Chapter 8
Biochar Application to Soil for Mitigation of Nutrients Stress in Plants

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Abstract Nutrient stress is a worldwide problem which may alter the biochemical, physiological, and molecular processes in all kinds of plants. In addition, such nutritional stress is the major cause of malnutrition in the developing and poor countries. Generally, plants require 17 macro and micro nutrients for the optimum growth, development, and yield. Moreover, some other additional mineral elements are very crucial for the survival of the plants under stress conditions or help the farmer to produce the quality products. The proper and timely management could reduce its

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impacts. The impact of nutrient stress depends on plant age, soil types, plant species, ecology, climatic conditions, and genome of it. Usually, morphological characteristics of the plants are considered the quick, valuable, accurate, and strong identification of nutritional deficiency of the specific nutrients. Biochar (BC) is a cheap potential source of Carbon (C) which not only improves health and fertility of soil but also improves the quality and productivity of crops both in normal and under stress conditions. Here we reviewed that BC is the source of various kind of elements such as C, H, N, P, K, Mg, Ca, S and some other nutrients that are key for healthy plant growth. Moreover, it improves the soil physico-chemical properties such soil porosity, surface area, CEC, soil hydrophobic capacity, soil aeration and soil surface oxidation which results into increase in soil nutrients availability and further their retention in the rhizosphere. In conclusion, all these properties of BC could help the plant to survive under the nutrients stress conditions.

Keywords Nutrient stress · Biochar · Environmental factors · Climate change · Plant growth

8.1 Introduction

The human global population will expected to reach 9.7 billion in 2050 (Rodés-Guirao 2013) and definitely will increase the demand of human food and feed requirements (Golden and Cotter 2021). Numerous abiotic stresses are threatening the global food security (Crandall et al. 2022). In addition to water and carbon dioxide, the plant growth needs balanced and sustainable nutrient acquisition to roots from soil for the production of carbohydrate (Amsili et al. 2021). Nutrient stress is a significant environmental factor that influences the plant growth and development (Bechtaoui et al. 2021). In addition, all stages of plant growth and development, including the whole plant, individual tissues and cells, and even subcellular levels are significantly affected (Holland et al. 2020). Some time, longer period of stress can harm plants by disturbing the protein aggregation and increased membrane lipids fluidity (Ogden et al. 2018; Li et al. 2020b). The healthy cell can create the cross link of different polymers and proteins and hence improve the stiffness of cell wall (Wang et al. 2016). The cell wall structure and components dictate the cell and tissue morphology depending the nutrient availability. Moreover, some time, it changes the pattern of cell growth and development (Ogden et al. 2018). The enzymes inactivation in mitochondria and chloroplast can be happened in some sever nutrient stress (Borysiuk et al. 2022).

Balanced proportions of macro-nutrients (carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium and sulfur and micro-nutrients (iron, zinc, manganese, copper, boron and molybdenum are vital for optimal growth and plant harvest (Pandey 2018). Nutrient stress could be resulted into nutrient specific phenotypes, growth inhibition, incomplete plant phenology and oftentimes, reorganization of root architecture (van der Bom et al. 2020; Al-Zahrani et al. 2022; Rajesh et al. 2022; Anam et al. 2021; Deepranjan et al. 2021; Haider et al. 2021; Amjad et al. 2021; Sajjad et al. 2021a, b; Fakhre et al. 2021; Khatun et al. 2021; Ibrar et al. 2021). Crops have some native ability in coping and tolerating these stress signals that communicate with one another (Bukhari et al. 2021; Haoliang et al. 2022; Sana et al. 2022; Abid et al. 2021; Zaman et al. 2021; Sajjad et al. 2021a, b; Rehana et al. 2021; Yang et al. 2022; Ahmad et al. 2022; Shah et al. 2022). The productive phase includes the development of male and female floral components, the variation of both gender flowery parts and the formation of both gender characteristics is heavenly dependent on the nutrition (Souri and Hatamian 2019). Although each phase reacts to nutrient stress differently leading to decrease in net production. However, any stress during the productive stage (Zhang et al. 2018a;) has substantial implications since productive parts are essential elements of yield and the primary source of nutrition for the whole human population (Souri and Hatamian 2019; Muhammad et al. 2022; Wiqar et al. 2022; Farhat et al. 2022; Niaz et al. 2022; Ihsan et al. 2022; Chao et al. 2022, Qin et al. 2022; Xue et al. 2022; Ali et al. 2022; Mehmood et al. 2022; El Sabagh et al. 2022; Ibad et al. 2022).

Reactive oxygen species have a detrimental effect on cellular metabolic processes and harm all biological components (Nieves-Cordones et al. 2019). Therefore, it is crucial to detoxify these reactive oxygen species, and plants have evolved extensive defenses against them (Hasanuzzaman et al. 2018a; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018a, b, 2019a, b, 2020, 2021a, b, c, d, e, f, 2022a, b). Plant cells often increase the action of reactive oxygen species sifting enzymes and boost their creation of anti-oxidants in response to elevated reactive oxygen species levels in order to maintain redox equilibrium (Mittler et al. 2022).

