Interdisciplinary Research in Microbial Agroecology Provides Solutions for Sustainable Agriculture

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Agriculture is one of the oldest forms of labor for humans, but it has evolved with modern technology to become so much more than it was. Now agriculture is studied and researched as a science, with the latest technological advancements applied to increase production and the economical aspect of agriculture. The industrial revolution led to many modern inventions that have increased crop production and decreased labor, but there is still not enough food in some parts of the world (Chrispeels, 2000). Modern agriculture has developed pesticides, herbicides, and fertilizers to enhance crops and protect them from pests, pathogens, and weeds. Water irrigation systems have made more land suitable for crops, but there is currently a water shortage and drought crisis in many parts of the world (Altieri, 2000). Humans have come up with many alternatives to the forces of nature concerning agriculture, and many ways to change the environment in order to suite our own needs. These modern accomplishments may seem beneficial at first glance, but if people study the effects of modern agriculture on the environment or the ways that agriculture is lacking, especially for poor countries, perhaps we will realize that our chemically and physically engineered agricultural advances are causing more harm than good (Ogle et al., 2014).

There has been a more recent trend in agriculture to provide for solutions that will be better over time for humanity and the environment. The idea of an agricultural system that is self-sustaining would be implemented using evolutionary and biodiversity concepts of symbiosis and functioning ecosystems to create agricultural ecosystems (Altieri, 2000). Instead of using modern chemicals and engineering to alter land in a way that it will support the crops a farmer has set out to grow, sustainable agriculture makes a spatially designed plan of crops and organisms that enhance crops to produce a better crop yield without harming the environment or redirecting water resources (Altieri, 2000). The concept of sustainable agriculture may seem like humanity is taking a step backwards by not utilizing these new developments to increase agricultural production, but the current agricultural methods are failing this planet and sustainable agriculture holds more promise for the future.

Agriculture should not be taking away from the environment or causing more detriment than good; it should be self sustaining and available to everyone. From this idea of sustainable agriculture, the field of agroecology has grown. The scientific field of agroecology has embraced the concept of sustainable agriculture as its central dogma and has led the way for current agroecological research (Altieri, 2000). As an interdisciplinary field that formed from the collaboration of agriculture and ecology, agroecology focuses on ways to improve agriculture using ecological principles (Altieri, 2000). Much of the recent agroecology research has dealt with microbes and has brought about a collaboration with the field of microbiology in order to provide solutions to the problem of sustainable agriculture (Bhardwaj, Ansari, Sahoo, & Tuteja, 2014). Most people understand that there is plenty of food being produced in certain parts of the world while other areas lack food or resources to provide food to their people. Although world hunger is a complex problem involving politics, ethics, and societal issues, there are also scientific solutions that can provide relief to places suffering from a lack of food availability (Ogle et al., 2014). The following paper will provide support to show that the interdisciplinary field of agroecology in conjunction with microbiology can provide sustainable agricultural solutions for polluted and infertile soil, which could reduce the world hunger crisis by increasing crop production worldwide while decreasing pollution.

Agricultural Issues and Ethics

Agriculture may seem an unlikely area to consider ethical issues, but there are many ethical debates centered around agricultural problems. One ethical issue of modern agriculture is the increased pollution that it causes, and another is the way that modern agriculture is balanced in favor of the wealthy countries (Chrispeels, 2000). As modern agricultural practices have advanced with technology, farming has become an industrial practice in which many poorer countries cannot compete (Chrispeels, 2000). Countries that have struggled with modern agriculture tend to have soil polluted by chemicals or environments not conducive to modern farming practices (Singh, Pandey, & Singh, 2011). Chemical pollutants have destroyed ecosystems that would have sustained modest farming practices, and the balance of soil microorganisms has been altered. The commercialized view of large scale agriculture has become ingrained in modern society, and developing nations do not have the funding to support these chemically intensive agricultural techniques (Chrispeels, 2000). The ethical issue centers around the monetary gain by large corporations who push for modern agriculture when an ecological agricultural perspective would be better for the environment and developing countries.

