Content list available at http://epubs.icar.org.in, www.kiran.nic.in; ISSN: 0970-6429

Indian Journal of Hill Farming

Special Issue 2022, Volume 35, Page 181-191


Indian Journal of Hill Farming
Special Issue 2022 Volume-35

Biological Approaches for Assessment and Management of abiotic stress for Resilient Agriculture

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ARTICLE INFO

Article history:
Received: 12 September, 2022
Revision: 23 September, 2022
Accepted: 26 September, 2022

Key words: soil resistance, abiotic stresses, soil biological indicators, soil management practices, soil health.

DOI: 10.56678/iahf-spl2022.22

ABSTRACT

The impact of abiotic stresses such as extreme temperatures, drought, water logging, high salinity, heavy metal toxicity, limiting crop productivity and sustainability are being witnessed all over the world. In order to sustain crop productivity, it is therefore crucial to establish simple and low cost technology for abiotic stress management. Natural resource management strategies can play a significant role, in this respect, as it has strong influence on soil resistance to check deterioration of soil health through selective influence on microbes and its functional attributes. These selective attributes are the indicator of soil resistance to different stresses. Identification of resistant microbes to extreme environments and their successful deployment in rhizosphere can be another significant approach to induce systemic resistance in plants to sustain productivity under stressful environment. However, extensive research for development of the technology and its assessment under diverse agro-ecological condition should be accomplished before recommendation. This paper reviews the literatures on impact of abiotic stress on agriculture, different aspects of soil resistance and resilience, its assessment and management strategies to combat the upcoming stress for resilient Agriculture. Till now, a lot of work on soil resistance to stress has been accomplished. So far soil physical and chemical attributes were given priority to assess the resistance capacity of a soil to different stresses, in general, compaction, water logging, nutrient toxicity etc., in particular. The dynamic soil characteristics such as microbial community structure and soil specific functions, in general, enzymes activities are known to respond more quickly to changing environmental conditions and crop management practices than total or available soil organic carbon or other available soil nutrients. Therefore, use of microbes and their enzymes systems as well as soil functional attributes are current leads to asses soil resistance to abiotic stress, which results in deterioration of soil health and ultimately to poor crop quality.

1. Introduction

The increase incidences of abiotic and biotic stresses causing stagnation or reduction of productivity in principal crops are being witnessed worldwide. In future, extreme events like prolonged droughts, intense rainfall and flooding, heat waves and frost damages are expected to further increase due to climate change. Natural and anthropogenic factors are increasing stresses in crop production, particularly in tropical regions. In many parts of South Asia, there are reports on yield declines of major crops like wheat and paddy crops due to increasing water stress, reduction in amount of rainfall and increased air temperature (Samra and Sing, 2004; Aryal et al., 2020). Such impacts of climate change are likely to impose severe stress on land and water resources, thereby causing serious negative impacts on crop growth and productivity. In this scenario, it is strongly urged to adopt strategies which can maximize crop stand and economic returns from stressful environments. Most commonly followed strategies like breeding of stress tolerance crop, screening and selection of the existing germplasm of potential crops, production of genetically modified (GM) crops and use of osmoprotectants etc., are

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*Corresponding author: joymati.loit@gmail.com time consumable and expensive. Moreover, the vertical resistance developed thereby loses its stability under multiple stress pressure (Kamoshita et al., 2008). Problem associated with the development of such technology is of over dependence on large scale seed production companies.

In this context, development of simple and low-cost biological methods can be one of the promising approaches for managing abiotic stress. Microorganisms could play an important role, if the unique qualities of microbes to tolerate extremities, genetic diversity and their interaction with crop plants can be exploited successfully to develop technologies for their implementation in agriculture production systems under stressful environment (Grover et al. 2011; Hou et al. 2021; Sandrini et al. 2022). It is also globally hypothesized that natural resource management restores resources and combats the stresses by improving soil health and stabilizing the ecosystem and thus, optimizing the crop yield. Crucial role of soil management in sustaining productivity under multiple abiotic stresses has been highlighted in many literatures (Sapkota et al., 2015; Cui et al., 2017; Aryal et al., 2020). Integrated nutrient management, in this respect, can pay a significant contribution. Under INM, the production system as a whole acquires resistance to extreme events either by enriching the soil ecosystem with biodiversity, particularly, the mycorrhizal diversity, elaborating enzymes and metabolites or by enhancing important plant metabolic activities or by both (Evelin et al., 2009; Gogoi et al., 2021; Kumar et al., 2021).