Different management practice is being used to combat the different kind of stresses (Saud et al. 2013, 2014, 2016, 2017, 2020, 2022a, b). Biochar a carbon-based solid created through the burning of organic substances, including wood, animal dung, poultry manure, and municipal sludge (Amoakwah et al. 2020; Adnan et al. 2018a, b, 2019, 2020). It is sometimes referred to as burned biomass or black carbon. Controlling plant nutrition can help plants become more resilient to other different kind of environmental stresses (Fig. 8.1). The discovery and breeding of nutrient stress tolerant cultivars are now being worked on with better root architecture (Campobenedetto et al. 2021). One of these uses is utilizing a soil conditioner like biochar to shield plants from the harm caused by salt stress (Ameur et al. 2018).

8.2 Biochar to Alleviate Nutrient Stress

In the current climate change era, poor crop productivity has been obstructed due to unexpected seasonal climatic variations such as decreased precipitation/intense precipitation for short period, a length dry period, a short duration increases in moisture, frequent thunder storm and abrupt increase in temperature. These issues are

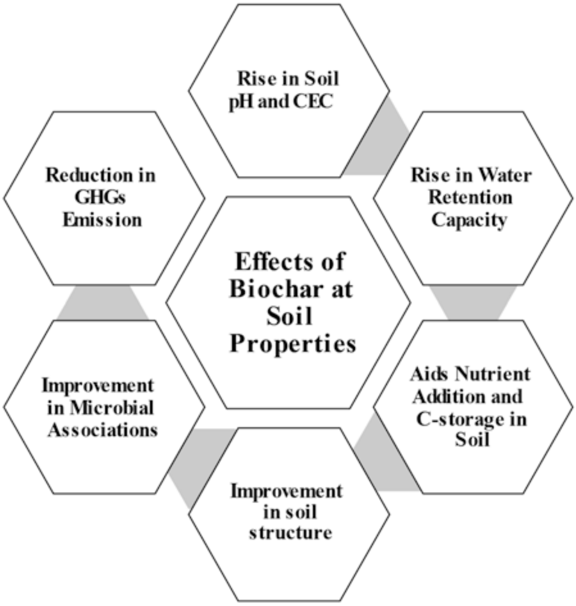

Fig. 8.1 Effect of biochar on physicochemical properties of soil. *CEC* cation exchange capacity, *GHG* greenhouse gases

very much challenging for agriculture in arid and semi-arid regions (Hasanuzzaman et al. 2018a). It is not possible to stop these challenges but can be managed and their destructive effects on the crops can be minimizes. Nowadays, a serious issue of nutrients stress tolerance is seen in Pakistan and around the globe. Althoufh scientist are working on it but it takes time. The plants show different kind of responses against the nutrient stress in different environmental conditions. But, all kind of plants show multiple biological responses such as production of reactive oxygen species. All the plant species can easily manage reactive active species in their systems but they require the proper dose of all nutrients.

Processed carbonous material can sustain for longer period of time as compared to non-processed organic material in arid and semi-arid climate where high temperature always burned the organic matter (Dalal and Carter 2019) resulting into to no addition of organic masses into the soil systems. Therefore, plant-based materials such as biochar is an integrated approach for soil fertility management under environment-based nutrient stress which may help achieve sustainable agricultural outputs; nevertheless, these methods require significant land modification and financial commitment (Fig. 8.2). Such kind of organic amendments has been widely used in many developed but least in developing countries which are revitalizing the nutrient deficiency in all kind of soils. Additionally, producing biochar from organic waste is an economical way to recycle the agricultural waste materials (Dai et al. 2016).

Burning agricultural waste significantly negatively affects the environment because it produces carbon dioxide, the main greenhouse gas generated by human activities. To overcome the drawbacks of direct burning, it has been proposed to

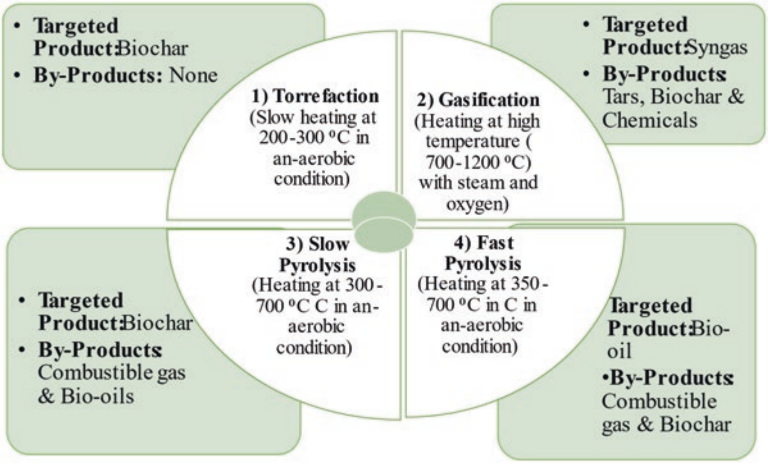

Fig. 8.2 Methods of biochar production from raw biomass

carbonize woody wastes to produce biochar, a material like charcoal. Due to its resistance to biological deterioration, biochar's acoustic impacts may last far longer in terrestrial settings than compost or plant leftovers. Carbonization by pyrolysis to generate biochar is a useful technology to reduce negative impacts on environmental and health. Global warming is lessened by a dark material called biochar, which includes refractory organic carbon. High solubility of water and nutrient could be a reason of biochar addition to soil as a soil conditioner to increase soil nutrient content (Da Silva Mendes et al. 2021). Furthermore, biochar increases pH, cation exchange capacity, organic carbon, and nutrient content in soils while reducing carbon dioxide emissions. Thus, the soil amendments should be an alternative and short-term solution for sustainable nutrients under the nutrient stress (Clough et al. 2013; Chintala 2014; De Jesus Duarte et al. 2019; DeLuca and Gao 2019).

