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Review

Multifaceted Ability of Organic Fertilizers to Improve Crop Productivity and Abiotic Stress Tolerance: Review and Perspectives

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Abstract: The long-term use of chemical fertilizers poses a serious threat to crop productivity and soil quality. Organic fertilizers are used to improve the soil fertility and crop productivity. The application of organic fertilizers improves soil health and plant growth by improving the soil organic matter (SOM), soil structure, aggregate stability, nutrient uptake, water-holding capacity, cation exchange capacity, nutrient use efficiency and microbial activities of soil. The intensity of abiotic stress is continuously increasing, which is a serious threat to crop productivity and global food security. However, organic fertilizers have been reported to improve tolerance against drought, salinity, heat and heavy metal (HM) stresses. The application of organic fertilizer improves the leaf water status, nutrient uptake, nutrient homeostasis, synthesis of chlorophyll, osmolytes, hormones, secondary metabolites, antioxidant activities and gene expression, resulting in improved tolerance against drought, salinity, heat, and heavy metals. In the present review, we have discussed the ability of organic fertilizers to improve soil fertility, crop yield, and the nutrient use efficiency. We have also presented the various mechanisms through which organic fertilizers improve tolerance against drought, salinity, heat, and heavy metals. Therefore, this review will put forth new directions for researchers working on the use of organic materials to improve soil fertility, crop productivity and tolerance against abiotic stresses.

Keywords: antioxidants; salinity stress; organic fertilizers; organic matter; nutrient uptake; microbial activity

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1. Introduction

Organic fertilizers possess an appreciable potential to improve environmental sustainability and plant growth [1]. Generally, organic fertilizers are made from the composting of animal manure, human excrement, household waste, municipal waste, agriculture waste and plant parts [2]. The application of organic fertilizers improves the soil organic matter (SOM), soil structure, nutrient availability and microbial activities of soil [3,4], resulting in a significant increase in crop productivity [4,5]. Organic fertilizers also change the soil cation exchange capacity (CEC), improve soil moisture, and change the composition of acidic soils and the soil fauna community structure [6]. Adding organic fertilizers benefits the stability and formation of earthworm communities, owing to the availability of more stable nutrients from manures after aerobic fermentation [7]. Conversely, the long-term use of chemical fertilizers reduces the SOM by causing soil acidification and soil crust, and changes the microbial composition and activity [8].

The use of organic fertilizers also reduces the reliance on chemical fertilizers, which in turn improves the soil health, environmental quality, and crop productivity [9,10]. Organic fertilizers revitalize soils owing to the fact that they are rich sources of SOM and nutrients [10]. By using organic fertilizers, it is possible to reduce the use of chemical fertilizers by 50%, which can reduce the production cost and also increase the soil fertility for better crop productivity [11]. Organic fertilizers contain an appreciable amount of micro and macronutrients, and they can also be used as important N sources for crops [12]. Different studies have reported that the application of farmyard manure, slurry, and compost substantially improves the productivity and quality of tomato, maize, and rice crops [13–15]. Besides this, organic fertilizer can also improve the physiochemical and biological properties of soil, and the availability of both micro and macronutrients to plants, thus maintaining better crop productivity and the sustainability of agro-ecosystems [16].

The intensity of abiotic stresses (drought, heat, salinity, and heavy metals) is continuously soaring, posing a major threat to crop productivity and global food security. The world's population is increasing rapidly, which demands the adaptation of efficient management practices to improve food production under stressful conditions [17]. The application of organic fertilizers is considered a promising strategy for better crop production under stressful conditions [18]. Different authors have noticed that the use of organic materials has great potential to improve crop yield and tolerance against drought, heat, salinity, and heavy metals [19–23]. Therefore, this review sheds light on the ability of organic fertilizers to improve soil quality, crop productivity, and abiotic stress tolerance. In the literature, hardly any reviews about the effect of organic fertilizers on major abiotic stresses and their corresponding impacts on soil quality, nutrient use efficiency, and crop productivity are available. Therefore, this review will put forth new directions for researchers studying the use of organic materials to enhance abiotic stress tolerance and crop quality.

Methodology Used to Write Manuscript

The data used to write this review were collected from different databases including Google Scholar, Scopus, and Web of Science. We used different keywords like "organic fertilizers", "organic manures", "soil fertility and organic fertilizers", "crop productivity and organic manures", "organic fertilizers and soil fertility", "organic fertilizers and nutrient uptake", "organic fertilizers and salt stress", "organic fertilizers and drought", "organic fertilizers and heat stress", "organic fertilizers and heavy metals stress" and "organic fertilizers improve abiotic stress tolerance". The data were collected by searching a wide range of findings from peer-reviewed sources. This included studies related to the topic, global studies and studies published in the English language.

2. Types of Organic Fertilizers

Fertilizers are materials that contain one or more nutrients in the form of chemical compounds with inorganic and organic natures. Fertilizers comprise two different types, i.e., organic and inorganic fertilizers. Organic fertilizers are natural materials from plants and animal sources (Figure 1) that directly and indirectly affect the soil's physiochemical and biological properties [24,25]. A bio-fertilizer is also a type of organic fertilizer that contains beneficial microbes (algal, fungal, bacteria) that improve plant growth by mobilizing the soil available nutrients through their biological activities [2,26]. Animal excreta is the greatest source of organic manure around the globe, followed by poultry and pig manures [27]. Cattle production in recent times has increased by 5% due to increased demands for milk and beef [27]. Therefore, the production of cattle manure, which can be used in agricultural soils for better environmental quality and soil fertility, has also increased. Animal manures are a good and sustainable source of NPK (nitrogen, phosphorus and potassium), and the total N excreted in animal manure globally ranges from 81.5 to 128.3 Tg y^{-1} [28,29]. However, it is important to mention that the type and amount of N in animal manure significantly varies [29,30].

The percentage of N in organic fertilizers depends on the animal species, feed, livestock bedding, animal bedding, and processes adapted to treat and process manures [31,32]. For instance, the N concentration in poultry manures is very high compared to pig and cattle manures; on the other hand, liquid manures have a higher concentration of ammonium (NH_4^+) and lower organic N compared to solid manures [31]. Moreover, the processing and storage methods and bedding material also significantly affect the type and amount of nutrients present in manure [33]. For instance, manures processed through aerobic composting and vermicomposting have high organic N and nitrate (NO_3^-) levels compared to solid manures. Conversely, manures processed anaerobically have higher N concentrations, with dominant NH_4^+ pools of N [26].

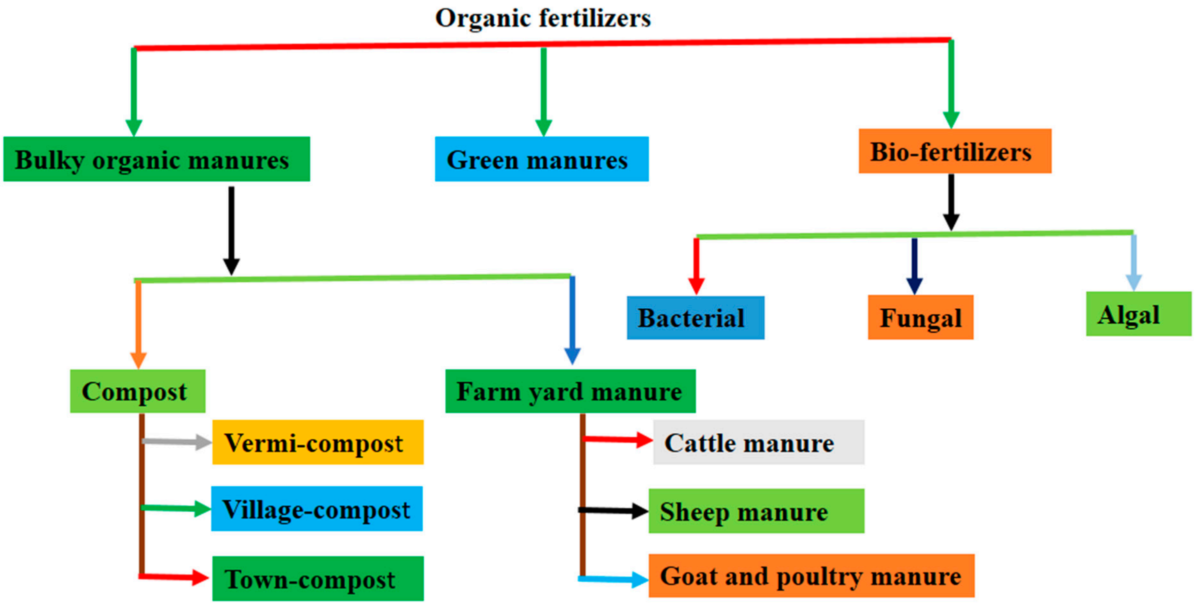

Figure 1. Different types of organic fertilizers used in agriculture.