Assessment of potentiality of crop management practices against stresses must be accomplished before their recommendation. The response of a management to any stress is defined by two components, i.e., resistance and resilience and their combined effects determine "ecosystem stability". Resistance is defined as the inherent capacity of the system to withstand disturbance, whereas resilience as the capacity to recover after disturbance (Seybold et al*.*, 1999; Griffiths et al*.*, 2001). Microbial community structure and soil specific functions, in general, enzymes activities, in particular are very sensitive to stress (Riah-Anglet et al., 2015; Bhogati and Walczak, 2022). They provide information well in advance with meaningful manifestation through their activities and preponderance. Thus, they are useful tools for studying stress resistance capacity of soil under different managements.

In this paper, we attempt an overview of current knowledge on how soil biological parameters give early warning to soil degradation or environmental change and serve as sensitive indicators for assessment of soil resistance to abiotic stress and different management strategies to alleviate abiotic stress through soil management and microbes.

2. Abiotic stresses and its impact on agriculture

In India about two-thirds area, forming parts of the arid and semi-arid eco systems are affected by abiotic stresses like drought or water stress, high temperatures, soil salinity or alkalinity, and heavy metal toxicity. Drought is one of the major abiotic stresses, which affects agricultural production globally. In a study to monitor global drought for about two decades (2001–2019), Khan et al. (2021) calculated drought indices using big geospatial data sets from Google Earth Engine and revealed that 70% of the global land is under continuous effect of soil moisture fluctuation giving severe impact on vegetation. In a recent study, Orimoloye (2022) also observed reduction in maize and sorghum production in Africa due to the impact of drought. In India, the humid sub-tropical Upper Middle Gangetic Plain region, which contributes about 18–20% of national annual cereal production, comes under highly drought-prone area (Nath et al., 2017). The drought occurrence frequency of this region is 40-50% and cereal production in the region is following a gradual declining trend from 2000 onwards. With the consistent increase in drought-affected areas, the cereal production is declined from 20–25% to 50–60%, before and after 2000, respectively. It is also estimated that irrigation requirement in arid and semi-arid regions will be increased by 10% with every 1˚C rise in temperature.

One prediction model claim that average annual maximum temperature of South Asia, may increase by 1.4–1.8 °C in 2030 and 2.1–2.6 °C in 2050, and heat-stressed areas in the region is expected to increase by 12% in 2030 and 21% in 2050 (Tesfaye et al., 2017). According to literature, by 2050 almost half of the Indo-Gangetic Plains (IGP) of South Asian region may become inappropriate for wheat production due to heat stress (Ortiz et al., 2008). There is report of wheat productivity loss by 4.4 million tons in Northern India, due to the unprecedented heat wave in 2004 (Samra and Sing, 2004).

Soil salinity is another serious problem and is gradually increasing in arid and semi-arid areas. Saline soils occupy about 7% of the total global arable land (Ruiz-Lozano et al., 2001). By the middle of the 21st century, it is predicted that 50% of the arable land will be lost due to increase in salinization (Wang et al., 2003). Soil salinity has severe negative impact on agricultural crop production affecting crop establishment, their growth and development and resulted to huge loss in productivity (Giri et al., 2003; Mathur et al., 2007). In India, salt-affected soils pose a serious threat to national economy. In India, more than 6.74 million hectares of lands are under salt affected area which is either saline or sodic, thus creating a serious threat to national economy. However, it is reported that out of the total affected area, 2.1 million hectares have been reclaimed (Mandal et al. 2018).

Soil acidity has become a serious issue in agriculture as it impairs crop productivity. Approximately 30% of the world's total land areas are under acid soils affecting above 50% of potentially arable lands of world, particularly in the tropics and subtropics (Kochian et al., 2004 and Kochian et al., 2015). Acid soils, thus, make food production critical in many developing countries l limiting crop production. Acid soils hamper plant growth bringing nutritional disorders, deficiencies, unavailability of essential nutrients such as calcium, magnesium, molybdenum, and phosphorus, and toxicity of iron, aluminum and manganese (Takala, 2019). In India, acid soils cover about 34.5% of cultivated lands (Maji et al., 2012), out of which the highly acidic soils are restricted to Himalayan red and laterite region of both the southern and eastern plateau and some areas in greater plain of the country.