8.3 Nutrients Stress and Plant Growth

In order to maintain cell sustainablity and ensure life under the nutrient stress, plants have developed several adaptive/resistance mechanisms. Sever nutrient stress disturbs the flexibility of membrane lipids, which might alter the structure of the membrane (Peng et al. 2019b). By sifting reactive oxygen species produced under nutrient stress, nitrogen oxides may serve as an antioxidant and defend plants against stress (Rai 2022). According to several prior studies, nitrogen oxide signals to development of thermotolerance in plants by activating enzymes that use oxygen (Hasanuzzaman et al. 2018b; Ahmed et al. 2020; Li et al. 2020b; Fonseca-García et al. 2021). Moreover, enhancing a plant's ability to withstand environmental shocks requires proper nourishment for the plant (Adetunji et al. 2020). Similarly, potassium is crucial for agricultural plants to survive under challenging environmental conditions (Kong et al. 2020). It can improve the process of photosynthesis, turgidity maintenance and stress-induced enzyme activation under nutrient stress (Saghaiesh and Souri 2018). In most of cases, the potassium stress may hamper the carbon dioxide fixation, cell ion channels and cell wall permeability (Zhang et al. 2018b). Such turbulences lead to an excess of photosynthesis-generated electrons, which increases electron transport to oxygen and subsequently stimulates reactive oxygen species production (Kong et al. 2020). The sustainable transport of photosynthetic electrons transportation is heavenly disturbed during the nutrient deficiency because it causes oxygen to be converted to reactive oxygen species (Nieves-Cordones et al. 2019). Sometime, the cell sustainablity may be shielded against oxidative damage brought on by nutrient signalling in low potassium soil media (Wu et al. 2018). However, increasing the potassium concentration of irrigation water significantly protected the cell and its function.

8.4 Nutrient Stress and Plant Cell Functions

In order to achieve the necessary gains in food production, it is predicted that fertilizer use will need to double over the next 20 years (Fischer and Connor 2018). In order to increase crop production and maintain soil fertility, research on plant nutrition looks to be a top priority in the future decades (Hackman et al. 2022). To survive and produce when faced with environmental obstacles, crop plants must develop adaptive mechanisms to prevent or minimize nutrient stress (Ahmed et al. 2020). Phosphorus is required for strength generation, magnesium and nitrogen are structural components of chlorophyll that are necessary for photosynthesis while potassium is necessary for osmotic control and enzyme activation, and phosphorus is a structural part of essential plant compounds (de Souza Osório et al. 2020). Therefore, a plant that receives enough nutrition should produce more smooth and sustainable growth (Sung et al. 2018). Moreover, the hydraulic conductivity of the cortical root cells was much lower in plants that were nitrogen and phosphorous deficient (Praveen and Gupta 2018). In addition, availability of proper plant nutrient concentration are crucial to increase the water use efficiency and nutrient use efficiency enhancement of the crops (El-Nakhel et al. 2019).

Numerous studies have shown the sufficient availability of different kind of nutrients may help the plant in reducing the effects of different abiotic stressors. For example, silicon and potassium have been shown to boost tolerance of wheat crop against nutrient and salt stress (Sales et al. 2021). Nitrogen deficiency reduce the plant ability to tolerate the different kind of stresses i.e. cold, heat and salinity stresses (Ahmed et al. 2020). In addition, these stresses impaired impair plant growth and nutrient uptake. The suitable concentration of nitrogen may trigger the light harvesting and hence accelerate the process of photosynthesis (Ahmed et al. 2020). So that is why, health plant growth and yield could be achieved. Sometime, the surplus of unused light energy is anticipated in nitrogen deficient leaves, increasing the likelihood of photo-oxidative damage (Rai 2022). Similarly, a lack of nitrogen in rice plants exposed to intense light is associated with increased lipid peroxidation in the cell system (Yoo et al. 2018).

The role of sun energy in electron movement during kelvin was greater in nitrogen sufficient crops compared to nitrogen-deficient crops (Bloch et al. 2020). Additionally, nitrogen deficient plants may withstand high levels of photosynthetic activity and the production of defensive mechanisms (Rai 2022). To protect against photo-oxidative damage caused by excessive light, the thylakoid membrane provides an additional energy release mechanism, which releases heat (Manoj et al. 2020). However, in nitrogen-deficient plants, the generation of zeaxanthin and the conversion of xanthophyll cycle pigments increased, decreasing the chlorophyll concentration (Gebregziabher et al. 2021). Compared to nitrogen adequate spinach plants, nitrogen deficient spinach plants lose up to 64 percent more of the light energy that is absorbed (Moriwaki et al. 2019). This gap was attributed to alterations in the xanthophyll cycle pigments, with zeaxanthin and antheraxanthin accounting for around 65% of total xanthophyll pigments in plants havening less nitrogen (Moriwaki et al. 2019). Similarly, the use of captivated sun energy in carbon dioxide fixation is decreased in nitrogen deficient plants, leading to a more significant need for protection against excessive light energy (Prescott et al. 2020). As a method of releasing excess light energy, it was discovered that bean leaves provided with nitrate converted violaxanthin to zeaxanthin more strongly than those supplied with ammonium (Holzmann et al. 2022). Similarly, the bean plants grown in nitrate were more resistant to photodamage than bean plants grown in ammonium (Posso et al. 2020). Ammonium-grown plants showed greater lipid peroxidation levels and antioxidative enzymes due to the increased light intensity (Fonseca-García et al. 2021).

