Alysha Blömker

The British School in the Netherlands

The Hague, The Netherlands

Nigeria, Sustainable Agriculture

Nigeria: The potential uses of mycorrhizal symbioses as bio-fertilizers

Introduction

Nigeria, like the rest of the world, faces the unprecedented challenges of sufficient food production for an exponentially growing population; Changing climate conditions, such as desertification; As well as the concurrent negative environmental impacts of conventional agricultural methods that result in frail soil. It is of paramount importance to not only remediate depleted soils, but to also utilize as much land as possible for agriculture, whilst circumventing the devastation of natural ecosystems. Mycorrhizae are a natural symbiosis between soil fungi and plants that are ubiquitous in healthy soils and supply plants with vital nutrients; But in fields the intensive use of fungicides and agricultural methods such as tillage and leaving fields fallow have resulted in an absence of mycorrhizae in farming soil. The ill state of agricultural soil in Nigeria can be remediated through the re-introduction of mycorrhizae on fields and thus mycorrhizae have the potential to be a novel component in our imperative strive towards sustainable agriculture.

Introduction to Nigeria

Nigeria is the most populous country in Africa, with a current population of 200 million and a predicted population of 410 million by 2050 (Worldometer). Currently, 48.1% of this population is living in rural areas. Nigeria's GDP in 2017 was 375.8 billion USD (Worldbank); 25.08 % of which was from the Agricultural sector (National Bureau of statistics). Nigeria follows a democratic governmental system and the ideas of human rights, equality and freedom have become vital to the nation.

Being one of the largest countries in West Africa, Nigeria covers a total land area of 910,768 km^2. The majority of Nigeria is composed of savannah or desert areas in which rainfall is scarce. Only in the south does the tropical climate allow the growth of mangrove forests and the formation of swamps. This decrease in water availability from south to north is reflected in the annual rainfall; In the south, the average rainfall is 3,000mm compared to the 500mm of rain in the north. High temperatures are common across the country as a whole (Brittanica). Nigeria experiences the cycles of rain- and dry season, but in the north, the rain season is significantly shorter at an average of 4 months (from May to September) compared to 9 months (from March to November) in the south (Brittanica). This means that the northern part of the country experiences a dry season that can last up to 8 months, which is a vital challenge to agriculture in those areas.

Nigerian Agriculture

To sustain the Nigerian population an estimate of 78.5 million hectares of farmland is required in Nigeria, however, currently only 30 million hectares of farmland that are being cultivated (Export "Nigerian Agriculture"). This insufficiency of farming land will exacerbate in the future and is a major threat to food stability in Nigeria.

The Nigerian agricultural is largely composed of smallholder farmers and the sector employs nearly two-thirds of all labour forces (FAO). Farms are thus often family-based and owned. The children of farmers aid in the fields and will likely inherit and continue the farming practices of their parents. Currently, many farmers lack the understanding of and money for modern agricultural techniques, thus governmental assistance is common (Export). Conversely, the declining trend of federal expenditure on agriculture, which decreased from 290 million dollars in 2010 to 210 million in 2016, and is continuing to decrease, will have adverse effects on Nigerian agriculture (Olomola & Nwafor 2018). It should also be noted that Nigeria's power supply still experiences problems which make the implementation of highly mechanized systems difficult, alternatively, lower input systems and biological-based methods of crop production, such as Mycorrhizae, may be favourable (Export) (Mukhongo, et al. 2016).

Since the 1970s rice has become an essential part of the Nigerian diet and this is reflected in the high consumption, production and import of rice in Nigeria (FAO). With an annual production of 50 million tonnes, Nigeria is the largest cassava producer in the world (FAO); Cassava is a vital food security crop in Nigeria and the surrounding sub-Saharan area. Similarly to the rest of Africa, maize is frequently cultivated in Nigeria with an annual production of nearly 8 million tones (Agric). In addition to this, Nigeria is also the largest consumer of cowpeas, which are a low-cost protein staple of the Nigerian diet ("Nigerian Farmers Learn How to Increase Cowpea Production").

Nigerian Soil

Desertification is an urgent problem, especially in the north of Nigeria; As a result, the livelihood of around 40 million people is under threat (Unah 2019). In addition to the impacts on agriculture, desertification also has dire socio-economic consequences such as the forced migration of victims from the impacted areas to surrounding cities. It is estimated that Nigeria uses around 350,000 hectares of land to desertification annually. Desertification is a result of both drought and partially from unsustainable human agricultural practices (Olagunju 2015). Furthermore, extensive periods of drought continue to challenge the stability of Nigerian agriculture. The increase in soil erosion has also been estimated to have resulted in the loss of 30% of Nigeria's agricultural land and to have decreased crop yield by 30-60% (Olagunju 2015).

The agricultural productivity in sub-Saharan nations has been gradually declining because of drought and the lack of phosphorus, potassium and nitrogen in the soil (Mukhongo et al. 2016). This poor fertility of soils has lead to a dependency on the use of inorganic fertilizers in Nigeria.