Altieri (1998) explains in his article about the ecological impacts of industrial agriculture that occurred when switching from an ecological perspective on agriculture to an industrial one around the middle of the twentieth century. Once this change took place more agricultural problems developed, but they are still being solved from an industrial viewpoint instead of an ecological one. Although these new techniques have increased the mass production of crops and to a lesser extent food availability, the pollution produced by modern agricultural techniques and the destruction of surrounding environments is a high price to pay for economical gains. Another issue to consider is the depletion of fertile soil in response to this detrimental way of farming, which may cause more crop failures in years to come (Ogle et al., 2014). Current analysis of agricultural and ecosystem data has already shown some of the detrimental effects from mass monoculture and chemical-driven agricultural practices.

The modern methods of industrial scale farming have only been in practice since the middle of the twentieth century, when new agricultural advantages became available for large scale operations (Altieri, 2000). Before this time, agriculture depended on ecological factors, and farmers had to be aware of the way they rotated crops and how certain crops would handle the local environment (Altieri, 2000). This was an ecological approach to farming, and it worked to provide a modest output. As agricultural research provided the ability to enhance crops and the land, ecological perspectives died away. This shift in agricultural methods has been highlighted by the increase in agricultural problems, which have been solved with more chemical alterations and genetic enhancements. As Altieri (1998) has pointed out in his research, the implementation of single crop growth in one specific area causes an increase in specialized pests for those crops and a depletion of specific nutrients that those crops require. To counter these problems stronger pesticides are utilized and chemical fertilizers are added to the soil, but this only temporarily fixes the problem. Evolution of pests still occurs and leads to more resistant pests that require stronger chemicals to kill them. The ethics behind these practices have proven to be for economical gain, without consideration of the environment, local ecosystems, or future implications. Modern industries have found that specializing in specific crops on a large scale and using quick fixes to ecological problems is more economical than ecological farming techniques. According to Altieri (1998), the use of monoculture crops has required chemical interventions to the point where they are now producing the same yields as ecological farming techniques produced.

After decades of using these modern techniques for economical gains in agriculture, the negative consequences are becoming more pronounced and scientists have found data to establish connections between these modern practices and current pollution problems. The destructive effects of agricultural practices has been documented by environmental lawyers and scientists as well. Current environmental regulations do not apply to farmers, and farm land is exempt from pollution compliance standards (Kim, 2013). Because of these loopholes, industrial agricultural practices have polluted water supplies, soil, and surrounding ecosystems (Kim, 2013). The use of fertilizers has been implicated in dangerously high nitrate levels in drinking water which has been connected to an increased incidence of cancer and genetic disorders for communities located near agricultural land (Dowd, Press, & Huertos, 2008). Pesticide and fertilizer use has also leached into freshwater habitats and has become detrimental to water dwelling species (Dowd, Press, & Huertos, 2008). Along with the danger to macroscopic organisms, these chemicals have profound effects on the microscopic ecosystem. Soil bacteria and fungi are necessary components of agricultural ecosystems that have been mostly overlooked in modern agricultural practices. The scientific discipline of agroecology has provided solutions to these agricultural issues and ethical considerations through the application of sustainable agricultural techniques.

Agroecology

Although the field of agroecology is not new, it has been revitalized for the twenty-first century with scientific research providing new data to contribute towards sustainable agriculture. As environmental scientists have found new evidence supporting global climate change and the impact of modern practices on the environment, there has been a resurgence in environmental movements aimed at reducing pollution and increasing sustainable use practices (Wezel, Bellon, Doré, Francis, Vallod, & David, 2009). Agroecology is a unique interdisciplinary field that has arose out of the need to incorporate ecological, ethical, and political sciences into the agricultural field. According to Altieri (2000), "Agroecology provides a framework by applying ecological theory to the management of agroecosystems according to specific resource and socio-economic realities, and by providing a methodology to make the required interdisciplinary connections," (What is Agroecology section, para. 4). A review of current literature provides a positive outlook on agroecology research and possible applications for sustainable agriculture in both agriculturally developed and poorer, developing countries.