8.5 Physiological Alteration and Role of Micronutrients Under Nutrient Stress

Different element had different function inside the plant body and the deficiency of any other them may halt the numerous physiological processes and require for serval co-factors and enzymes of metabolism (Janpen et al. 2019). Moreover, some elements play their role at the earlier stage of plant growth and some require at the grain filling and ripening of crop. Plants are unable to complete their life cycle successfully without availability of specific elements (Zhou et al. 2021). Generally, macro-element is available to plants but they do not have micro-elements which are equally important for plant health active. Acute nutrient (micro-nutrient) stress directly harms plants by causing protein denaturation and aggregation and increased membrane lipid fluidity. The balance presence of different elements is very vital and sometime their antagonistic effect may lead to abnormal growth. Therefore, it may induce different changes in the biosynthesis of different compounds and structural components.

Such nutrients stress for longer period can lead to over production and accumulation of reactive oxygen species that could had toxic effect to nucleic acids, metabolites, proteins, and lipids of plant cells (Ogden et al. 2018). Most common ROS that plants produce under the nutrient stress including singlet oxygen, superoxide anion, and hydrogen peroxide which are generated in to all cell organelles i.e., mitochondria, peroxisomes, and chloroplast (Kim et al. 2021). However, the maintaining of some specific physiological level of reactive oxygen species is a matter of life and death for the aerobic living organism otherwise leading to death within a few hours. The proper concentration of different types of micronutrients helps the plant cell to produce the antioxidant defensive systems which is dully supported by the enzymatic and non-enzymatic compounds to tackle the harmful effects of reactive oxygen species (Nadeem and Farooq 2019).

Calcium ion is a vital ubiquitous intracellular messenger, which play a lead role in several signal cell trans transduction pathways. Moreover, the transient perturbations such as free cytosolic calcium are indispensable and translate the cell signals into various biological responses. The increase in cytosolic calcium levels resulted into higher production of calcium sensor relay proteins such as calmodulin that is called calcium biding proteins. calmodulin regulated the several transcription factors which involved in many physiological, bio-chemical, and molecular functions in the cell. Some time, cytosolic calcium activates the calmodulin-binding transcription activator which is major contributor of transcription factors. Moreover, calcium is thought to be essential for healing from stress free because it promotes the cellular membranes protein adenosine triphosphatase, which is required to transport back nutrients depleted during cell damage. calcium modulates the pressure throughout freezing damage, repair work, and cold tolerance adaptation (Pathak et al. 2020). Moreover, it also fastens the process of repairing of the damage cells and it is observed that it also enhances the tolerance against the freezing injury (Thor and Kathrin 2019; Zhang et al. 2020). In addition, it stimulates the adenosine triphosphatase enzymes which help the cell wall to recover aggressively in cold damage by mobilizing the available cell resources. Calcium is also an important element in maintaining cell structure and cell integrity (Zhang et al. 2020).

Through several physiological and biochemical processes, magnesium influences plant growth phase (Pickering et al. 2020). It is necessary for several metabolic processes, including photosynthesis (Xie et al. 2021). Even slight variations in magnesium levels significantly affect numerous necessary chloroplast enzymes (Peng et al. 2019a). Both a magnesium shortage and an excess are harmful to plant photosynthesis (Veronese et al. 2020). However, the rate of photosynthesis is noticeably decreased in the leaves of magnesium deficient plants. The nutrient stress causes several metabolic pathways in various cellular compartments, such as chloroplast, mitochondria, and peroxisomes, to continuously produce reactive oxygen species. Mineral nutrient deficit stress includes oxidative stress (Zhang et al. 2019). In addition, magnesium increased the content of antioxidant molecules and the activity of antioxidant enzymes in bean (Torabian et al. 2018), maize (Iqbal et al. 2020), wheat (Tian et al. 2021), rice (Ahmed et al. 2021) and pepper (Zirek and Ozlem 2020).

Additionally, plants lacking in micro-nutrients such as iron, boron and magnesium which decrease the accumulation of malondialdehyde into the cell (Oustric et al. 2021). The sustainable availability of these nutrients increase the root growth and surface area that helps the plants to absorb water and nutrients from the deeper layer of soils (Ali et al. 2020). In addition, they also rise the quantity of sucrose in the leaves and improves sucrose transfer from the leaves to the roots. Sometime, they also improve phloem export to boost glucose translocation under temperature stress (high or low). Moreover, the improved feeding of micronutrients increase the photosynthetic rate leading to higher yield by maintaining chloroplast structure in Cassava plants (Busener et al. 2020). However, sometimes, protein synthesis is inhibited leading to inhibition and membrane integrity is lost due to higher level of deficiency.

