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Soil-Plant-Microbe Interactions in Stressed Agriculture Management: A Review

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ABSTRACT

The expected rise in temperature and decreased precipitation owing to climate change and unabated anthropogenic activities add complexity and uncertainty to agro-industry. The impact of soil nutrient imbalance, mismanaged use of chemicals, high temperature, flood or drought, soil salinity, and heavy metal pollutions, with regard to food security, is increasingly being explored worldwide. This review describes the role of soil-plant-microbe interactions along with organic manure in solving stressed agriculture problems. Beneficial microbes associated with plants are known to stimulate plant growth and enhance plant resistance to biotic (diseases) and abiotic (salinity, drought, pollutions, *etc.*) stresses. The plant growth-promoting rhizobacteria (PGPR) and mycorrhizae, a key component of soil microbiota, could play vital roles in the maintenance of plant fitness and soil health under stressed environments. The application of organic manure as a soil conditioner to stressed soils along with suitable microbial strains could further enhance the plant-microbe associations and increase the crop yield. A combination of plant, stress-tolerant microbe, and organic amendment represents the tripartite association to offer a favourable environment to the proliferation of beneficial rhizosphere microbes that in turn enhance the plant growth performance in disturbed agro-ecosystem. Agriculture land use patterns with the proper exploitation of plant-microbe associations, with compatible beneficial microbial agents, could be one of the most effective strategies in the management of the concerned agriculture lands owing to climate change resilience. However, the association of such microbes with plants for stressed agriculture management still needs to be explored in greater depth.

Key Words: beneficial microbes, fungi, microbial agents, mycorrhiza, organic manure, pathogen, plant health, plant growth-promoting rhizobacteria

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INTRODUCTION

The primary challenge in agricultural sciences is to develop technologies that not only increase crop yield, but also endow with nutritional security and sustainability of agriculture, especially under constrained environments (Gepstein and Glick, 2013; Patel *et al.*, 2015; Hamilton *et al.*, 2016). The current agricultural practices, which heavily rely on the extensive use of agrochemicals for high yield, also lead to environmental disturbances (Singh *et al.*, 2011; Paul and Lade, 2014; Singh, 2015a). Consequences of the on-going rise in human population, dramatic change in global climate, shrinking agricultural lands, rapid urbanization, and extensive use of agrochemicals have collectively affect crop production worldwide (Glick, 2014; Rashid *et al.*, 2016). Besides, climate change and erratic weather are the two most challenging issues confronting mankind today (Ahmed *et al.*, 2015).

Escalating environmental concerns and global hunger open the door for lucrative interest in environment-friendly, sustainable, and climate-smart agricultural technologies (Singh *et al.*, 2011; Rashid *et al.*, 2016). While the control of intensifying human population is a sluggish process, escalating global hunger has knocked the brains of researchers for suitable answers. Thus, increases in the agricultural productivity seem to be the only answer to insuring food security. With no enough room to expand areas of cultivation, a critical supervision of the available fertile land seems to be a good strategy to manage agricultural productivity, ensure economic growth, protect biodiversity, and meet the increasing food demands of incessant rising global population.

The role of microorganisms in improving nutrient availability to plants is an important strategy and related to climate-smart agricultural practices (Pereg and McMillan, 2015; Hamilton *et al.*, 2016). Beneficial