Solution: Mycorrhizae

Mycorrhizae are a symbiosis between certain species of soil fungi and a vascular host plant where the fungal mycelium forms associations with the plant roots. They are ubiquitously present in almost every soil and approximately 80% of all known land plant species form mycorrhizal connections; Mycorrhizae are thus an integral part of a healthy soil biota (Wang & Qiu 2006). Records of fossilized fungal hyphae from 460 million years ago are the earliest findings that resemble the modern-day mycorrhizal fungi (Redecker 2000) and suggest that mycorrhizae played a crucial role in the initial establishment of vegetation on land.

Mycorrhizae can be used to improve plant growth and health by improving nutrient uptake, mitigating the impacts of water shortages, making plants better able to deal with biotic and abiotic stress factors, and enhancing the stability of soil aggregates, which decreases the rate of soil erosion. All of these are very desirable properties of mycorrhizae that make it suitable for the enhancement of food production.

In the mycorrhizal symbiosis, the plant host supplies the fungal symbiont with photosynthetically fixed carbon (Finlay 2008). In return, the fungus supplies the host plant with essential nutrients such as nitrates and phosphates, where experiments with single plants and plant communities have shown that up to 90% of phosphate uptake by plants can be contributed to AM (Marcel G. A. Van Der Heijden, et al. 2008). This bidirectional exchange of resources is mutually beneficial and allows for both partners to thrive and thus it is important to note that Mycorrhizae are not parasitic.

The Mycorrhizae can be thought of as an extension of the plant's root system. Fungal hyphae are thinner and grow faster (ranging from 738 to 1067 mm per day) and longer (extent of 10-40 mm per mm of root length) than plant roots (Giovannetti, et al. 2006). In effect, this allows for increased absorption of nutrients and water, because of the increased total surface area of the root system. Since the fungal hyphae are thinner and smaller than plant roots, they can penetrate the soil better and create a sponge-like a network which has the ability to absorb nutrients and water more efficiently. This property is especially advantageous in areas of Nigerian soil that have suffered from nutrient depletion or are naturally low in nutrients. A study by Marcel G. A. Van Der Heijden focusing on the impact of mycorrhizae on the nutrient loss from grassland microcosm during a rain-induced nutrient leaching event showed that Grassland microsomes containing arbuscular mycorrhizae lost 60% less phosphorous than those without (Marcel G. A. Van Der Heijden 2010). This is especially relevant considering the periodically heavy rainfall in Nigeria where the majority of semi-arid soil experience severe nutrient erosion (FAO). In addition to the prevention of nutrient loss, mycorrhizae also possess properties that prevent the physical erosion of soil. The network of hyphae created by mycorrhizal fungi can encapsulate soil particles, forming a gauze which in effect stabilizes the soil (Chen, et al. 2018). Furthermore, soil aggregates are kept together through the secretion of the adhesive protein glomalin by mycorrhizal fungi ("Mycorrhizal Colonization and Soil Health" 2019).

Another prominent threat to Nigerian agriculture is the loss of farmable land through desertification. Here mycorrhizae can be utilized in revegetation strategies as well as the re-establishment of a healthy soil biota in affected areas (Jeffries, et al. 2002). Research with the arbuscular mycorrhizal fungi Glomus intraradices has shown that around 20% of water uptake is directly related to the mycorrhiza (Ruth, Khalvati & Schmidhalter 2011). The presence of mycorrhizae can have a significant impact on the robustness of crop plant in the face of water shortages and drought.

Specificity to major Nigerian Crops

It is important to understand that the dynamics between the specific host plants and the type of soil fungi, as well as the conditions of growth, which can elevate or impair the positive effects of mycorrhizae. Thus, for the Nigerian agriculture, mycorrhizal fungi that are compatible with the correct crops need to be selected.

The mycorrhizal fungi Scutellospora calospora has been shown improved the growth of maize root systems, which subsequently increased maize growth, thus concluding that arbuscular mycorrhizae are a suitable substitute to chemical fertilizers (Priyadharsini & Muthukumar 2017). The use of the mycorrhizal fungi Glomus clarum has also been shown significantly increase the Maize yield in degraded Ultisol soils (soils that suffer under intensive weather degradation as is the case in parts of Nigeria) (Stephen, Fagbola & Iyamu 2013). In addition to the improved yield of maize, the use of Glomus clarum benefited the overall nutrient content of the soil (Stephen, Fagbola & Iyamu 2013).

Concerning rice cultivation, the genera Gigaspora is common in the West and North of Nigeria and specifically Gigaspora gigantae has been shown to improve root system of rice plants as well as the growth of rice (Sanni 1976). The growth of rice (Orya sativa L.) has also been improved through the use of Glomus mossae; This resulted in a decreased need of chemical fertilizers in wetland rice growth or in combination with appropriate volumes of chemical fertilizers to promote nutrient uptake (Huising, et al. 2017).