8.6 Management of Nutrient Stress

Traditional agriculture has been replaced by intensive crop cultivation due to food demand and supply (Garnier et al. 2019). Intensive (or tiring) agricultural farming has reduced the availability of plant nutrients, which harms plant protentional badly (El-Nakhel et al. 2019). Healthier crop nutrition may help plants become more resilient to different kind of stresses and increase the production of antioxidant system. The anti-oxidants protect chloroplast membrane integrity, reduce photo-oxidation, scavenge reactive oxygen species, and promote photosynthesis in the plants (de Souza Osório et al. 2020). It was also seen the availability and management of healthy concentration of macro-and micronutrient may increase the chlorophyll contents (Purbajanti et al. 2019). It was worth noted that availability of nutrients can increase of generation of strong chlorophyll pigments and general plant progress in cow pea plants even under water stress (Laranjeira et al. 2021). Moreover, the sufficient concentration of potassium and calcium encourage water uptake, assisting stomata and improves the ability of plants to withstand temperature pressure by sustaining a steady temperature.

8.7 Sustainable Plant Growth Under a Stressed Environment with Biochar

The rosehip seeds biochar applied at the rate of 2% (200 gram per pot) improved the shoot dry weight of sugar beet (29.82 gram per plant) under drought stress condition as compared to control (with no biochar treatment) (Durukan et al. 2020). Due to typical nature of biochar towards the binding of various micro and macro-nutrients on its charged sites due its electrostatic attractions, can increase the biding of water particles and thus decrease the frequency of irrigation and plant may save the plants from drought susceptibility (Khan et al. 2021). In addition, under nutrition stress environment, comparative higher surface area and porous structure of biochar that increase its adhesive and cohesive forces with the water and nutrients in the soils may result into slow release and gradual availability of nutrients and water to plants (Kätterer et al. 2019; Abideen et al. 2020). It was also noted that the functional groups especially oxygen related functional groups help the biochar to conserve more water molecules and plant may use in stressed environment (Suliman et al. 2017).

Enough Biochar addition to plants can elevate the stresses on stomatal conductance transpiration, photosynthesis, respiration, and turgor pressure by improving the nutrient and water availability (Phillips et al. 2020). The addition of biochar (600 °C) at rate of 2% increase the biomass (shoot and root) of licorice by 80% and 40% under the saline environment (50 mM NaCl). In addition, it also improved the root architectural characteristics such as root surface area, root length, root volume, project area and nodulation (Egamberdieva et al. 2021). Moreover, in alternate root-zone drying irrigation, overall growth (plant height and shoot biomass) and yield (grain yield) of quinoa by 11.7%, 18.8 and 10.2 % respectively compared to deficient irrigation (Yang et al. 2020). During the growth period of quinoa, it was noted that the water use efficiency, stomatal conductance and leaf photosynthetic rate and leaf Abscisic acid was also improved under the saline stress conditions as compared to non-saline environment (Yang et al. 2020).

Acceleration of nutrient cycling and carbon sequestration in the upper soil layer (0–15 cm) was achieved in the rice straw biochar treatments and improved the reduced the soil bulk density and increase the availability of nutrients. Ultimately, this phenomenon was enhanced vegetative biomass and yield (Wu et al. 2021). Similarly, the microbiome population in the soil reduced the production of reactive oxygen species under nutrients stress and improved the carbon stock leading to better nutrient availability to plants (Tang et al. 2020). Stress tolerance with biochar are associated with the release of considerable concentration of micro-nutrients (carbon, nitrogen, phosphorus, and potassium) and macro-nutrients (calcium, manganese, iron, zinc, coper) (Abd El-Mageed et al. 2020). In addition to earlier reports, positive effects of biochar materials were noted on the plant growth and development. But it was concomitant with the release of essential soil nutrients such as nitrogen, potassium, calcium and magnesium into the soil media (Zhao et al. 2020).

8.8 Physiochemical Changes in Soil After Biochar Addition

The physiochemical properties of all kind of soils play vital role towards the alleviation of nutritional stress and availability of nutrients. Hence, biochar is magical material which had the ability to enhance the plant growth and improve the soil health (Sattar et al. 2020). Biochar had the ability to play magical role even in nutritionally dead soil (Minhas et al. 2020). Generally, it can change the pH, cation exchange capacity, electrical conductivity, inherent nutritional capacity, electrical conductivity, solubilization ability and hence, improve the access of plant to nutrients into the soil media (Zhu et al. 2020). Biochar had the ability to clean the soils from different organic and inorganic pollutants which are increasing the soils after the haphazard application of chemicals to agricultural crops (El-Naggar et al. 2020; Khalid et al. 2020). Moreover, the leaching of fertilizers and runoff of soil is very common phenomenon in the arid and semi-arid areas. It reduces the efficiency and loss of outputs and other hand its polluting the fresh water resource. Hence, continuous and repeated application of biochar not only reduce the runoff and leaching but also sustaining the soil productivity (Ippolito et al. 2020).

Biochar application into the soil increase the soil moisture and resistant to microbial degradation which slows down the degradation process (may decrease to 0.3% per year) leading to long term sustainable availability of nutrients and accelerated the process of carbon sequestration in the arid climate (Papageorgiou et al. 2021). It was worth noted that the activities of proteases, acid phosphomonoesterases and soil fluorescein diacetate hydrolase was improved under the saline condition by the addition of biochar (600 °C) at rate of 2% under the saline conditions (50 mM NaCl) (Egamberdieva et al. 2021).