Heavy metal toxicity is another major abiotic stress facing in agriculture. Heavy metals like cadmium (Cd), lead (Pb), copper (Cu), and Arsenic (As) etc. are known to have adverse effect on agricultural ecosystem (plant and soil) by affecting microbial processes and biomass in soils (Srivastava et al., 2017). In agriculture, heavy metal pollution can take place due to sewage sludge and metal-based pesticides application (Sharma et al., 2017; Alengebawy et al., 2021).

3. Resistance and Resilience in terms of microbial and biochemical aspects

Soil systems are generally exposed to a variety of natural and anthropogenic environmental stresses that can potentially affect soil functioning related to carbon and nutrient cycling, carbon sequestration and microbial activities. The degree to which such soil functions are impaired after the application of a stress can be defined as the resistance of the soil system, whereas the rate and extent of recovery, bringing back to near original state is considered as its resilience. Resistance and resilience are both considered as the components of functional stability of soil (Pimm, 1984). The concept of soil resilience in maintaining sustainability is indicated by Seybold et al. (1999), however it is arguable whether resistant or resilient soils are desirable for maintaining sustainable soil. Despite of recognizing soil resilience as a fundamental component of soil quality by numerous soil scientists, it has been given less attention (Lal, 1994; Seybold et al., 1999). Majority of the work done in this area consists of assessment of soil physical resilience (Griffiths et al., 2005), like novel measurement of clay soil's self-mulching potential by Grant et al. (1995) and measurement of soil strength characteristics like plasticity, swelling and shrinking potential, compaction, maximum dry density of soil etc. (Saha et al., 2015). The interest in the research line of resistance and resilience of soil functions have been ever increasing, since Griffiths et al. (2000) provided the first experimental and quantitative data on soil biological resilience (Griffiths et al., 2001; Dungan et al., 2003; Girvan et al., 2005; Ludwig et al., 2018).

Soil microorganisms play significant role in conducting various soil functions such as organic matter decomposition and nutrient cycling, etc. Thus, decrease in soil microbial diversity may probably decline the soil resistance to stress. Soil biodiversity is considered as an important soil property determining the capacity of soil to recover from perturbations (Pankhurst et al., 1997; Ludwig et al. 2018). Variation in species diversity may influence the stability of soil processes, enhancing temporal variability and ability to withstand and to recover from a stress event, i.e., resistance and resilience. Numerous authors indicated this concept in various experiments (Bardgett and Caruso, 2020; Shade et al., 2012). On the other hand, recent studies provided evidence that apart from species diversity, broad-scale shift in soil microbial communities' composition could be of significant importance for soil nutrient retention under stress condition. The soil biological property which is taken into consideration here is the relative abundance of bacteria and fungi, as they change markedly due to disturbance and changes in the intensity of land management practices (Bardgett and Mc Alister, 1999; Smith et al., 2003). In a study, Gordon et al., 2008 showed that unfertilized grassland soil abundant in fungal population retain more nutrients under alternate drying–wetting stress than the fertilized grassland soil having greater abundance of bacterial relative to fungi. Thus the role of microbial diversity towards soil resistance is still controversial and unclear.

Microbial parameters are sensitive indicators and response quickly when the soil ecosystem is subjected to any kind of stress (Riah-Anglet et al., 2015; Bhogati and Walczak, 2022) and microbial activities are proven to have direct influence on the fertility and stability of ecosystems (Hu et al., 2011). The performance of microorganisms may be affected by different type of stress factors. Adaptation of microorganisms to stress is a complex process where many processes and genes may be involved (Srivastava et al., 2008, Kaushal, 2019). In order to thrive at high temperature and salinity, certain microorganisms activate metabolic process like enzymatic activities and membrane stability respectively at optimum level (Madigen 1999, Kumar and Nussinov, 2001), whereas some other microorganisms combat the stress by developing different adaptation mechanisms (Ali et al., 2009, Koza et al., 2022).

4. Methods for measurement of resistance and resilience of soil

4.1. Resistance and resilience indices

Soil resistance is defined as the capability of a soil to continue its functioning without any changes throughout the period of a stress or disturbance (Herrick and Wander, 1998), whereas the magnitude of decline in the capacity of soil to function is defined as the degree of resistance to change (Seybold et al., 1999). Soil resilience, on the other hand, is defined as the ability of a soil to recover its “functional and structural integrity” (Seybold et al., 1999) after a stress or perturbation and returning back to a new equilibrium which is similar to the previous original state. Soil performs several dynamic functions like organic compounds decomposition, microbial activity, nutrient immobilization and transformation, nutrient cycling to main its functional integrity. Soils also has intrinsic capacity to maintain its structural properties like soil aggregation, porosity and bulk density etc. and are known as its structural integrity.

