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Short communication

Mitigating climate change through managing constructed-microbial communities in agriculture

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A B S T R A C T

The importance of increasing crop production while reducing resource inputs and land-use change cannot be overstated especially in light of climate change and a human population growth projected to reach nine billion this century. Mutualistic plant–microbe interactions offer a novel approach to enhance agricultural productivity while reducing environmental costs. In concert with other novel agronomic technologies and management, plant-microbial mutualisms could help increase crop production and reduce yield losses by improving resistance and/or resilience to edaphic, biologic, and climatic variability from both bottom-up and top-down perspectives.

1. Crop production, feeding 9 billion people, climate change, and system feedbacks

Food security is an important issue globally (International Food Policy Research Institute, 2012; Organization of Economic Cooperation and Development, 2012a,b) according to the International Panel on Climate Change report (Intergovernmental Panel on Climate Change, 2013) climate in the next 25 years will disrupt agricultural production with many regions experiencing production losses due to a variety of stresses resulting from climate change (CC) and climate variation (Intergovernmental Panel on Climate Change, 2013; OXFAM, 2013). Although, cereal production yields have stabilized worldwide in the past decade this stabilization is at levels 25% less than what is needed to meet projected population demands by 2050 (Mwongera et al., 2014; United National Environment Programme, 2009). Reductions in crop yields are predicted to be greater than or equal to 10% less current average annual yields (Schlenker and Roberts, 2009; Organization of Economic Cooperation and Development, 2012b; Elbehri et al., 2011; Food and Agriculture Organization of the United Nations, 2012; Intergovernmental Panel on Climate Change, 2013). Thus, future challenges due to extreme droughts and rainfall events will result in losses and degradation of critical agricultural soil and water resources (Intergovernmental Panel on Climate Change, 2013; Mwongera et al., 2014) and exacerbate current food safety and security challenges.

Globally, agricultural practices generate 30% of greenhouse gas emissions, particularly when land-use change is included in the estimate (Food and Agriculture Organization of the United Nations, 2012). Under the status quo, current agricultural practices lead to increased agrochemical usage as a means of achieving pest and disease resistance, which concomitantly reduces or retards microbial mutualisms (Bever 2015) and negatively impacts long-term host resistance to some crop pests (Kennedy and Smith, 1995; Bale et al., 2002; Logan et al., 2003; Elbehri et al., 2011). Compounding this, global warming is predicted to increase both pest and disease occurrence by favoring their relatively rapid reproductive cycles through higher temperatures and increased larval survival (as reviewed in Logan et al., 2003). This potentially leads to a positive feedback cycle in which increased warming

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leads to increased plant production and/or resource requirements leading to increased agrochemical production and utilization, and resulting in higher GHGe from soils indirectly, and directly and through chemical production processes (Smith et al., 2013; Organization for Economic Cooperation and Development Compendium of Agri-environmental Indicators, 2013). Changes in agricultural practices are needed to address these feedbacks in order to positively contribute to mitigation of, and adaptation to CC through advances in crop production and management.

One globally available, adaptive opportunity may be found in the soil and plant microbiomes (see review by Singh et al., 2011). Employing novel technologies based on well described biological, ecological, and evolutionarily phenomena, in concert with classic breeding technologies with or without enhanced by transgenic tools, (as reviewed in Dangl et al., 2013), addresses complexities inherent in cropping systems (e.g., heterogeneous soil properties, variable pest exposure). This approach recognizes a role for breeding of plant, microbe, and symbiotum (Box 1) traits contributing to, and optimizing host performance. For example, microbial symbionts known to increase host defenses can be used as a means of producing a plant phenotype more resistant and/or readily responsive to pest/pathogen adaptation (see review by Berendsen and Pieterse, 2012; Lambrecht et al., 2015; Box 1).

2. All of the above approach

We propose expanding management approaches such as Climate Smart Agriculture (CSA) to include the microbial components of crops and soils. Combining breeding strategies and biotechnology with utilization of co-adapted, mutualistic plant-microbial associations (endophytic and rhizosphere) could result in an agricultural approach called *constructed microbial communities*. A *constructed microbial community* approach (Box 1) is a microbial mixture designed to utilize evolutionary and ecological phenomena to inform and develop mutualistic microbial communities. The result is increased production of crops with the ability to adapt to climate change while simultaneously reducing the economic and ecological costs of production e.g., reductions of agrochemical applications.