Significant concentration of some minerals i.e., magnesium, iron, and calcium and inorganic carbonates has been increased after the application of biochar into soil that improved the plant growth and development. In addition, soil carbon contents, soil permeability and soil productivity were also improved when was observed during the crop growing period and at harvest (Antala et al. 2019; Leng et al. 2019). Moreover, the biochar stimulate the microbial activities in the rhizosphere that increase the yield by improve the soil nutrients availability and soil water contents (Zhu et al. 2017). The soil porosity and cation exchange capacity was also enhanced but it was more prominent in the clay soils as compared to sandy and silt soils (Nguyen et al. 2017). Due to change in electrostatic charges of soil, it increase the release and retention of nutrients in soils, improving the plant nutrient use efficiency resulting to higher plant yield (Akhtar et al. 2014).

Addition of biochar could initiate and accelerate the process of different biochemical and enzymatic activities in the soil. Initially, the soil microbial abundance and activities has been started and provided the food to all kind of soil biota. Furthermore, they may coordinate and fasten the nutrients cycling process (Liu et al. 2017). Many nutrients solubilizing microbes like *Bacillus mucilaginosus*, *Bacillus edaphicus* and *Azotobacter chroococcum* may starts their actives from sluggishness due to unavailability of nutrition (Rahimzadeh et al. 2015). They mineralize the fix/Nex/chelate nutrients into solution form. The activities of some Bacillus species could be promoted by 5-fold when they are incubated with biochar of corn stover (0.6%). The nutrients release activities of soil is increased by 80% (Liu et al. 2017). It has been worth noted that application of B. mucilaginosus into mica rich soil boost up the growth and development of lemon grass. This could be due to more mobilization of the potassium from the available resources of mica (Basak et al. 2021) (Fig. 8.3).

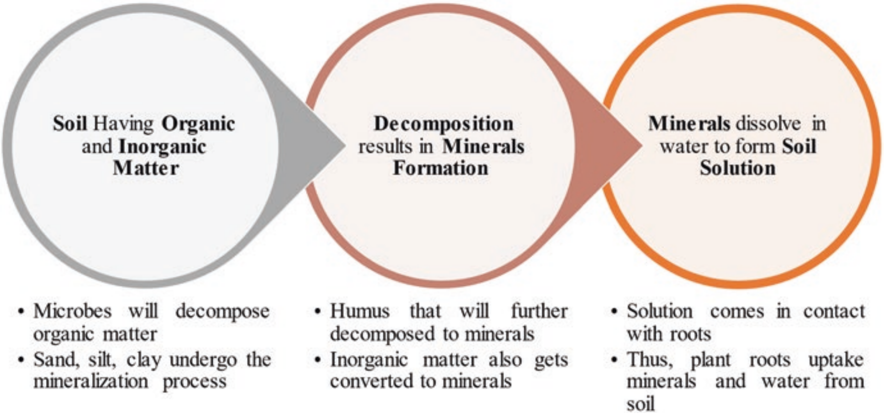

Fig. 8.3 Soil nutrient availability to plants

8.9 Management of Nutrients by Biochar Under Nutritional Stress

The biochar had the ability to mitigate numerous environmental stresses such as drought, salinity, heavy metals, nutritional stress, heat stress, climate change effects and pollution effects etc. from the plants. Usually, it was noted that all plants accumulates ethylene under the stresses including the nutritional stress (Khan et al. 2015). That production of ethylene under stress condition is high dangerous to plant cell and starting its damage from degradation of cell membrane lapis of chloroplast and then further activates the chlorophyllase gene (chlase) (Michaud and Jouhet 2019). The chlorophyllase may lead to degradation of chlorophyll and finally chlorosis may result. Biochar could slow down the process of ethylene production by providing of nutrients through its slow-release mechanism. Thus, a large number researcher reported that biochar could eliminate the nutrient stress in all kind of soils (Wacal et al. 2019; Chen et al. 2022; Shaheen et al. 2022).

Biochar is generated from biomass that has been paralyzed in a low-oxygen environment and is a fine-grained charcoal with a high concentration of refractory organic carbon (Lehmann and Joseph 2015; Amoakwah et al. 2020). Its application in agricultural soils to capture carbon, enhance soil functioning, and other purposes has been hotly contested (Lehmann 2007). Carbon-rich biochar may increase soil fertility by enhancing the ability of soil to retain nutrients. All the crop nutritionist suggested that carbon-rich biochar is the game changer to enhance the soil fertility of poor soil in the arid and semi-arid climate. Moreover, the structure of carbon based material is aromatic which give it a lot of characteristics like low density, large surface area, high ion exchange capability, and great porosity which make it more resistive to disintegration (Agegnehu et al. 2017). The material and pore volume of carbon-based material can greatly enhance the physical and chemical properties of soil, which are essential for soil cooling and crop production. These properties include water retention, hydraulic properties, aggregate stability, pH, organic carbon, and cation exchange capacity (Dai et al. 2016; Baiamonte et al. 2019). Moreover, the physical properties of soil has been improved because of presence of micropores and less density of carbon based particles (Lehmann et al. 2011). Additionally, the presence of nitrogen in biochar may alter the dynamics of soil nitrogen by influencing the quantity of soil nitrogen that is available to plants, and it increases its ability to absorb more nitrogen, and accelerate the biological processes of nitrification (Ameur et al. 2018; Amoakwah et al. 2020).