3. Pros and Cons of Organic Fertilizers

Organic fertilizers substantially improve the SOM, soil structure, soil aeration, water retention, microbial activities, nutrient mobilization, and availability of soil, which in turn increases the soil quality and crop yield [4,9,20,34]. Organic manures also improve the soil structure, soil aggregate stability, and CEC, which improves root growth, ensures better nutrient and water uptake, and consequently ensures better crop performance [35]. Besides this, organic fertilizers also work as a buffering agent for undesirable fluctuations in soil pH [36]. The addition of organic manures improves soil aggregation and increases the soil surface area, which improves the water-holding capacity (WHC) and thus improves plant growth [37,38]. Moreover, organic fertilizers also bring favorable changes in soil microbial activity, diversity, and composition, which ensure the better release of nutrients and improve crop productivity [36]. Organic fertilizers also improve the quality of the environment by reducing nutrient losses and greenhouse gas emissions (GHGs), and they also improve crop yield by improving soil fertility and suppressing plant pests and diseases [39].

However, organic fertilizers also have many cons, as they contain pathogens that are considered to be harmful to plants and animals [39]. Organic fertilizers contain a low quantity of nutrients; therefore, their large-scale use in agriculture is very difficult without chemical fertilizers [40]. The composition of organic fertilizers is also highly variable; therefore, the accurate application of nutrients to plant production is quite difficult [39]. Besides this, organic fertilizers are not readily available owing to the fact that they are needed in large quantities [41]. The decomposition of organic fertilizers is very slow and their decomposition is strongly affected by the soil temperature and moisture, which affect the release of nutrients from organic fertilizers [39,42]. Moreover, organic fertilizers also contain heavy metals, fecal coliforms, and nutrients. When they enter water bodies, they substantially degrade the quality of water and impose a serious health threat [43]. The successive use of a high quantity of sewage sludge and dairy manure can increase the risk of ground and surface water pollution [44]. Organic manures also lead to an increase in NO_3^- levels in groundwater and the eutrophication of surface water [39].

4. Effect of Organic Fertilizers on Growth and Yield of Crops

The application of chemical fertilizers is a method widely and commonly used to supply nutrients to plants [45]. Nonetheless, the use of inorganic fertilizers induces many negative impacts. For example, 50% of N and 90% of P applied through chemical fertilizers are lost to water and the atmosphere [46], which causes water eutrophication, GHG emissions, and environmental issues [47,48]. Therefore, people are now focusing on using organic fertilizers to fulfill the nutrient requirements of crops. Although the rate of nutrient release from organic fertilizers is slow when compared to chemical fertilizers [49], they significantly improve crop growth and quality [50,51].

The seedling stage is an important stage in plant leaves, and the application of organic fertilizers improves seedling growth by improving nutrient uptake, nutrient availability, microbial activity, and the physiological functioning and antioxidant activities of plants [16]. In another study, Adekiya et al. [52] found that rabbit manure, cow dung, and pig manure effectively improved the growth of okra plants. Likewise, Khaitov et al. [53] conducted a study in pepper and noted that livestock manures (265.4 kg ha^{-1}) favorably improved the growth traits and nutrient uptake of pepper plants. Elsayed et al. [54] performed a study on dill cultivars and noted that organic fertilizers appreciably improved the number of leaves per plant, chlorophyll contents, carbohydrates, and NPK concentration (Table 1). These authors found that 100% organic fertilizers resulted in taller plants with the maximum leaves, antioxidant activity, carbohydrates, and NP concentrations [54]. Zilio et al. [55] noted that the maize yield obtained from soil receiving sludge-based digestate was equal to the plants grown with urea. The residual effects of organic fertilizers appreciably improved the growth and yield traits, and the application of farmyard manure (FYM) + 75% NPK appreciably improved the plant height, tillers, chlorophyll content and grain yield. The experimental findings of Yu et al. [56] indicated that the application of organic fertilizers effectively improved the panicles, green leaf area, seed set, and final grain production of rice.

Table 1. Effect of organic fertilizers on growth, yield and quality of crops.

Crop	Organic Fertilizers	Dose of Organic Fertilizers	Major Effects	References
Oryza sativa	Chicken manure	2.5 t ha^{-1}	Chicken manure improved the plant height, tillers, grain and straw yield, grain weight and grain NPK concentration.	[57]
Solanum lycopersicum	Agro fish pallet	18 kg per plot	Agro fish pallet increased the leaf area, root fresh weigh, number of flowers and fruit yield.	[58]
Abelmoschus Esculentus	Poultry manure	4.1 t ha^{-1}	Poultry manure increased the plant height, pods/plant, leaf area, yield, protein, ash, carbohydrates and NPK concentration.	[52]
Curcuma longa	Vermicompost	11.36 t ha^{-1}	Plant height, leaves/tiller, tillers/plant, fresh, dry rhizome yield, and available NPK contents increased with vermicompost application.	[59]
Raphanus sativus	Poultry Manure	15 t ha^{-1}	The combined application of poultry manure improved the plant height, number of leaves, shoot and root length, root diameter, fresh and dry weight of root and shoot, and biological yield of radish.	[60]
Oryza sativa	Animal manure	5 t ha^{-1}	Animal manure improved the plant length, tiller $hill^{-1}$, leaves/plant, panicle length, 1000-grain weight, grain yield and protein percentage compared to chemical fertilization.	[61]

Table 1. *Cont.*

Crop	Organic Fertilizers	Dose of Organic Fertilizers	Major Effects	References
Ziziphus jujuba	Decomposed soybean cake fertilizer	5 kg per pot	Organic fertilizer significantly promoted the chlorophyll contents, photosynthetic rate, reproductive growth and nutritional quality of Pear-jujube.	[62]
Vitis vinifera	Cow dung manure	10 t ha^{-1}	Cow dung improved the root dry matter, individual fruit weight, fruit number plant^{-1} and fruit yield.	[63]
Cucumus sativus	Liquid fertilizer of Mexican sunflower	5 kg/pot	Liquid fertilizers improved the growth, yield and nutrient concentration in cucumber.	[64]
Zea mays	Poultry manure	10 t ha^{-1}	The application of poultry manure improved the crop growth (leaf area, leaf area index, plant height), yield (1000-grain weight, grain yield, biological yield), and grain protein and oil contents.	[65]

The use of rabbit, cow, pig, and poultry manures, green manure, and NPK increased the yield of okra by 35.3%, 57.9%, 36.2%, 39.2%, 45.5%, and 3.2%, respectively, compared to the control [52]. Gao et al. [66] evaluated 769 datasets from 107 research papers and reported that organic fertilizers improved the tomato yield by 42.18%. Moreover, the research findings of Zhou et al. [1] indicated that organic fertilizer application increased the wheat yield by 26.4% to 44.6% and the maize yield by 12.5% to 40.8% compared to chemical fertilizers [1]. The study findings from a trial conducted in Belgium indicated that swine manure could be a substitute for synthetic N fertilizers without yield losses [67]. Tsachidou et al. [68] found that raw digestate could be a partial substitute for N, without compromising on the biomass yield and N content in pasture systems.

