et al., 2010). Similarly, with the application of poultry manure, P and K uptake was also increased compared to the control. The improvement in nutrient uptake may be due to the influence of pH and improvement in soil physical properties. These findings confirm our results.

Drought stress as compared to control treatment significantly affected nutrient uptake of drought-sensitive and tolerant maize hybrids (Fig. 2). Several previous studies have reported that drought can decrease the uptake and transportation of macronutrients (such as nitrogen, phosphorus, and potassium) in various plant species (Farooq et al., 2011; Asrar et al., 2011; Suriyagoda et al., 2014).

4.4. Chlorophyll contents

Our results showed that organic sources application increased the uptake of N, P, and K. Organic sources application enhances the nutrient uptake, mainly N uptake by reducing mineral leaching (Fig. 3). Soil Nutrient uptake affected crop physiology and increased the leaf chlorophyll content. The leaf is a factory for food synthesis in the plant. Improvement in leaf chlorophyll contents might be due to the N uptake from organic fertilizer sources. Among the organic fertilizer sources, poultry manure and farmyard manure are rich sources of N nutrients. Nitrogen is an integral part of chlorophyll. Moreover, maximum leaf area was observed in the application of poultry manure and farmyard manure application, respectively. A larger leaf area allows for more photosynthesis, which can improve maize grain yield and related traits by increasing the uptake of nutrients and water through increased transpiration. These findings are consistent with our results.

Drought stress significantly affected chlorophyll contents when compared with the control condition (Fig. 3). Chlorophyll contents were reduced under drought stress. These findings were revealed with previous findings. Chlorophyll, the pigment responsible for photosynthesis in plants, is particularly sensitive to drought stress. Upadhyaya et al. (2008) and Oneto et al.

(2016) reported that drought stress can reduce the amount of chlorophyll in leaves, which can impair photosynthetic efficiency and plant growth.

4.5. Soil physical property

Results showed that the interactive effect of maize hybrids with organic fertilizer sources under drought stress on soil bulk density was not significant. While soil porosity showed a significant effect on drought-sensitive and tolerant maize hybrids with the application of organic fertilizer sources under drought stress (Fig. 4). The improvement in crop growth was subjected due to improvement in the soil's physical properties. The decrease in soil bulk density and increase in soil porosity by application of organic fertilizer sources significantly improved the nutrient uptake by the plant. Organic fertilizers are naturally available mineral sources that contain a moderate amount of plant essential nutrients. Organic amendments have profound influences on soil's physical properties. They gradually release nutrients into the soil and maintain nutrient balance for the healthy growth of crop plants (Shaji et al., 2021). Several studies revealed that the application of organic manures decreased the bulk density (Tejada et al., 2006; Mehmood et al., 2017) and total porosity (Celik et al., 2004; Yang 2011; AlAmin et al., 2017; Roy et al., 2020). The increase in porosity was due to an increase in soil organic matter (Aggelides et al., 2000). The decrease in soil bulk density and increase in soil porosity by application of organic fertilizer sources significantly improved the nutrient uptake by the plant. The finding support our results. These findings support our results.

4.6. Antioxidant activity

Results of this experiment showed that drought stress induced the production of enzymes by their defense system and organic sources improved this production. Maize hybrids were also significantly affected by drought stress and organic sources application (Fig. 5). Drought leads to increased generation of reactive oxidative species (ROS) in the plant cell. To mitigate the negative effects of ROS in plants, different ROS-scavenging enzymes like superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) are produced by the antioxidant defense machinery (Hussain et al., 2018; Khalid et al., 2021a,b). Plants rely on complex antioxidant systems to counteract the production of reactive oxygen species (ROS) and protect themselves from oxidative damage (Sharma et al., 2012; Hussain et al., 2016; Zafar et al., 2018). The application of organic fertilizer sources improved the generation of these enzymes to mitigate the drought stress effect (Hussain and Shah, 2023). The drought-tolerant maize hybrid was also significantly affected under drought stress and application of organic fertilizer sources as compared to the drought-sensitive maize hybrid. These findings support our results.

Conclusions

The application of organic fertilizer sources improves crop yield, yield attributes and maize quality with increasing nutrient uptake. Organic amendments also mitigate the adverse effect of drought through the antioxidant defense system with the production of different ROS-scavenging enzymes. Among the maize hybrids, the application of 10 t/ha poultry manure followed by farmyard manure and biochar is more effective as compared to chemical fertilizer application. Organic manure also improved the efficiency of drought-sensitive maize hybrids (P-1429) under drought stress. The price of chemical fertilizers is increasing day by day and marginal formers of Pakistan cannot afford the high price of chemical fertilizers. So, the application of 10 t/ha application of poultry manure is an alternative to chemical fertilizers.

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