Current agroecology research has been aimed at analyzing the agricultural traditions of small farmers in poor countries to determine their techniques that were adapted over generations to provide sustainable crops in harsh environments (Altieri, 2002). Although many important traditional farming practices have been lost, there are still some important agroecological concepts that can be gained from the small farmers found in remote areas of the world (Altieri, 2002). Agroecologists have found that poor farmers with limited access to modern chemical agriculture agents, have developed sustainable agroecosystems which work with their specific environmental conditions to provide modest crop outputs without overuse of natural resources (Altieri, 2002).

This new focus of agroecological research is driven by an integrated natural resource management approach to agriculture (Altieri, 2002). For example, agroecologists have found that poor corn farmers in latin american countries rotate their crops every year with velvetbean, and agroecologists have found that the velvetbean helps to retain water in the soil while also preventing the growth of weeds (Altieri, 2002). This system of crop rotation works to provide crops without the need for chemical interventions. The agroecological principle of facilitation is the use of specific crops to enhance environmental conditions for other crops, and this has been a central focus of current agroecological research (Altieri, 2002). One key point of this research is that agroecosystems with a greater abundance of species diversity are more resilient and can handle a greater amount of environmental stressors. Current data suggests that a diversity of plants in an agroecosystem can sustain drought conditions better than monoculture agricultural systems (Altieri, 2002). Another important area of agroecological research has been with soil microbiota, and the benefits of interactions between plants and microorganisms. With the increased attention to soil microbiota and symbiotic relationships of microorganism to crop plants, the field of microbiology has uncovered many interesting applications for agroecology research.

Microbiology

When most people consider the field of microbiology, they think of pathogenic organisms and research focused on ways to treat pathogenic infections. The application of microbiology research to biomedical science is very important, but it also tends to overshadow some of the beneficial ways that microorganisms interact with the environment. Although the field of microbiology has been largely focused on antibiotic resistance and emerging pathogens, there have been some branches of this diverse field devoted to the ecological aspects of microorganisms. The recent focus of molecular biology techniques to microbial ecosystems has brought a renewed interest in composing data on various microbiomes with the hope of understanding the ways that microorganisms contribute to their surrounding ecosystems (Singh, Pandey, & Singh, 2011). Previous studies of plant and soil microbes was limited from the restrictions on culturing abilities in the laboratory setting (Singh, Pandey, & Singh, 2011). Now that molecular techniques have been established in microbiology, more bacterial species are being found. Also, recent microbiology techniques of growing soil bacteria in natural environment settings has provided more insight into the ways that bacteria contribute to ecosystems and new techniques for culture of previously unknown species (Singh, Pandey, & Singh, 2011). Microbiologists are finding more ways in which bacteria and fungi contribute to the world around us and the important roles that these organisms play in sustaining life on this planet.

Current research in microbiology has led to the discovery of bacteria in every imaginable place on Earth, with few limits on their ability to adapt in every environment they encounter. Certain species have adapted important characteristics that have proven beneficial to many other living organisms, and plants are no exception. Microbiologists are finding symbiotic relationships of bacteria with every living thing, and nurturing these relationships has provided positive results. Specific types of bacteria and fungi have symbiotic relationships with crop plants that enable the plants to gain important nutrients from the soil and help stimulate the growth of plant roots to find available water and nutrients in the soil (Philippot, Raaijmakers, Lemanceau, & Van Der Putten, 2013). The symbiotic relationship of specific rhizobacteria in the roots of legume plants is an example of the beneficial bacteria that microbiology research has revealed (Philippot, Raaijmakers, Lemanceau, & Van Der Putten, 2013). These bacterial colonies live inside of the root tip and stimulate root growth (Philippot, Raaijmakers, Lemanceau, & Van Der Putten, 2013). Some beneficial microorganisms also protect plants from pathogenic organisms and remove harmful toxins from the soil (Singh, Pandey, & Singh, 2011). Microbiology research has found ways to use bacteria for many other areas of scientific research including bioremediation to break down pollutants, chemical synthesis, organic nutrient enhancement, pest and pathogen control, biofuel production, and protection of host species from environmental stressors (Singh, Pandey, & Singh, 2011). With the recent data that has been compiled on the benefits of microorganisms for agricultural crops, an interdisciplinary relationship of microbiology and agroecology has been formed with the intent of ushering in sustainable agricultural practices.