Moreover, by enhancing the physical environment of the soil, which prevents or lowers anaerobic denitrification, carbon dioxide flow, and methane gas generation, applying biochar to soil may also reduce greenhouse gas emission (Ali et al. 2017). Additionally, adding biochar to field improves infiltration and water-holding capacity, particularly in soils with a coarse texture or a high concentration of macrospores (Agegnehu et al. 2017). Biochar contains different amounts of nitrogen and carbon depending on its feedstock and production conditions and its additives sequester more carbon and nutrients in the soil because of their promotive properties. The natural ability of biochar in controlling nutrients uptake that is ultimately reduces the reactive oxygen species and abscisic acid in the cabbage seedlings. Under the nutrients stress conditions, biochar was effective at reducing Nitrate (NO_3), Ammonium (NH^{4+}), phosphate ($PO_4{}^{3-}$), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) (Gao and DeLuca 2018). In addition, it is worth noted that potassium leaching is significantly reduced with the addition of biochar.

Physical and chemical soil factors such as, water-holding capacity, cation exchange capacity, pH, surface area, porosity, bulk density, carbon, nitrogen, nitrogen used efficiency, and total accessible nitrogen and phosphorus are between the physical and chemical soil parameters that biochar affects. It was noted that majority of macro and micro-nutrients such as hydrogen, oxygen, magnesium, and macronutrients including nitrogen, phosphorus, and potassium are all present in biochar and can help most crops throughout the globe grow more quickly. It was seen the biochar increased the nitrogen retention efficiency that in return decrease the use of synthetic fertilizer to the crops. Upon the addition of maize residue biochar at the rate of 1–2% (weight/weight), the amount of total nitrogen increased by 41%, the amount of accessible P by 165%, the amount of available potassium by 160% (Saffari et al. 2020). In addition, Adekiya et al. (2020) recorded that soils that have amendment of biochar had higher levels of essential nutrients.

Biochar improved the nitrogen concentration in the stem, root, fruits, and leaves under the normal and stress conditions as compared to control treatments (no biochar). Under drought stress condition, the rosehip seeds biochar applied at the rate of 2% (200 gram per plant) increased the nitrogen concertation at 1.72% as compared to control treatments (no biochar) (Park et al. 2019; Durukan et al. 2020). Moreover, the electrostatic attraction among the various micro and macro-nutrients and the charges sites of biochar may increase the concentration of ammonium and nitrate ions. However, this higher release of ammonium ions was seen when the biochar was produced at low temperature (400–500 °C) (Xu et al. 2019; Zhou et al. 2019).

Biochar can alter the amount of accessible phosphorus in soil in solution form to plants and prevent its fixation and sorption on the clay minerals (Uchimiya et al. 2015; Zhao et al. 2016). Moreover, biochar could help the farmers of poor and developing countries in increase the soil phosphorous use efficiency and reducing the phosphorus losses due to its ability of slow releasing of nutrients. Hence, it may work as phosphorus fertilizers for future generations and could increase phosphorus use efficiency for longer term especially in nutrient deficient period (Li et al. 2020a). The success stories of its residual effects on crop growth and development are also confirmed. Due to different surface properties like as basic, acidic, heterogeneous a and hydrophilic characteristics, biochar can increase solubility and availability of phosphorus under the various climatic conditions (Trazzi et al. 2016; Glaser and Lehr 2019). The rosehip seeds biochar applied at the rate of 0.5% (50 gram per plant) increased the nitrogen concertation at 1.01% as compared to control treatments (no biochar) (Durukan et al. 2020).

Soil potassium is divided into four types basis on its availability such as exchangeable/soluble potassium, non-exchangeable potassium, water-soluble potassium, and mineral potassium. All these potassium fate into the soil systems is in dynamic equilibrium and play vital role for its availability and update into the plant system (He et al. 2015). Although the potassium reserves are large in the soil system of arid and semi-arid system of the globe but are in non-exchangeable potassium form. However, application of biochar at different rates was significantly increased the proportion of exchangeable potassium into the soil media that is readily available to plant rooting system from the longer period. In addition, some time, potassium is present in mineral potassium or exchangeable potassium forms that is sparingly or partial available in the rhizosphere (Oram et al. 2014). A lot of research question are still unexplored regarding to interaction of biochar time/amount and potassium or biochar application and type of clay minerals. Moreover, the specific interactions and process between the biochar application timing and its interaction with the soil components and the processes involved in it. Moreover, the rosehip seeds biochar applied at the rate of 2% (200 gram per plant) increased the potassium concertation at 2.33% as compared to control treatments (no biochar) (Durukan et al. 2020).

On the other hand, potassium is conserved during the biochar production process and easily available in the form of potassium containing salt having high solubility but its ability is heavenly dependent on the input material from which it is produced. So, that is why, several past studies indicated that potential source of potassium in the form of biochar could be a chief substitute of conventional and synthetic fertilizers. Some studies exhibited that quick release of potassium may result into unavailability of potassium after first year but non the other hand, it was noted in the previous studies that role of soil properties such as including soil texture, type, pH, inherent potassium-reserves, and concentration of clay minerals is determined the dynamic of potassium into the soil and rhizosphere.