The application of poultry and farmyard manure improves the crop productivity and soil nutrient (Zn, Cu, Fe and Mn) concentration [69–71]. In another 40-year long-term study, the application of organic fertilizers considerably increased the maize and soybean yield and soil productivity [72]. Likewise, other authors also found a significant increase in crop productivity and soil with the application of organic fertilizers [73,74]. The application of organic fertilizers also improves crop quality. For instance, Gao et al. [16] noted a significant increase in the starch, protein, amino acid and carbohydrate concentration of maize after the application of organic fertilizers. Further, other authors have also reported a marked improvement in the yield, protein and carbohydrate concentration with the application of organic fertilizers [75–78]. In conclusion, organic fertilizers improve the growth and yield of plants by improving the properties, nutrient uptake and functioning of soil.

5. Effect of Organic Fertilizers on Quality of Crops

Organic fertilizers effectively promote the vegetative as well as reproductive growth and final quality of crops [79]. While Yao et al. [80] found that organic fertilizers markedly reduced the nitrate contents of peppers [80], the study findings of Ye et al. [62] showed that the application of biochar and soybean cake fertilizers significantly improved the fruit water contents, total soluble solids (TTSs), and flavonoid contents of Pear-jujube in the Loess Plateau [62]. Likewise, another group of authors noted that organic fertilizers significantly increased the TSSs, soluble sugars (SSs), lycopene, vitamin C, and nitrate content by 11.86%, 42.18%, 23.95%, 18.97%, and 8.36%, respectively, compared to normal fertilizers [66]. The application of organic manures in the form of vermicompost improved the post-harvest quality; however, microbial compost showed the maximum fresh weight and a premium quality compared to conventional fertilizers [81].

Moreover, Lin and co-authors found that the protein concentration was increased with organic and chemical fertilizers, while the oil contents were decreased with the same treatment. These authors also noted that the combined use of chemicals and organic fertilizers resulted in a reduction in their starch contents, and there was no significant impact of this combination on the nitrogen harvest index (ratio of N accumulated in grain to N accumulated in grain plus straw) [82]. The use of organic fertilizers substantially increased the seed quality parameters and nitrogen use efficiency (NUE) of plants [83,84]. The research conducted by Munoz-Vega et al. [85] found that the application of organic fertilizer to blueberries significantly increased their yield and quality depending on the rate of organic fertilizer application [85].

Likewise, Ye et al. [86] studied the impact of sheep manure and soybean cake fertilizers on pear-jujube (*Ziziphus jujube*) and found a substantial increase in yield and quality with both of these organic fertilizers; however, the effect was more pronounced with the use of soybean cake [86]. Similarly, in another study, the maximum TSSs (10.0%Brix), titratable acidity (1.18%), ash (0.84%), fiber (3.03%), and phenols were recorded with the application of press mud [87]. Poultry manure is an important organic fertilizer and, in a study, it was reported that poultry manure (6 t ha^{-1}) resulted in the maximum seed protein (48.23%), ash (8.71%), and oil contents (67.95%) [88]. Vermicompost is also an important organic fertilizer and it was reported that vermicompost significantly improved the acid contents, antioxidant activity, and fruit yield under field conditions [89]. Adekiya et al. [64] found that organic fertilizers combined with chemical fertilizers increased the mineral concentration of cucumber and that organic manures also significantly increased the tomato and cucumber weights by 137 and 198% compared to the control [64]. It has been reported that chicken manure can increase the tomato yield and soluble protein content by 43% and 23% [90]. Similarly, Begum et al. [91] also observed that AMF substantially increased the yield and oil contents owing to improved antioxidant activities and nutrient uptake [91]. To summarize, organic fertilizers appreciably improve the quality of crops; however, this depends on the type of organic fertilizer applied.

6. Effect of Organic Fertilizers on Soil Quality

Soil fertility refers to the inherent ability of soil to supply essential nutrients to plants for their survival [92]. The fertility of soils largely depends on the parent material, topography, soil microbial activities, and local climatic conditions such as rainfall, temperature, and solar radiation [5]. Soil fertility maintenance refers to retaining, cycling, and supplying the nutrients needed for plant growth over several years.

The application of organic manure is considered an imperative strategy to improve the soil fertility (Figure 2) and sustainability of the agro-ecosystem [93,94]. The soil microbial biomass carbon (MBC) and N indicate the microbial size and soil fertility [95]. Soil microbes play an important role in soil fertility, and the activity of soil microbes is strongly affected by the SOM and soil physio-chemical characteristics [96]. The addition of organic matter by organic fertilizers increases microbial activity, which degrades the SOM and improves the soil fertility status [97,98]. The application of organic manures significantly improves the soil quality by increasing the nutrient uptake and SOM (Table 2); the microbial composition and these details are described in the below sections.

Table 2. Effect of organic fertilizers on soil quality and nutrient use efficiency.

Organic Fertilizers	Dose of Organic Fertilizers	Major Effects	References
Organic manure	7.5 t ha^{-1}	Manure application improved the SOM, NPK, NUE and abundance of soil bacteria (*Proteobacteria*, *Bacteroidetes*, and *Gemmatimonadetes*) and beneficial fungi (*Mortierella*).	[99]
Organic manure	3370 kg ha^{-1} y^{-1}	Organic fertilizers improved the nitrogen and phosphorous uptake indices (NUE and PUE), SOM, and available nutrient contents.	[100]

Table 2. *Cont.*

Organic Fertilizers	Dose of Organic Fertilizers	Major Effects	References
Organic fertilizers	7 t ha^{-1}	Organic manure improved the soil aggregate stability, NPK availability, NUE and PUE in alkaline soils.	[101]
Organic manure	2250 kg ha^{-1}	The addition of organic fertilizer increased the P uptake in grains, and increased the PUE.	[102]
Organic fertilizer (OrgN) combined with a 25% reduction (RN) in N input	41 kg N ha^{-1}	Organic fertilizer increased the soil organic matter content, promoted grain N accumulation, and improved rice production.	[103]
Biochar + FYM	10 t ha^{-1}	Biochar increased the phosphorous use efficiency (PUE), SOC, and available N contents.	[104]
FYM	10 t ha^{-1}	FYM improved carbon assimilation, the net photosynthesis, plant biomass, yield, SOC, SOM and soil moisture contents.	[105]
Organo-mineral biochar fertiliser	7.5 t ha^{-1}	OMBF significantly increased photosynthesis, the N use efficiency (NUE), and aboveground biomass compared with the control.	[106]