The stability of a soil system is defined by the resistance and resilience capacity of soil to stress and it influences several properties and processes of ecosystem. Indices that can provide a relative quantitative measurement of both the resistance and resilience of a response variable to any stressful condition are essential in order to compare the stability of different systems.

Most of the resistance and resilience indices have problems like difficulty in interpretation, or they do not fit in some situations. According to Orwin and Wardle (2004), the index of resistance or resilience should meet many criteria to work properly: (1) as resistance or resilience increases the index should also increase monotonically; (2) the index should be able to give an identical value in case of increment or reduction of the response variable relative to the control after a disturbance (3) the index should not tend to infinity but should be bounded for both positive and negative values; (4) zero should not come in the denominator while developing the index; (5) undisturbed control soil should be used for standardization of resistance and the initial amount of change due to disturbance should be calculated for determining resilience.

In comparison with the other indices, Orwin and Wardle (2014) indices are the only indices that increases similarly as resistance or resilience increases, and gives identical values for same magnitude of positive and negative effects. The resistance index works even when extreme values are encountered, for example, when glucose is added to soil, P_o value may exceed C_0 value. The index of resilience also confined even in extreme situations, for example, in some condition, even after the termination of disturbance, the effect of disturbance continue to change when the response variable (i.e. when $|Cx - Px| > |C_0 - P_0|$). The resilience of different types of soils can be distinguished statistically at various point of time with the resilience index. However, one should take care while measuring resistance to disturbances because disturbance may be ended at different points for different soil, thus it will be a difficult task to determine the exact time when the disturbed soil returns to the similar state of control soil. During recovery the system probably oscillates significantly, therefore choosing specific point of time may not be meaningful. These indices could be useful in studies for comparing soils under different fertility or disturbance gradients, or examining the effect of environments and climates change on ecosystem functioning. Response variables could be of any soil parameters including microbial diversity to soil respiration or soil chemical properties.

4.2. Biological indicators for assessment of soil resistance and resilience

Seybold et al. (1999) evaluated the idea of soil resilience in combination with resistance proposing three methods for assessing soil resilience: (i) measuring recovery directly after a disturbance (ii) quantification of recovery mechanisms integrity after a disturbance, and (iii) measurement of soil properties that act as indicators of those recovery mechanisms.

Table 1. Different indices of resistance and resilience

Source	Formula for resistance	Formula for resilience
Kaufman (1982)	$\frac{Co}{Po}$	$\frac{Px}{Co}$
Griffiths et al. (2000, 2001)	$\left(C_{o-}\frac{Po}{C_o}\right)100$	$\left(C_{x-}\frac{Px}{C_x}\right)100$
Orwin and Wardle, 2004	$1-\frac{2\lvert D_{o\lvert}}{(C_{o+}\lvert D_o\rvert_)}$	$\frac{2\lvert D_{o\lvert}}{(\lvert D_{o\lvert+}\lvert D_x\rvert_)}-1$

Where, C_0 = response variable value of the undisturbed control soil at the end of the disturbance, P_0= response variable value of the disturbed soil at the end of the disturbance. $D_0 = C_0 - P_0$. Cx= value of the response variable of the undisturbed soil at time x after the end of the disturbance . Px = response variable value of the disturbed soil at time x after the end of the disturbance, $Dx = Cx - Px$.

A biological indicator is defined as an organism, collection of organisms, product of an organism such as enzyme and biological processes which can provide a part or whole information of environment quality (Pankhurst et al., 1997). Soil microorganisms are an essential component of the ecosystem as they play significant role in maintaining soil fertility involving in different processes of organic matter decomposition and nutrient cycling. However, these microbes are under adverse effect when soil is exposed to several stress factors like extreme temperature, pH, salinity, and chemical pollution, (Schimel et al., 2007; Paz-Ferreiro and Fu, 2016). Soil biological and biochemical properties can serve as indicators of soil resistance or resilience to disturbances as they are very sensitive and response even to a small changes happening in soils, thus are able to provide immediate and precise information (Dick and Tabatabai, 1993; Ros et al., 2003).