The rosehip seeds biochar applied at the rate of 2% (200 gram per plant) was improved the micro-nutrient concentration (magnesium and manganese) in the stem of sugar beet (Durukan et al. 2020). The electrostatic attraction among the opposite charges ions may increase the concentration of many micro-nutrients such as calcium, iron and magnesium etc. (Chandra et al. 2020). In addition, biochar helps the soil media to release the significant concentration of fixed micro-nutrients such as manages, iron, calcium, copper, and zinc. Hence more concentration these micronutrients was noted in the plant body (Abd El-Mageed et al. 2020). In long run, the application of handful amount of biochar into soil may reduce the need of synthetic fertilizers and pesticides because it can improve the concentration of micronutrients, organic matter, soil carbon concertation, nutrients cycling, soil enzymes activities, soil fertility and soil microbial activities leading to achieve the sustainablity and profitability of the farming community (Abd El-Mageed et al. 2020).

It was seen the under nutrient stress, the addition of biochar to the crop may correct the imbalance concentration of calcium, iron, zinc, and sulfur etc. that are vital from plant growth and development (Mwando et al. 2020). Moreover, biochar plays vital role in improving the human and animal nutritional status that are heavenly dependent on the plants for its nutrition. Generally, it was observed that micronutrients (magnesium, calcium and manganese) was fixed into the soil particles but was easily released into soil system in long term field experiments when biochar (corn straw biochar) was added to soil before the seed sowing (Zhao et al. 2020).

8.10 Conclusion

Nutrient-nutrient interconnection and responses and further its impact on ions accumulation into the cell are well explored. However, the nutrient based cell signalling is still a topic to debate. Such signal may deceive the cell other signal. So, it may disturb the cell routine activities. How all the terrestrial plants crop with poor nutritional acquisition in soil is an interesting question in biology. Now a days, nutrient stress along with climate change challenges which plants are facing in nature. That is why, sudden changes in growth capacity of plants can be seen due to abrupt changes in ion homeostasis interactions with in plant cell system (Fig. 8.4).

The combinatorial signal mechanism among the different cell of the plant under the nutrient stress yet to be focused in the future research program. Moreover, there is dire need to improve the plant genetic system to tackle the combined stresses and it may lead to development of plant species with better genetic architectures that may handle each individual stress response. Therefore, future research program should be designed to exploring the answer the question of how the nutrient homeostasis in plant body push the plant to change its genetic architecture and how it identifies the effect of the combination of different nutrient stress on a single plant in the field condition. Moreover, the lack of research of the role of molecular mechanism of integrated nutrient stressed cell signals for the development process of cell is the demand of the current era. Similarly, the use of 3D network modelling could be a handy tool to understand and predict the ionome for any combination of nutrients for any specific genotype at the given time and space. The interaction of different nutrients stress singles with ionome and growth and how they change the different mechanism pathways in the cell that may re-regulate ion homeostasis and

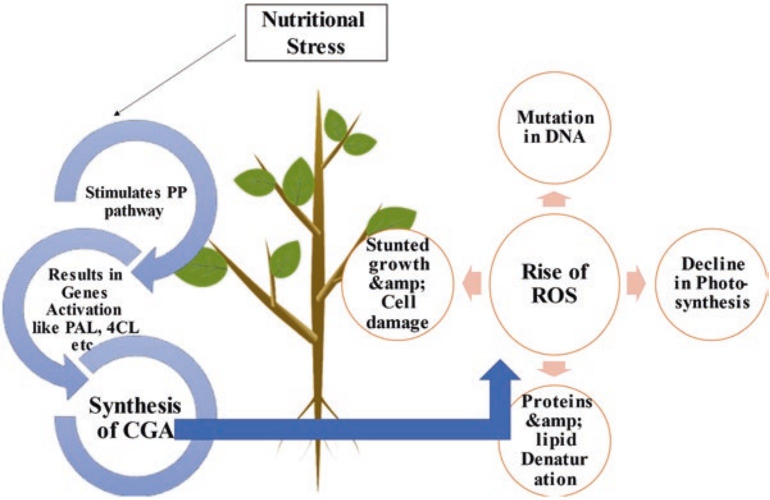

Fig. 8.4 Effect of nutritional stress on plant cell metabolism. *PP* pentose phosphate Pathway, *DNA* deoxyribonucleic acid, *PAL* Phenylalanine ammonia lyase, *4CL* 4-coumarate: *CoA* ligase gene, *amp* amplification, *CGA* chlorogenic acid, *ROS* reactive oxygen species

plant development. Sometimes, such signals deceive the plant systems with immune signaling pathways that produces different chemicals into the soil. These chemicals are very necessary to cohabitate plants with soils to manage the limited nutrients in the soil system. This interconnection between the cell signalling and immunity needs a lot of attention of plant researchers. Therefore, cellular level improvement is needed to cope with nutrient stress signalling system. So, any molecular mechanism improvement that may help the plant breeder to introduce the plant ideotypes. It will be a game changer in precision farming era and ensure the food security in the climate change scenarios.

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