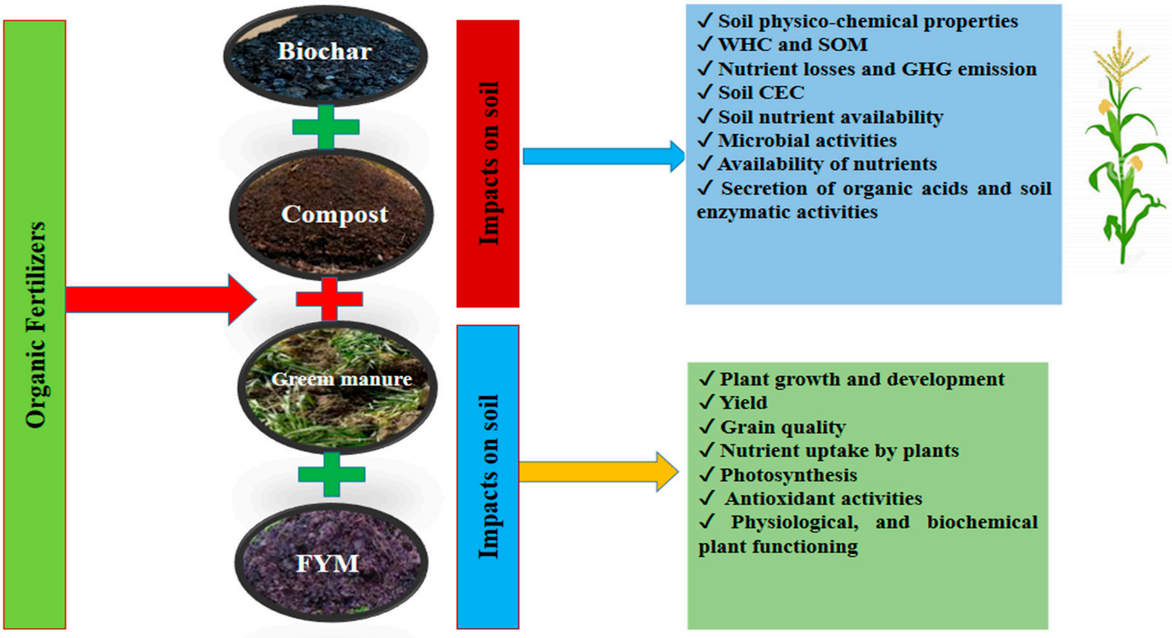

Figure 2. The application of organic fertilizers improves the growth and yield of crops, soil organic matter, cation exchange capacity, nutrient uptake, microbial activity and plant functioning.

6.1. Effect of Organic Fertilizers on Soil Nutrient Status and Nutrient Use Efficiency

Organic fertilizers are considered an effective approach to improving the nutrient uptake and nutrient concentration in plants. For instance, Shang et al. [107] found that vermicompost and mushroom residues significantly increased the available P and K in soil; however, the SOM and available nitrogen were not significantly affected by the application of vermicompost [107]. In another study, Alzamel et al. [108] found that poultry manure and press mud resulted in the highest levels of available NPK, good microbial activities, and a deceased soil pH compared to inorganic fertilizers [108]. Moreover, the findings of Mahmood et al. [75] showed that organic fertilizers in combination with chemical fertilizers greatly increased the SOC and total NPK status, while this combination decreased the soil pH and soil bulk density. Further, these authors also found a significant positive correlation (R_2 = 0.52, 0.91 and 0.55) between the grain yield and soil NPK status [75].

In another study, organic fertilizers (farmyard manure and phosphorus) significantly improved maize productivity, the soil physical properties and phosphorus use efficiency [109]. Likewise, Liu et al. [110] found that, compared to the control organic fertilizers, organic fertilizers significantly increased the available N and P contents of soil; however, the K content in the soil that received organic fertilizers was slightly lower than that receiving the control and NPK treatments [110]. Moreover, organic fertilizers also increased the total available NPK [111]. At the same time, organic fertilizers can reduce the leaching losses of NPK caused by the SOM and soil aggregate stability [112]. Likewise, Tabaxi et al. [113] set up a study with four different treatments (manure, compost, NPK, and control) and found that organic fertilizers appreciably increased the NPK concentration in soil by reducing the leaching losses of these nutrients [113].

The improved soil physiochemical properties and SOC owing to chemical fertilizers and organic fertilizers cause a significant increase in the N accumulation rates in soil [114]. The application of organic manures considerably increased the soil pH, available NP concentration and exchangeable potassium (K), calcium (Ca), and magnesium (Mg). In contrast, chemical fertilizers (NPK) decreased the soil pH, and the exchangeable Ca concentration did not affect the N and Mg concentration and increased the concentration of available P and exchangeable K [115]. Microbes play an important role in soil fertility and crop productivity. For instance, a microbial (*Bacillus* and AMF)-based bio-fertilizer showed promising results and improved the yield, root and shoot biomass and nutrient uptake of maize plants [116,117].

Organic fertilizers possess an excellent potential to improve the nutrient use and subsequent productivity of crops [118]. The combined use of chemical and organic fertilizers has been reported to increase the nitrogen use efficiency (NUE) compared to chemical fertilizers [83,84]. However, some authors found no advantage of chemical and organic fertilizing in increasing nutrient uptake and the NUE [119]. Other authors also found that the combined use of chemicals and organic fertilizers increased the N partial productivity (NPP), N agronomic efficiency (NAE), fertilizer use efficiency and N fertilizer recovery rate (NFRR) in maize and soybean [82,120]. The slow and gradual release of nutrients and the increase in organic matter with organic fertilizers is linked with an improved NUE [121–123]. Other authors also reported a substantial increase in the NUE, N recovery efficiency (REN), agronomic efficiency (AEN), and partial factor productivity of nitrogen (PFPN) with the addition of organic fertilizers [124–126]. The increase in the NUE through the application of organic materials emphasizes the importance of balanced crop nutrition that can ensure better crop productivity [127–129].

6.2. *Effect of Organic Fertilizers on Soil Organic Matter and Soil Carbon*

Organic fertilizers play an important role in increasing the SOC and SOM and result in increased soil fertility. For instance, Du et al. [129] found that organic manures appreciably increased the SOC, total organic carbon (TOC), and particulate organic carbon (POC), and also found that compared with conventional fertilizers, the use of 50% and 100% organic fertilizers increased the TOC storage by 5.91% and 7.84% compared to the control. Further, these authors also found that the replacement of chemical fertilizers with organic manures can increase macro-aggregates, POC, TOC and the yield of crops compared to conventional fertilizers [129]. Organic materials have a positive effect on increasing the SOM (on average 12.9%) compared to the control [130–132].

An increase in carbon cycle enzymes (α-glucosidase, β-glucosidase, and cellobiohydrolase) in soil aggregates (0–20 cm) is considered to be responsible for the increase in the SOC, which indicates a strong connection between the SOC and enzyme activities in soil macro-aggregates [133]. The application of organic manures exerts a strong effect on the SOC, and it was observed that organic fertilizers in combination with lime increase the value of humic acids (HAs). The maximum humic acid (0.67% of C) was observed under FYM, which creates favorable conditions for carbon sequestration [134]. Likewise, Li et al. [135] found that organic manures significantly increased the SOM and its quality.

These authors also found that organic manures increased the quality of humic and fulvic acids and that organic fertilizers increased the total organic carbon, HA, and fulvic acid (FA) by 70%, 89%, and 74%, respectively, compared to the control conditions [135].

Brar et al. [136] conducted a study to determine the impact of organic fertilizers on SOC pools. They found the lowest SOC concentration (7.3 Mg ha^{-1}) in the control and the maximum SOC (11.6 Mg ha^{-1}) with the application of 100% NPK + FYM. Moreover, these authors also found that improved SOC and physical conditions resulted in higher maize yields, and the further application of organic fertilizers also substantially increased the SOC, aggregate stability, and final quality of the crop [136]. In another study, it was found that the MBC was increased by 43.13% compared to control. Further, the build-up and fluxes of the soil microbial biomass, microbial biomass nitrogen (MBN), and microbial biomass phosphorus (MBP) significantly increased with organic manure application [137]. Thus, organic fertilizers improve the SOC and SOM, which in turn improve the overall soil fertility and productivity.

6.3. Effect of Organic Fertilizers on Soil Microbial and Enzymatic Activities

Soil microbes play an important role in the decomposition and release of nutrients from organic materials. Organic fertilizer application enhanced soil enzymatic activities and resulted in a substantial increase in the SOC. For instance, it was reported that the activity of sucrase, alkaline phosphatase, and catalase increased to different degrees under the application of vermicompost; however, the urease activity decreased with vermicompost application [107]. Organic manure changes the soil bacterial structure and increases the abundance of beneficial bacteria including *Bacilli* and *Flavobacteriales*. Organic fertilizers also increase processes related to carbon-related functional groups including aromatic hydrocarbon degradation and *chitinolysis* [110]. Moreover, the use of organic manures also increases enzymes such as dehydrogenases and β-glucosidase, which in turn improve microbial activities [138,139].