The soil microbial community is considered as the more-reactive component to external environment than plants and animals in the terrestrial ecosystem (Panikov, 1999) and is involved in many ecosystem functions, such as nutrient cycling and decomposition of organic matter (Schimel, 1995; Sowerbya et al., 2005). As stress increases soil microorganisms divert more energy from growth into maintenance and it indicates that microbial metabolic quotient, qCO_2 (ratio of respired C to biomass C) can act as a more sensitive indicator of stress (Killham and Firestone ,1984; Killham 1985). The qCO_2 has been widely used as a biological tool for assessing soils under different cultivation regime (Anderson and Domsch, 1990), gradients of pollution (Ohtonen, 1994), effect of extreme temperature (Anderson and Domsch, 1986; Anderson and Gray, 1991), forest ecosystems (Anderson and Domsch, 1993), soil acidification (Wolters, 1991) and heavy metal toxicity (Brookes 1995). Microbial parameters appear to be sensitive indications of soil pollution by heavy metals and in order to get more precise information, measurement of microbial biomass and its activity including soil respiration and different enzyme activities are advisable rather than single microbial parameter, (Nannipieri et al., 1990).

The soil enzymatic activities can serve as important indicator for microbial activity and organic carbon status of soil (Bandick and Dick, 1999). The glucosidase activity play an important role in C-cycle and it reflects reflects soil-management effects (Bilen et al. 2010). Similarly, urease, phosphatase and arylsulfatase activity are responsible for N, P and S cycling in soil (Li et al., 2010; Rahmansyah et al., 2009; Adetunji et al. 2020). Soil enzymes, being sensitive to changing management and environmental factors, can be employed successfully to evaluate the productivity of agricultural soils under various environmental conditions. Soil enzymatic activities, thus, are suggested as potential biological indicators to assess the changes in soil quality (Bastida et al., 2008; Hu et al., 2011). Therefore, in order to get immediate and accurate information related to changes in soil quality, it has been suggested to measure microbiological and biochemical properties, such as microbial biomass carbon, microbial community composition, microbial metabolic activity and functional diversity and various soil enzymatic activities (He et al., 2008; Hu et al., 2011).

5. Management strategies and resistance/resilience capacity of soil to abiotic stress

In order to feed the increasing global population, intensive agriculture is followed with intensive utilization of chemical fertilizers and energy. These chemical fertilizers are major sources of environmental pollution and it leads to many problems like soil alkalinity, acidity and ultimately yields stagnation in long run. Therefore, emphasis has been given towards research exploring the alternative organic options for inorganic chemical fertilizers.

Regarding management of input, several researchers observed that repeated application of FYM cause a significant shift in soil microbial communities with concomitant improvement of soil resilience and resistance and some ecosystem functions (Toyota and Kuninaga, 2006; Wada and Toyata, 2007). Repeated application of FYM improve soil functional stability though enhancement of microbial diversity, stability of microbial community structure and increasing their substrate utilization ability and it was evaluated by measuring resistance and resilience of some selected biological functions against soil disinfection (Katayama et al. 2002). Ecosystem with more diverse soil microbial community possessed higher soil functional stability (Griffiths et al. 2000). Application of organic amendment is also reported to reduce impact of fumigation by enhancing resilience and resistance of soil (Dungan et al., 2003). Further, Griffiths et al. (2005) also observed higher rate of grass decomposition in soils amended with undigested sewage sludge than no-sludge soil after application of heat (40°C) stress and copper toxicity and thus inferred enhancement of soil resilience in organic matter-amended soil.

Addition of organic matter is also suggested as a remediation measure to improve the soil quality of degraded soils of semiarid region (Ros et al., 2003). Organic amendment application increase the organic matter content of soil, thereby improving the soil water-holding capacity and microbial activity, which is crucial for several soil functions like nutrient transformation, nutrient cycling and microbial diversity (Tejada et al., 2006; Heuso et al., 2012). However, the microbial community composition is affected by the amount and type of organic matter applied to soils as the phospholipid fatty acids (PLFA) composition of microbial communities are different for farming systems with different amounts of organic inputs application (Bossio and Scow, 1998; Lundquist et al., 1999).

The problems associated with acid soils can also be mitigated by addition of organic sources like compost, farm yard manure, green manure, plant debris, vermicompost etc. (Mesfin, 2007, Takala et al. 2019). Long term application of integrated nutrient management (INM) was observed to improve the acid soil ecosystem of rice cropping system in North-East India. The treatment comprising of recommended dose of fertilizer (RDF) + Azolla and RDF + farm yard manure improved the soil microbial population and soil enzyme activities like dehydrogenase, urease, phosphatase and fluorescein diacetate hydrolyzing activity (Gogoi et al. (2021).