Microbial Agroecology

The interdisciplinary collaboration of microbial agroecology may be new but there has been a great deal of progress towards the goal of sustainable agriculture. Current research has focused on symbiotic relationships uncovered by microbiologists and soil microbiota that can enhance crop production (Singh, Pandey, & Singh, 2011). The use of certain bacterial strains for bioremediation of polluted soil has also been studied as a way to provide for more farmland in polluted areas of developing countries that have few farming capabilities (Singh, Pandey, & Singh, 2011). Through this scientific research biofertilizer and biopesticide products can be designed with the right balance of microbiota to enhance crops without polluting the environment (Singh, Pandey, & Singh, 2011).

There are numerous examples of symbiotic bacterial relationships with crop plants, which can be classified into various groups of bacterial species. Endophytic bacteria have the ability to fix nitrogen and solubilize phosphorus from the soil for plants to use, while the previously mentioned rhizobacteria live inside plant roots and stimulate root growth (Bhattacharyya & Jha, 2012). Actinomycetes are a group of bacteria involved in the cycling of nutrients in the soil, and they have also been found to promote plant growth (Bhattacharyya & Jha, 2012). Another important benefit of bacterial colonization in and around plants is protection from pathogenic species. Scientific studies have linked the inoculation of actinobacteria to prevention of disease in tomato and banana plants (Bhattacharyya & Jha, 2012). By inhabiting the plant, the beneficial bacteria are passively keeping pathogens away from the plant and some species also have the ability to produce specific antibiotics against pathogenic bacteria (Bhattacharyya & Jha, 2012). One specific bacterial species, *Bacillus subtilis* has been proven to promote plant growth and crop yield when introduced to the rhizosphere of plants by stimulating plant growth hormones (Bhattacharyya & Jha, 2012).

Now microbial agroecologists are studying the microbiome of plants that grow in harsh environments to determine their role in enabling plants to withstand environmental stressors. Plants that can withstand extreme temperature fluctuations or drought have help from microorganisms that provide nutrients, water, and chemical signals that protect them (Sheng, Gao, Xue, Ding, Song, Feng, & An, 2011). By finding the microbial species that encourage crop production under harsh conditions, land that was once considered infertile and unsuitable for growing crops, may be able to sustain agricultural production. Sheng and colleagues (2011) discovered endophytic bacteria in the tissue of plants growing along glaciers where the plants are exposed to extreme temperature fluctuations and windy, icy weather conditions. To better understand how these plants have adapted to this harsh environment, the researchers studied the molecular structure of endophytic bacteria in subnival plants from mountainous glacial tundra (Sheng et al., 2011). Their research indicates that unique species of bacteria have evolved within these hardy plants in such a way that they are more resistant to the extreme weather and they help plants survive the extreme weather as well (Sheng et al., 2011). The research by Sheng and colleagues is just one more way by which the study of microbiology can be applied to agroecology for providing solutions to sustainable agriculture. With the vast amount of promising research that has come from the recent collaboration of microbiology and agroecology, there are many ways in which sustainable agriculture could be implemented.

Sustainable Agriculture

How can these research findings be applied to sustainable agriculture, and will it make much of a difference? With all of the new data that has come from studying microbial agroecology, there is a wealth of information that needs to be passed from the scientists to farmers, and the ability to produce biological fertilizing agents in large quantities for agricultural use. Along with this issue, there also needs to be regulations in place for the use of these biofertilizers and and crop layout plans for the development of agroecosystems. The ethical issues involved in current agricultural practices and the lack of sustainable crop yields in many developing countries has prompted the need for sustainable agriculture. Sustainable agriculture is a viable solution to agricultural pollution and world hunger if it is implemented properly, and the use of sustainable agricultural techniques needs to be made available soon.