Research conducted by Cui et al. [140] showed that the long-term use of organic manures increased the abundance of *Proteobacteria* and *Chloroflexi*; however, a high abundance of *Firmicutes*, *Actinobacteria* and *Planctomycetes* was noticed with the combined use of organic materials and chemical fertilizers [140]. Ikoyi et al. [139] noted that the abundance of bacteria genera linked with nutrient cycling and plant growth including *Burkholderia*, *Allorhizobium*, *Terrimonas*, *Chryseolinea*, *Terrimonas*, and *Ohtaekwangia* was considerably higher in the grassland that received organic fertilizers compared to mineral fertilizers [139]. Moreover, organic fertilizers also induce changes in soil properties that provide a favorable environment for the microbial communities [112].

Conversely, some authors also found no significant difference in the abundance of bacteria and fungi owing to the application of both inorganic and organic fertilizers [141]. It is well acknowledged that organic fertilizer affects soil microbial communities, and it has been reported that fertilizer regimes and the time of application have a strong influence on the bacterial community structure [142]. Likewise, crop species and environmental factors (soil moisture and temperature) also affect the composition of microbial communities [143,144]. Ryegrass treated with slurry has a higher abundance of nematodes, mycorrhizal colonization, and heterotrophic bacteria depending on the rate of slurry compared to urea application [139]. In another study, it was found that sheep manure significantly increased the *Proteobacteria*, *Actinobacteria*, and *Ascomycota*; however, sheep manure application caused a reduction of 24.11%, 23.28%, 38.87%, 19.88%, 18.28%, and 13.89% in *Acidobacteria*, *Gemmatimonadetes*, *Bacteroidetes*, *Verrucomicrobia*, *Basidiomycota* and *Chytridiomycota,* respectively [145]. Microbial growth can be stimulated by the presence of carbon substrates, and the addition of organic manures improves the microbial activity and results in a significant increase in plant performance [137,146]. The organic fertilizers mediated an increase in soil organic matter and microbial and enzymatic activities, resulting in a significant increase in the growth and yield of crops [147,148].

6.4. Effect of Organic Fertilizers on Soil Aggregates, Bulk Density and Water Holding Capacity

The application of organic fertilizers has been reported to increase the soil aggregate stability and water-holding capacity. For instance, Brar et al. [136] found that the integrated use of FYM and 100% NPK significantly increased the water infiltration and aggregate stability compared to the control. However, there was no significant difference between the treatments for electrical conductivity (EC) and bulk density (BD) [136]. The long-term use of chemical fertilizers with organic fertilizers can increase humus mineralization and degrade the soil quality with different consequences, including nitrogen leaching, an increase in toxic metals, and slow energy availability for microbes. The application of organic manures helps to achieve stable yields while maintaining the SOM, SOC, CEC, soil pH, bulk density (BD), and aggregate stability [3,21,52]. The findings of Bhanwaria et al. [137] showed that vermicompost (5 t ha^{-1}) significantly increased the moisture retention and available water at 33 kPa and 1500 kPa. Further, vermicompost increased the water-holding capacity, SOC, CEC, and EC, and decreased the soil pH and BD [137].

Regardless of the soil type, the addition of organic manures increased the Cu and Zn concentration, soil pH, and dissolved organic matter (DOM). However, excessive and higher rates of nitrogen application lead to a reduction in soil pH. Nitrogen can form or contain ammonium that increases the soil acidity until plants directly absorb the ammonium ions. Therefore, the greater the nitrogen rate, the greater the soil acidification [149]. The long-term use of organic manure-amended soils exerts a positive effect that offsets the concomitant increase in Cu and Zn contaminations [149]. In another study, it was reported that the long-term use of low, medium, and high rates of organic manures increased the soil pH by 2.6%, 5.6%, and 9.0%, while they increased the yield by 11.0%, 12.6%, and 3.2%, respectively [150]. The long-term use of NPK fertilizers and organic fertilizers can prevent soil acidification and result in a substantial increase in crop yield [151]. Organic fertilizers have a low bulk density and high porosity; therefore, mixing organic materials with dense mineral fractions can reduce the soil BD [152]. This reduction in BD and increase in SOM with different rates of organic fertilizers has been reported in diverse soils [153].

Guo et al. [154] found that the application of organic manures reduced the BD at soil depths of 0–10 cm and 10–20 cm compared to chemical fertilizers. On the other hand, Yu et al. [155] found that the total soil porosity and macro-porosity were 33–47% lower under manure compared to the control and NPK. Likewise, meso-porosity was also lower under manure. Further, these authors also found that an increase in the soil bulk density following manure application was linked with changes in soil microstructures, i.e., a decrease in pores, throats, paths, and porosity [155].

7. Role of Organic Fertilizers against Abiotic Stresses

The world’s population is continuously growing, and thus a substantial increase in crop productivity is needed. However, the intensity of abiotic stress is increasing while soil fertility is decreasing, posing a serious threat to global crop productivity and food security [18]. Thus, to feed the increasing population and maintain soil fertility, there is a need to develop modern, effective, and eco-friendly ways to improve soil fertility and resistance against abiotic stresses [18]. The literature suggests that the application of organic materials can alter the biochemical and molecular processes of plants that enable them to withstand abiotic conditions [156]. Besides this, organic manures also substantially improve soil fertility, which results in better crop growth and yield under both normal and stress conditions [157] (Figure 3).

7.1. Role of Organic Fertilizers to Mitigate Salinity Stress

Soil salinity is a serious abiotic stress and a major threat to crop productivity. The application of organic materials significantly improves plant performance under saline conditions [158]. For instance, vermicompost application has been reported to improve the morphological and biochemical traits of plants under saline conditions [158,159]. Further, VC also increased the exclusion of Na^+ and the accumulation of K^+, which improve the stomata movements, chlorophyll synthesis, and antioxidant activities (Table 3) that prevent the damaging effects of saline conditions on plants [160]. In addition, these organic manures also improve the chlorophyll and carotenoid contents, which improve the photosynthetic efficiency and subsequently assimilate production [22]. They also decrease malondialdehyde (MDA) and hydrogen peroxide (H_2O_2) by increasing the activities of catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD), thereby resulting in improved growth and yield [22,161].

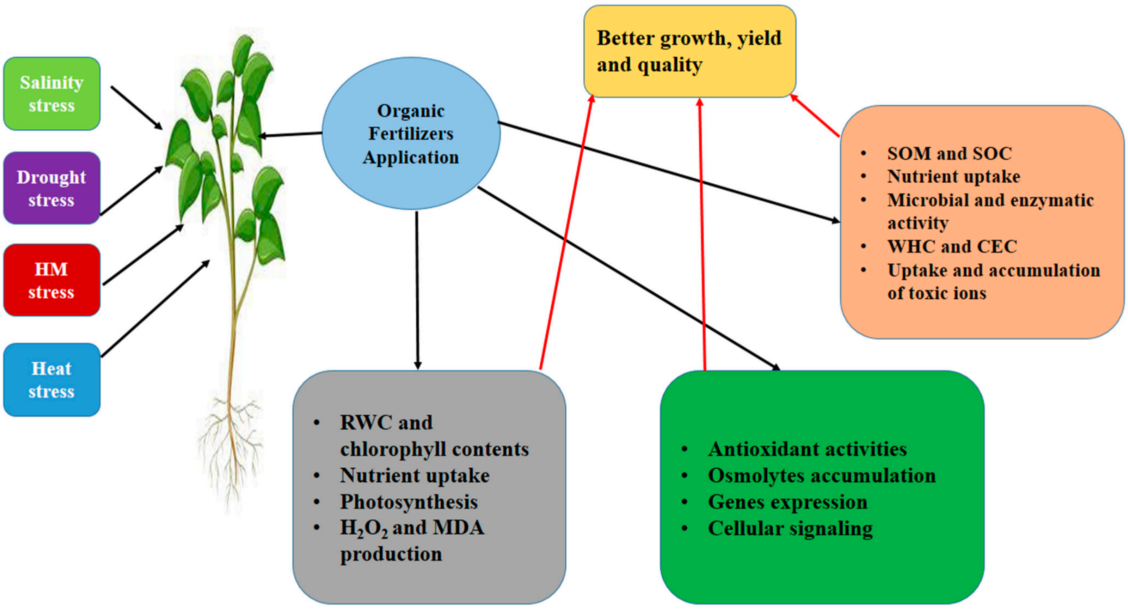

Figure 3. The application of organic fertilizers improves nutrient uptake, photosynthesis, antioxidant activities, gene expression, and soil properties, and reduces MDA and H_2O_2 accumulation, improving the stress tolerance of plants.