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interactions have been reported among plants and microorganisms in the environment and the derived ecosystem functions (Cosme and Wurst, 2013; Nadeem *et al.*, 2014; Rashid *et al.*, 2016; Singh *et al.*, 2016a, b, c). Root exudates are responsible for rich microbial diversity around the root zone (Singh and Strong, 2016). They provide nutrition to the microbes which in turn endorse plant growth using different growth-promoting attributes (Patel *et al.*, 2015). The plant growth-promoting rhizobacteria (PGPR) and mycorrhizal fungi are well known for their unique plant growth-promoting capability under stressed environments (Singh *et al.*, 2011; Meier *et al.*, 2012; Singh, 2013; Nadeem *et al.*, 2014; Kumar *et al.*, 2015; Bach *et al.*, 2016). The PGPR facilitate the plant growth through diverse mechanisms, which include acquisition of resources (Bhattacharyya and Jha, 2012), enhancement of transformation and acquisition of nitrogen (N) (Bell *et al.*, 2015), mineralization of organic phosphorus (P) (Bhattacharyya and Jha, 2012), production of phytohormones (Kurepin *et al.*, 2015), synergism with other bacteria-plant interactions (Rashid *et al.*, 2016), and mitigation of plant stresses (Singh, 2015a; Vimal *et al.*, 2016). They can also protect plants through the control of soil- and seed-borne phytopathogens (Bach *et al.*, 2016) and induction of systemic resistance (Jain *et al.*, 2013), and the production of volatile compounds (Bhattacharyya *et al.*, 2015) that can inhibit the growth of plant deleterious microbes. Most vascular plants on the earth form symbiotic associations with mycorrhizal fungi (Hashem *et al.*, 2015). Mycorrhizal associations benefit the agroecosystems using growth-promoting attributes (Smith and Read, 2008) such as improved dinitrogen (N_2) fixation by collaborating with rhizobia (Krapp, 2015), synthesis of bioactive compounds (Goicoechea *et al.*, 1997), enhanced photosynthetic rates (Ruíz-Sanchez *et al.*, 2011; Hashem *et al.*, 2015), enhanced phosphatase activity (Liu *et al.*, 2015), osmotic adjustments under stress thus enhancing productivity of marginalized soils (Jain *et al.*, 2013; Xun *et al.*, 2015), metal detoxification (Amir *et al.*, 2013; Zong *et al.*, 2015), and increased resistance against biotic (Yuan *et al.*, 2016) and abiotic stresses (Fabbro and Prati, 2014; Hashem *et al.*, 2015). The PGPR-mycorrhiza interactions represent the intimate interface with the host plants and promote plant health through suppressing the plant pathogens under stressed environments (Kohler *et al.*, 2010; Barnawal *et al.*, 2014; Sundram *et al.*, 2015). The PGPR and mycorrhiza display multiple mechanisms and roles in enhancing plant growth and health, combating phytopathogens and helping in coping under abiotic stressed conditions. Simultaneous working of diverse mechanisms by plant growth-promoting microbes (including both bacteria and fungi) under natural conditions can not be considered as their specific role and thus may dilute the concept of classifying them as direct or indirect mechanisms (Arora *et al.*, 2013). The PGPR and mycorrhizal associations can enhance the plant growth and simultaneously protect it from diseases including those from phytopathogens and deficiencies even under stress conditions/soils.

Organic amendments are important in soil nutrient management including the macro- and micronutrient status of the soils (Barnawal *et al.*, 2014). Plant-microbe-manure tripartite interactions may have vital roles in sustainable stressed agricultural management because such associations play an imperative role in improving performance of crop plants. The PGPR and mycorrhizal inoculations have been reported to be helpful in reducing the use of agrochemicals and in restoring soil health (Rashid *et al.*, 2016). Microbes improve the efficiency of applied fertilizers and manure and also the crop yields (Singh *et al.*, 2011; Rashid *et al.*, 2016). Organic amendments not only improve the soil physico-chemical status, but also increase the possibility of viability and survival of novel bio-inoculants for the reclamation of stressed agriculture and eco-restoration (Rashid *et al.*, 2016). Land use changes and the associated loss of beneficial microbial diversity are the major reasons for deterioration of soil fertility and agricultural productivity (Singh *et al.*, 2010; Singh and Singh, 2012; Singh, 2014). Therefore, the areas related to plant-microbe associations to combat problems of stressed agriculture need to be investigated in greater depth. There is also a need to explore the diversity of stress-tolerant microbes in relation to host plant species, their habitat, and the geographical locations for management of stressed agriculture. This review comprehensively summarizes the possible plant-microbe interactions along with amendment of soils with organic manure for improving plant fitness and combating stressed agricultural problems. The possible roles of beneficial microbes in combination with amendment of soils with organic manure in management of stressed agriculture are shown in Fig. 1.

ENVIRONMENTAL STRESSES AND PLANT HEALTH

Abiotic and biotic stresses directly affect agricultural productivity. High salinity and temperature suppress plant growth and reduce crop yield. For survival, plants have to adapt and acclimatize to their surrounding environment, but the metabolic activities get dis-

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