According to the Food and Agriculture Organization of the United Nations (FAO, 2014), current agricultural practices will not sustain future generations of humans unless more land or different techniques are used to produce higher crop yields. A recent survey of agricultural land by the FAO has revealed that most of the available land in Africa has been depleted or polluted and is not viable for growing crops (FAO, 2014). By using the knowledge gained from microbial agroecology research, scientists have found ways to renew soil that has previously been considered unsuitable for agriculture. For instance, Beškoski and colleagues (2011) have discovered bacterial isolates with the ability to break down heavy residual fuel oil that has polluted soil. Because land contaminated with fuel oil is not suitable for agriculture, using bacteria for bioremediation of the soil could make more land available for agricultural purposes. Another way in which bacteria have been useful for bioremediation is cleanup of tobacco pollution. Tobacco waste that leaches nicotine into the soil has a detrimental effect on crop plants and can cause soil to become unusable for agricultural purposes, but a specific species of *Pseudomonas* has been found to efficiently degrade nicotine in the soil, making polluted land more suitable for agricultural purposes (Wang, Tang, Yao, Wang, Min, & Lu, 2013). Many poorer countries that have limited agricultural resources and soil polluted from war practices can benefit from bioremediation, but they also have to compete with drought and water availability issues.

Another interesting area of research that has been discovered in microbial agroecology involves the use of beneficial microorganisms to enable crop plants to survive drought conditions. Marulanda, Barea, and Azcón (2009) have found that certain fungi and bacteria that have adapted coping mechanisms to survive in arid climates can stimulate plant growth under dry conditions and enable roots to grow deeper in order to obtain more water and nutrients in the soil. The combined inoculation of specific bacterial strains with mycorrhiza encouraged better shoot development and root system in plants that would otherwise be unable to withstand drought conditions (Marulanda, Barea, & Azcón, 2009). By using the right strains of bacteria and fungi, farmers can utilize land that was previously unsuitable for agriculture and provide crops for their local communities.

Conclusion

As previously mentioned, the goals of implementing sustainable agriculture involve providing sustainable agricultural practices to developing countries and reducing the amount of agricultural pollution from industrial sized farms. The first goal was addressed by the use of specific bacterial and fungal strains for bioremediation, soil enhancement, and improving plant tolerance to environmental stressors. The second goal can be achieved by providing alternative solutions to chemical fertilizers and pesticides. By industrializing the use of fertilizers, which are the beneficial bacteria and fungi, farmers can choose eco-friendly alternatives to enhance their crops. In an effort to improve the understanding of agricultural ecosystems on a microscopic level, Vogel and colleagues (2009) have begun a metagenome project for soil microbes similar to the human genome project that has provided insight for medical research. Their goal is to understand to relationships of microorganisms to soil ecosystems and find the beneficial balance of bacteria and fungi for improving plant growth and development (Vogel et al., 2009).

Organic farming practices are another solution to provide for more sustainable agricultural practices but the pollution of soil and farming land requires more extensive proactive solutions, rather than the passive solution of conventional organic farming. By actively renewing the soil and replenishing organisms for an agroecosystem, better crop production can be restored and improve the environment as well. Perhaps after bioremediation and natural soil enhancement, future crops may be grown by common organic methodologies without the need to implement additional ecological measures. There still needs to be a framework developed for sustainable agriculture incorporating the microbial agroecology research data into agricultural design and large scale manufacturing of biological enhancement media. Scientists involved in microbial agroecology research must be able to communicate their findings in order for them to be properly implemented and beneficial microorganisms must be mass produced for development of suitable land. Biodiversity is an important part of any ecosystem, and the agricultural ecosystem is no exception. The collaborative research of microbiology and agroecology has found solutions to providing sustainable agricultural practices that need to be implemented for reducing agricultural pollution and the world hunger crisis in developing countries.

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