The addition of organic fertilizers (Vermicompost and biogas slurry) also increases the availability of nutrients (Ca, Fe, Mg, Mn, K, and Zn) and reduces the accumulation of toxic ions (Cl^- and Na^+), resulting in a significant increase in plant height, dry matter and final productivity [162–164]. Another group of authors also found that under saline conditions, organic fertilizers improved the RWC, stomata conductance, chlorophyll synthesis, and activity of antioxidants (APX, CAT, and SOD) that decreased MDA production and electrolyte leakage, thereby preventing the toxic effects of salinity on plants [165–167]. Biochar is also an important organic material and its application under saline conditions improves root growth, dry matter production, leaf area, and yield compared to control conditions [168].

Table 3. Effect of organic fertilizers on growth, physiological and biochemical functioning of plants under saline conditions.

Crop	Saline Stress	Organic Fertilizers	Major Effects	References
Oryza sativa	7 44 dS m^{-1}	SPM (7.5 t ha^{-1})	SPM improved the NPK, Ca, Mg, Fe and Zn uptake and accumulation, and improved the tillers, grain weight, and grain yield.	[169]
Phoenix dactylifer	NaCl 240 mM	Compost (5% *w*/*w*)	Compost application augmented the proline and sugar accumulation to mitigate ion toxicity, and enhanced the NPK and Ca^+ uptake, leaf water status, stomatal conductance, photosynthesis, growth and yield.	[170]

Table 3. *Cont.*

Crop	Saline Stress	Organic Fertilizers	Major Effects	References
Brassica napus	8 dS m^{-1}	AM (2% *w*/*w*)	AM significantly increased stomatal conductance, the transpiration rate, RWC (%) and photosynthesis, improved nutrient uptake, and decreased the Na/K ratios and EL.	[171]
Oryza sativa	5 dS m^{-1}	Biochar (45 g kg^{-1} soil)	Biochar decreased the Na^+/K^+ ratio and MDA content, and increased the K^+ concentration in roots.	[172]
Acacia senegal	20.5 dSm^{-1}	FYM (6% *w*/*w*)	FYM increased antioxidant enzymes (SOD, POD, CAT), Chl pigments, the root and shoot length and biomass, and decreased Na^+ uptake.	[173]
Dracocephalum moldavica	NaCl 100 mM	VC (10% *v*/*v*)	VC increased he chlorophyll content, proline accumulation, plant growth and biomass, and reduced Na toxicity.	[158]
Trigonella foenum-graecum	NaCl 200 mM	VC and fish flour (1:1)	Organic amendments improved the chlorophyll and carotenoids contents, phenylalanine ammonialyase (PAL) and peroxidase (POD) activities, growth and yield.	[174]
Borago officinalis	8 dSm^{-1}	VC (12 *w*/*w*)	VC increased the chlorophyll b and carotenoids contents, and reduced the MDA contents.	[175]
Helianthus annuus	8.6 dSm^{-1}	VC 1 kg/pot	VC increased the plant growth, yield, nitrate and protein content, and decreased sodium (Na^+) and chloride (Cl^-) toxicity; it thus increased N assimilation.	[162]
Pennisetum setaceum	NaCl 5.0 g per kg soil	VC 2 kg/pot	VC enhanced K^+ accumulation, stomatal conductance, leaf pigmentation, the net photosynthetic rate and root growth, and reduced the oxidative damage.	[160]
Sorghum bicolor	12.6 dSm^{-1}	BC (10% *w*/*w*)	BC improved the photosynthetic efficiency, stomata activity, transpiration rate, and CAT, POD, and SOD activities to increase the plant growth and yield.	[176]

SPM: sugarcane press mud, AM: animal manure, VC: vermicompost, BC: biochar.

BC application also boosted the photosynthetic rate, stomata conductance, and transpiration rate, increased the uptake of NPK, Cu, Fe, Mn, and Zn, and reduced Cl and Na uptake, which improved the growth and yield of wheat, sorghum and maize [165,168,177]. The major effect of organic manures under saline conditions is that they trap excessive Na and release the mineral nutrients that decrease osmotic and ionic stresses [168]. Studies have shown that organic fertilizers lower Na and decrease the Na^+/K^+ ratio, which assists in reducing the negative effects of salinity on plants [165,178]. Moreover, under saline conditions, organic fertilizers also improve osmotic balance by increasing the water-holding capacity and CO_2 assimilation, which results in a better photosynthetic rate, stomatal conductance, and transpiration rate [168]. Besides this, organic fertilizers also offset the negative effects of salinity by decreasing ABA and ACC, and increasing the accumulation of indole acetic acid (IAA) [179]. Likewise, Nikpour-Rashidabad et al. [180] found that organic fertilizers improved the IAA/ABA and IAA/ACC ratios and the vascular cylinder and parenchyma to mitigate the toxic effects of salinity. Further, saline conditions also improve RuBisco activity and the activities of other antioxidants, including glutamate dehydrogenase (GDH) and nitrate reductase (NR), that protect plants from the toxic effects of salinity [179]. The use of organic manures in top-saline soil helps to reduce evaporation and salt movements via the distribution of salts in the rhizosphere; this protects plants from the toxic effects of salinity [181].

The use of organic manures also improves the saline soil porosity, aggregate stability, and hydraulic conductivity, improving plant performance under saline stress [182]. It has been reported that organic fertilizers work as chelates for cations like Ca^{2+} and Mg^{2+} in the soil solution to promote their uptake and reduce Na uptake, thus maintaining a lower sodium absorption ratio for saline soil. Moreover, organic manures also improve the available NPK in soil and their uptake by tomato plants [183]. Souza et al. [184] noted that organic manure application reduced the effects of salt stress and improved the growth, side branches, and yield of yellow passion fruit. Further, El-Shazly et al. [185] found that the application of organic manure to olive and papaya plants improved the growth and biomass productivity, osmotic adjustments between the root and soil, and microbial activities of soil to mitigate the effects of salt stress [185].

Similarly, various other authors also found that organic manure application enhanced the chlorophyll contents and antioxidant activities and reduced the oxidative damage in different plants [186,187]. In addition, the use of organic fertilizers under saline conditions also increases the microbial population and gene expression, boosting biomass productivity and salt tolerance in plants [188]. These organic manures also reduce oxidative damage by increasing antioxidant activities and secondary metabolites, and decreasing ROS production in plants [189,190]. Organic fertilizers also improve the concentration of both micro and macronutrients, vitamins, hormones, and enzymes that reduce the harmful effects of salt stress on plants [191,192]. Additionally, organic manures attain a better environment through microbial activities that fix atmospheric N, P, and K, produce antibiotics and degrade organic matter, which contribute to an increase in salinity tolerance [193]. The use of AMF is an important approach to mitigate the effects of salt stress. It has been reported that AMF improves salt tolerance through improved soil nutrient uptake by increasing root growth and nutrient availability [194]. It also increases antioxidant activities and physiological activities, and reduces the uptake of toxic Cl^- and Na^+ ions, which in turn improve plant growth [194]. Moreover, organic fertilizers also increase the abundance of soil bacteria, gene expression, and the activity of antioxidants, which favors plant growth under saline soils [195]. In conclusion, organic fertilizers improve salt tolerance by improving nutrient uptake, the physiological functioning and antioxidant activities of plants, and by reducing the uptake of Cl^- and Na^+.