Soil management strategies like changing the pattern of tillage practice and zero tillage with crop residue retention can help the cropping system to combat the impact of climate change like excess water or moisture stress due to regular rainfall and high temperature (Aryal et al., 2017). The later practice is also reported to increase the soil organic carbon content by 4.66 tons per hectare over 7 years (Sapkota et al. 2017).Changing tillage practices can also help plant to adapt water and heat stress situations by reducing canopy temperature by 1–4 °C and increasing the irrigation water productivity by 66–100% as compared to conventional production systems (Sapkota et al., 2015). Soil organic carbon (SOC) sequestration is another important strategy not only to mitigate climate change as it has the potential to improve soil quality and resilience to stress (Chakraborty et al., 2014; Powlson et al., 2016).

6. Role of soil microorganisms in abiotic stress management

The role microorganisms in the area of plant growth promotion, nutrient management and disease control is remarkable. However, the role of microorganisms in management of abiotic stresses is gaining importance lately. The role of Plant growth promoting Rhizobia (PGPR) in aliviating abiotic stresses has been reviewed by several authors (Venkateswarlu et al., 2008; Grover et al., 2011; Koza et al., 2022). PGPR through the mechanism of Induced Systemic Tolerance (IST), bring about physical and chemical changes in plants, which enhanced plant tolerance to abiotic stress. Under stress, microorganisms not only produce exopolysaccharides to influence the physico-chemical properties of rhizospheric soil, but also induce osmo-protectants and heat shock proteins etc. in plant cells to combat abiotic stresses and extreme environments. Thus, the use of microbes to alleviate stresses in agricultural crops emerges as a new and promising approach.

Extensive research have been carried out to study functional diversity of agriculturally important microbes under stressed environments and it has also been reviewed by several authors (Zahran, 1999; Venkateswarlu et al., 2008; Grover et al., 2011; Koza et al., 2022). Soil of different stressed ecosystems of desert, acidic, saline and alkaline, highly eroded hill slopes and heavy metal contaminated soils are observed to harbor tolerant species of Rhizobium, Bradyrhizobium, Azotobacter, Azospirillum, Pseudomonas, Bacillus, Paenibacillus, Micrococcus, Acromobacter etc. (Selvakumar et al., 2009, Upadhyay et al., 2009; Asad et al., 2019; Juric et al., 2020; Khan et al., 2021).

Microorganisms adapt to extreme environment through different mechanisms, certain bacteria produce exopolysaccharides which enhance the water retention and regulate carbon sources diffusion in microbial environment in water stress condition (Sandhya et al. 2009). In tropical and subtropical regions, due to high temperature protein denaturation and aggregation cause cellular damage and creates problem in microbial colonization. Microorganisms synthesis a specific group of polypeptides known as heat shock proteins (HSPs) to survive in that situation. Likewise, cold tolerant bacteria adopt the mechanism of induction of cryoprotective protein (Koda et al., 2001). Moreover, microorganisms also secrete secondary metabolites like flavonoid sand lignin precursors, phytoalexins, phenylpropanoids, and carotenoids to defend harmful ROS and alleviate abiotic stress (Rajpoot et al., 2021). Microbial-induced secondary metabolites are applied in frost hardiness, drought resistance, heat acclimation, and freezing tolerance in plants (Kaushal 2019). Therefore, it is necessary to understand the response mechanisms of these resistant microbes to tolerate or adapt stress and engineer it into crop plants to manage the upcoming abiotic stresses resulted from climate change.

7. Conclusion

The impact of abiotic stress on agricultural crop production is expected to increase with climate change, making the environmental conditions harsher, particularly in regions where cultivation is practiced traditionally. Therefore, it is high time to find out the simplest and cost-effective strategies for sustaining crop production under the stress environment. Resource management practices can be helpful in sustaining cop productivity under multiple abiotic stresses as it can stabilize the ecosystem and optimize the crop yield improving soil health. Microorganism can play role for developing methods to mitigate abiotic stress and sustain agricultural production under stressful environment, if their unique properties to tolerate extremities, genetic diversity and their ability to interact crop plants can be explored successfully. Soil biological indicators being sensitive and respond quickly to the changing environment or management, can successfully be implemented for assessing soil resistance and resilience to abiotic stress and can give an early warning of soil degradation.

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