3. Brief introduction to mutualistic symbionts: wheels within wheels

Positive or mutualistic symbioses are ubiquitous and gaining increasing interest as we learn more about the prevalence and consequences of plant microbiomes (Supplementary Table S1; as reviewed Berendsen and Pieterse, 2012) and their impacts on host response to abiotic and biotic stress (as reviewed by Rodriguez et al., 2009; see also Mei and Flinn, 2010; and Hamilton et al., 2012). Although hidden from the naked eye, microbial mutualists are globally important classes of organisms due in part to their role in ecosystem functioning (as reviewed by Rodriguez et al., 2009) and their impacts on host plant performance (see Supplementary Table S1).

Mechanisms for why mutualists increase biomass production or maintain yields in response to abiotic and biotic stress (Bouton et al., 2002; Govindarajan et al., 2006, 2008) have extensive documentation (Supplementary Table S1; Assuero et al., 2006; Kevei et al., 2008; Rasmussen et al., 2009; Newcombe et al., 2010; Mei and Flinn 2010; Tian et al., 2010; Redman et al., 2011; Bücking et al., 2012; Fellbaum et al., 2012; Hamilton et al., 2012; Hamilton and Bauerle, 2012; Pellegrino et al., 2012; Tschaplinski et al., 2014; Singh, 2015). For example, enhancement of nutrient acquisition pathways, production of plant growth regulators, alterations in physiological and biochemical properties of the host plant, and defending plant roots against soil-borne pathogens are examples of multiple favorable phenotypes resulting from beneficial plant-microbial associations (as reviewed by Mei and Flinn, 2010 and Hamilton et al., 2012 see also Molitor and Kogel, 2009; Weston et al., 2012; Supplementary Table S2).

To create contextually effective, temporally stable, *constructed microbial communities*, collaborations between breeders and microbial ecologists will be necessary to develop plant-microbial systems maximizing crop yields and contributing to stable mutualistic symbioses (Fig. 1) while presuming unpredictable and/or unstable resource availability (e.g., water and nutrients). The resulting *constructed microbial community* (Box 1) could contribute to GHGe mitigation and agricultural adaptation to CC by decreasing resource requirements (i.e., fertilizers and pesticides).

4. Reduced inputs, increased profits

Mutualistic microbes can contribute to plant health via increases in:

1. the efficiency of plant resource uptake (e.g., N, water),
2. plant tolerance of abiotic stress (e.g., salt),
3. plant tolerance of biotic stress (e.g., pathogens).

Box 1
List of definitions.

Word	Definition	Example
Constructed Microbial Communities	Manipulation of plant microbiome and or soil microbial community composition designed to increased plant yields and/or resilience/resistance to perturbation; context cognizant design	Selection of mutualistic mycorrhizal and bacterial rhizosphere community membership with broad host taxonomic range with positive impacts on host phenotype, e.g., increased drought tolerance, increased host resistance., also increasing soil quality
Mutualisms	An interaction between a symbiotic organism mutually beneficial to both organisms	Pollinators and plants; gut microbes and mammals
Plant Microbiome	Community of microbial organisms residing within host tissues/organs likely spanning a continuum of interactions	Rhizobia, mycorrhizae, dark septate endophytes, foliar endophytes—simultaneous colonization
Precision Agriculture	Spatially explicit evaluation of soil and landscape conditions including and resulting from soil characteristic determined by topography and geology	Time and degree of till, quantity and quality of chemical applications based on soil heterogeneity at field-scale, utilization of polycultures to increase soil nutrients, changes in seeding and harvesting based on complex climate models, etc.
Climate Smart Agriculture	Sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals (Food and Agriculture Organization of the United Nations, 2012)	Inclusion of multi-cropping systems, low/no-till farming and novel technologies which employ context dependent solutions and include socio-economic limitations /opportunities
Symbiotum	An interaction involving two or more organisms resulting in changes to at least on organisms' phenotype	Pollinators and their plant hosts, fungal pathogens and plant/animal hosts, gut microbes