7.2. Role of Organic Fertilizers to Mitigate Drought Stress

Drought is prolonged dryness that negatively affects plant growth and development [196]. It has been documented that two-third of the cultivated area around the globe is facing drought stress, which will increase in the future owing to rapid climate change and global warming. Drought stress (DS) negatively affects the growth and productivity of plants through physiological and biochemical changes that pose a serious threat to food security [197]. It has been reported that organic fertilizers possess an appreciable potential to improve crop productivity under DS [21] (Table 4).

Table 4. Effect of organic fertilizers on the growth, physiological and biochemical functioning of plants under drought conditions.

Crop	Drought Stress	Organic Fertilizers	Major Effects	References
Triticum aestivum	45% FC	10% cow manure	CM improved panicle emergence, shoot and root growth, chlorophyll synthesis, biomass, and the grain Fe, Zn, and Mg contents.	[198]
Solanum lycopersicum	DS was imposed 15 days after seedling establishment	100 mg kg^{-1} VC	Vermicompost augmented osmolyte (proline, glycine betaine and sugars) production, reduced ROS activity, and increased the chlorophyll content, photosynthesis, PSII activity, growth and dry matter accumulation.	[199]

Table 4. *Cont.*

Crop	Drought Stress	Organic Fertilizers	Major Effects	References
Chenopodium quinoa	10% FC	5% corn straw BC	BC application enhanced the photosynthetic rate along with stomatal movement, plant height, shoot biomass, and grain yield.	[200]
Phragmites karka	40% WHC	2.5% BC	The application of BC improved plant biomass and the root to shoot ratio, increased the chlorophyll content and net photosynthetic rate, and reduced oxidative stress.	[201]
Triticum aestivum	35% WHC	5% rice straw biochar	Biochar application reduced transpiration, Chl pigments and photosynthesis, the stomatal response, WUE, H_2O_2, TBARS, and EL, and increased the antioxidant enzyme (SOD and CAT) activities under drought stress.	[202]
Glycine max	DS was imposed after two days of sowing	20 t/ha corn cob BC	Biochar considerably improved the sugar and proline contents, growth and yield under drought stress.	[203]
Triticum aestivum	20% PEG-6000 used to impose osmotic potential at −0.78 MPa for drought stress	BC of timber waste	BC improved chlorophyll a, chlorophyll b, the photosynthetic rate, transpiration rate, 100-grain weight, and grain NPK concentration.	[204]
Cicer arietinum	25% FC	30% BC	BC enhanced the leaf Ca^+ and K^+ contents, Chl pigments, transpiration rate and CO_2 assimilation, and improved the proline, POD, SOD, and CAT activity under stress.	[205]
Opuntia basilaris	30% FC	5% vermicompost	The application of VC increased the physiological and biochemical parameters, and led to a decline in the MDA and H_2O_2 contents under DS.	[206]
Ceratonia siliqua	70% FC for 4 months	5% BC	BC boosted the physiological and biochemical parameters and nutrient uptake in carob trees. It also increased the soluble sugar and protein content, stomatal conductance, PSII activity, leaf water potential, chlorophyll and carotenoid contents, and nutrient (N, P, K, Ca) uptake compared to the control treatment.	[207]

BC: Biochar, FC: field capacity.

Organic amendments retain the soil moisture and improve the soil fertility (Table 3), therefore maintaining better plant performance under drought conditions [208]. Poultry manure is an important organic manure and its application improves WHC and has a positive effect on the physiochemical and biological properties of soil [209]. Likewise, FYM also induces a positive effect on plant growth and improves plant productivity by increasing nutrient uptake and the physiological and biochemical functioning of plants [210–212]. Organic fertilizers have a porous structure and high surface area that provide a safe environment for microbes, increasing the availability of both micro and macronutrients. Moreover, organic manures also improve soil porosity, moisture retention, and water use efficiency (WUE), therefore improving plant performance under drought conditions [201,213].

The application of organic manures (compost, vermicompost, biochar, and FYM) has been reported to improve crop yield and resilience against drought stress [160,170,209,214]. The use of organic fertilizers increases the SOC, SOM, mineral nutrient concentration, and soil-water holding capacity, allowing plants to better withstand drought conditions [215]. Further, organic fertilizers also induce tolerance against water deficit conditions by increasing microbial activity and enhancing the fungal-to-bacterial ratio in soil [216]. The application of organic materials stimulates the physiological and biochemical activities under water deficiency and reduce the MDA and H_2O_2 production, mitigating the effects of drought on plants [206,217–219].

The use of organic manure also positively affects the physiological and biochemical functions of plants, inducing a positive effect on plant performance under drought conditions. For instance, it has been reported that organic fertilizers improve the WUE, stomata conductance, photosynthesis, and relative water content (RWC) under drought conditions [220]. Likewise, improvements in the RWC, transpiration rate, photosynthesis, and osmotic potential have been also reported with organic fertilizers under drought conditions [221,222]. Furthermore, organic manures also substantially improve CAT, POD, and SOD activities and result in lower MDA and H_2O_2 production; this consequently leads to better drought tolerance [223]. Likewise, Hafez et al. [224] also found that organic manures increase the POD, SOD, and APX activity with a decrease in H_2O_2, MDA, and EL under drought conditions. Moreover, Bhanwaria et al. [137] revealed that organic amendments also lead to better nutrient and water uptake, antioxidant activities, chlorophyll synthesis, and osmolyte accumulation, resulting in better plant growth and yield under drought conditions. The findings of previous research have also indicated that AMF improves growth by increasing the photosynthetic rate, chlorophyll synthesis, nutrient uptake and assimilation, osmolyte accumulation (proline, free amino acids, and sugars), relative water contents and antioxidant activities, and decreases H_2O_2 and MDA production [91]. Organic fertilizers also improve membrane stability and reduce lipid peroxidation, unregulated antioxidant activities, and osmolyte accumulation, substantially improving salt tolerance [199]. Thus, organic-fertilizer-mediated increases in drought tolerance are linked with increased antioxidant activities, WHC, and plant physiological functioning, and with reduced ROS production.

7.3. Role of Organic Fertilizers to Mitigate Heavy Metals Stress

Heavy metals (HMs) are also a serious threat to crop productivity and human health. The concentration of HMs is increasing in the environment due to anthropogenic activities. Organic fertilizers are being used to reduce the accumulation of HM in food plants. The use of organic fertilizers can reduce the concentration and availability of HM in contaminated soils [225]. Organic materials (cow manure, compost, poultry manure, sheep manure, and biochar) form complexes with HMs, therefore reducing their availability and uptake by plants [20,226–228]. Moreover, organic fertilizers also reduce the available portions of HMs, reducing the transfer of HMs to plants [20]. Likewise, Bashir et al. [210] found that co-composted FYM improved wheat growth and reduced the toxic effects of HMs by increasing chlorophyll synthesis and decreasing oxidative stress through enhanced antioxidant activities.

The use of compost biochar also decreased the exchangeable fractions of arsenic (As), cadmium (Cd), zinc (Zn), and copper (Cu) in the roots and shoots of the pakchoi cabbage [229]. Biochar can persist in soil for one hundred years and it has a porous structure and alkaline nature [230], which reduces the bioavailability of HMs, thus reducing their absorption by plants and subsequent transport to the food chain [231]. Besides this, organic manures also immobilize HMs, reduce their uptake and ensure better plant growth [232–234]. Humic acids have also shown high microbiological stability and can promote nutrient absorption and plant growth [229,235]. It has been reported that humic acid immobilizes Pb and Zn and decreases the fractions of these HMs [229] (Table 5).

Table 5. Effect of organic fertilizers on growth, physiological and biochemical functioning of plants under metal stress conditions.

Crop	Metal Stress	Organic Fertilizers	Major Effects	References
Gossypium herbaceum	Cd (4 mg·kg^{-1})	Biochar (3%)	BC application improved the seedling biomass, chlorophyll contents, photosynthesis, and SOD, POD and CAT activity, and reduced MDA and EL, and Cd absorption and transportation.	[236]
Atriplex undulata	Cd (0.42 mg kg^{-1})	Manure (1% of soil weight)	Manure increased the plant height, root fresh and dry weight, shoot fresh and dry weight, leaf area, chlorophyll, carotenoid and proline, and decreased the MDA concentration.	[237]
Atriplex nummularia	Pb (850 mg kg^{-1})	Biochar (1%)	BC reduced the metal uptake and increased the plant length, leaf area/plant, leaf numbers, bioaccumulation factor and translocation factor.	[238]
Vigna radiata	Cd (150 M)	FYM (2%)	FYM decreased the Cd acquisition, improved the stomatal conductance, leaf net transpiration rate and ascorbic acid (shoot vitamin C) contents, along with other antioxidant enzymes (catalase and phenyl ammonia lyase); meanwhile, the malondialdehyde and hydrogen peroxide activity decreased.	[239]
Brassica napus	Ni (50 mg kg^{-1})	AM (2% *w*/*w*)	Animal manure improved nutrient uptake, photosynthesis, transpiration, chlorophyll and RWC, and decreased the Na^+/K^+ ratios, EL, daily intake of metal (DIM) index, health risk index (HRI) values and Ni uptake in plants.	[171]
Nicotiana tabacum	Cd	CM (2%)	CM effectively reduced the leachability and metal uptake in leaves and improved plant growth and yield.	[240]
Nicotiana tabacum	Pb-Cd (100 mg kg^{-1})	CM (15 g/pot)	CM increased the plant dry weight, P uptake, soil pH and total glomalin concentration, and decreased the DTPA-extractable concentrations, Pb and Cd toxicity.	[241]
Pisum sativum	Cr (371 mg kg^{-1})	Peat moss (PTM) (50 g/pot)	PTM significantly reduced the bioavailability of metal and improved the health risk percentage, plant growth, yield and biomass.	[242]
Oryza sativa	As	FMBC (2%)	FMBC increased the ratio of essential amino acids and reduced the As toxicity to improve the dry weights of rice roots, stems, leaves, and grain yield.	[243]

BC: biochar, FYM: farmyard manure, AM: animal manure, CM: cow manure, FMBC: ferromanganese oxide biochar composites, Cd: cadmium, Cr: chromium, As: arsenic, Pb: lead, Ni: nickel.

Organic fertilizers decreased the TFs of Cd and Zn and substantially improved plant growth by increasing photosynthetic pigments, the photosynthetic efficacy, antioxidant activities, and the accumulation of potential osmolytes [244,245]. Organic manures adsorb HMs and reduce the plant toxicity while increasing plant biomass through an enhanced WUE, antioxidant activities, and reduced HM uptake, resulting in safe food production [245,246]. However, the effects of organic manure can vary with soil properties, the planting species, and the properties of the organic material [245]. In Cd-contaminated soil, the application of organic manure increased the biomass of *Bidens tripartite* while decreasing the Cd contents [247]; meanwhile, pig manure increased the phytoextraction of HMs by *Streptomyces pactum* [248]. Other researchers also found that cattle manure decreased lead (Pb) and Cd uptake and accumulation in the plant tissues of tobacco [249]. In another study, poultry manure application resulted in a higher accumulation of cadmium

(Cd), chromium (Cr), iron (Fe), and lead (Pb), whereas it resulted in a reduction in the accumulation of Cu and Zn in garlic. Further, it was also noted that the application of organic fertilizers reduced the pollution load index, health risk index, and daily intake of metals compared to control conditions [250]. Further, the use of organic manures also substantially improved the leaf water status, stomata conductance, photosynthesis, osmolyte accumulation, and antioxidant activities (APX, CAT, POD, and SOD), which improved the plant performance under HM stress [245,251]. In conclusion, organic fertilizers mitigated the HMs by improving the antioxidant activities, osmolyte accumulation and plant functioning, and reducing the HM uptake.

7.4. Role of Organic Fertilizers to Mitigate Temperature Stress

Temperature is one of the most important environmental factors regulating growth and yield [19]; however, low and high temperatures adversely affect plant growth and yield [252]. The use of organic manure is suggested as an important approach to improving heat tolerance in plants. Organic manure improved the chlorophyll concentration, leaf area, plant height, stem width, and biomass yield by 35%, 36%, 41%, 59%, and 78% under heat stress [253]. In another study, it was noted that organic fertilizers improved the soil water-holding capacity by 8% and decreased the maize canopy temperature, leading to a significant improvement in the photosynthetic characteristics and antioxidant activity [254]. The increased soil WHC following organic manure application shows that this is an effective approach to mitigating the adverse effects of heat stress (HS) on plants [254].

The study findings of Kumar et al. [255] showed that the combined application of FYM and NPK enhanced the heat tolerance in maize by improving the soil microbial activity, antioxidant activities and nutrient uptake. Likewise, in lettuce plants, the application of cattle manure mitigated the toxic effects of heat stress and improved the leaf area, leaf weight and chlorophyll synthesis [256]. On the other hand, the application of bio-fertilizers increased the tolerance against late heat stress. These authors found that the application of fertilizer enhanced the quantum yield of PS-II, chlorophyll fluorescence parameters and grain yield [257]. In another study, it was noted that biochar and compost application substantially increased the WUE under HS, resulting in a significant improvement in plant growth and yield [258]. These authors also found that cattle manure application improved the leaf nutrient status and efficacy of PS-II, and reduced oxidative stress by increasing jasmonic acid and decreasing abscisic acid (ABA). A very recent study indicated that the combined use of 50% nitrogen + 50% compost enhanced the grain-filling rate, grain protein, wet gluten, and grain productivity under heat stress conditions [259]. To summarize, organic fertilizers mitigate the adverse effects of HS by maintaining nutrient homeostasis, antioxidant activities, osmolyte accumulation, WUE, and reducing ROS production.

8. Conclusions and Future Prospects

The application of organic manures improves soil organic matter, macro-aggregates, enzymatic activities, and microbial activities, improving growth and yield. Further, the use of organic fertilizers has also been reported to increase stress tolerance in plants. The application of organic fertilizers substantially improves water uptake, water use efficiency, nutrient uptake, osmolyte accumulation, antioxidant activity and gene expression, providing better resistance against these stresses.

However, the role of organic fertilizers in mitigating abiotic stresses is not fully explored and many questions need to be answered in future research programs. The effect of organic fertilizers on germination is poorly studied; therefore, authors must explore the effect of organic fertilizers on seed germination and subsequent seedling growth. The application of organic manures improves nutrient uptake under stress conditions and it is mandatory to determine how organic fertilizers affect nutrient channels and signaling under stress conditions. Moreover, the role of organic fertilizers in protecting the photosynthetic apparatus from stress conditions must also be explored. The effect of organic manures on hormones and osmolyte accumulation is rarely studied in the literature and it is imperative to explore the role of organic manures in this respect.

The role of organic manures under heat, cold, and flooding stress is rarely studied; therefore, it is suggested that their effects under cold and heat stress are explored. The combination of organic fertilizers and chemical fertilizers affects the soil properties and improves crop productivity; however, more studies are needed on this aspect in a wide range of climate and soil conditions. The use of organic manure must be optimized for different crops considering the climate, soil, and crop conditions. Organic manures are bulky substances and there is a need to develop measures for a continuous supply of organic fertilizers. In this context, the combined use of organic fertilizers and chemicals can provide an excellent solution. There is an urgent need to give awareness to farmers about the use of organic fertilizers for field crops for the sustainability of agro-ecosystems. In addition, organic fertilizers also contain some toxic chemicals; therefore, proper care must be taken during their application.

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