A study focusing on the growth of cowpea sampled mycorrhizal fungi from the native soil which they used to inoculate the cowpea plants. Once again the establishment of the mycorrhizal symbiosis correlated with an increased Phosphate and Nitrate uptake of the host plant (Sanni 1976). The use of mycorrhizal fungi species that are native to Nigeria is a sensible approach to utilizing mycorrhizae in Nigerian agriculture. Furthermore, the application of Glomus deserticola and Gigaspora gigantea on cowpea roots has shown to mitigate negative effects of charcoal rot caused by M. phaseolina infections, as well as an increased drought tolerance (Oyewole, Olawuyi, Odebode & Abiala 2017).

The mycorrhizal fungi A. colombiana and A. appendicula have been shown to posses bio-protective properties on cassava plants against the nematode Meloidogyne spp. (Séry, Kouadjo, Voko & Zézé 2016). In field conditions, the native A. colombiana fungus has significantly increased cassava yield, even in comparison to commercial inoculants (Séry, Kouadjo, Voko & Zézé 2016). These reports of mycorrhizae native to Nigeria having more profound benefits on cassava yield, growth, water stress tolerance and nematode resistance seem intuitively logical given the natural adaptations of the mycorrhizal fungi to its geographical context.

Implementation

Lastly, the implementation of Mycorrhizal use has to be considered. The use of bio-inoculants is becoming increasingly common; Rhizobia (bacteria) are already a part of soil fertility management plans, so the use of mycorrhizal bio-fertilizers is realistically feasible.

The production of mycorrhizal inoculants can be conducted using substrate-based systems, which are fairly low-tech but require large spaces for the set up and laborious work; Solution based systems (which resemble hydroponic agricultural systems) and are suitable for mass-production of AM mycorrhizal fungi (Ijdo, Cranenbrouck &Declerck 2010), but require technical expertise; In vitro culturing methods that produce quality a and affordable inoculum, but like the Solution based systems they require qualified personnel (Mukhongo, et al.2016).

The main obstacle to the use of mycorrhizae in the Nigerian agriculture is the lack of technological research capacity and the difficulty of educating the predominantly smallholder farmer about such bio-fertilization methods. Currently, the majority of Mycorrhizal companies are based in Europe and Asia; This makes the import and transportation costs of mycorrhizal inoculants expensive for the Nigerian market. The pioneering mycorrhizal production units ‘Dudutech Ltd’ in Kenya and ‘Mycoroot Pty Ltd’ in South Africa are to-date the only Africa producers of mycorrhizal inoculants.

A major problem that hinders the use of mycorrhizal inoculant is the inconsistent quality of inoculating strains; If mycorrhizal products are contaminated their efficiency in the field is impaired. It is vital to ensure a national (possibly even international) standard of mycorrhizal quality or a standardized grading system based on purity. This can be enforced through the establishment of sub-sectors in the Nigerian governmental department for agriculture. Furthermore, it should be possible for customers to trace the origin of the mycorrhizal strain to ensure transparency in the industry; So establishing a fundamental legislative body on which Nigerian mycorrhizal companies can build is vital. In addition to this further initiative by the government through the support and encouragement of new mycorrhizal companies, in the form of subsidies and incentives, is recommended. The government can directly fund further research as well as the establishment of production facilities and create legislation that encourages the investment of private parties into the mycorrhizal industry in Nigeria. An example in which such an approach has been successful is in India; In the past decade, the mycorrhizal market in India has grown at an unprecedented rate. This growth in market capacity can be directly attributed to the promotion of mycorrhizal bio-stimulants by the Indian government (Chen, Arato, Borghi, Nouri, & Reinhardt 2018).

The education of farmers can be made possible by sending Nigerian representatives to conferences of the International Mycorrhizal Society and then the acquired knowledge can be cascaded to the Nigerian farmers themselves. Here organizations such as the United Nations Food and Agricultural Organization or other suitable bodies, that aim to improve the agricultural productivity of farmers, are central to the effort of teaching farmers about mycorrhizal technologies. The role of the local community is vital. There needs to be a positive and open-minded attitude towards such novel technologies; To ensure the co-operation of the farmers it is paramount that the representatives convey the benefits of using mycorrhizal inoculants, which are namely the improved resistance of plants, as well as an increase in yield. To further encourage the use of mycorrhizal inoculants within the Nigerian communities a 'hotline' which farmers can access should be set up. This will ensure that the maximum possible support is given to the farmers, as well as the most effective utilization of mycorrhizal inoculants.

Conclusion

Overall, Mycorrhizae have great potential to be a novel component in Nigerian agriculture. Too often the health of soil is overlooked; this neglect of the literal fundaments of agriculture has lead to the depletion of farming soil in Nigeria. The use of mycorrhizal inoculants can have direct benefits for the major Nigerian crops: Rice, Cassava, Maize and Cowpea. Furthermore, the singular benefits of mycorrhizae to combat desertification, to mitigate drought stress and to milden soil erosion are directly relevant to Nigeria's current concerns. It is vital for Nigeria to strive towards using sustainable farming techniques in order to sustain and enhance high yields, to meet the demands of the ever-increasing population. The domestic market should be a central interest of the Nigerian government, and they too need to encourage and incentivize the introduction of a mycorrhizal industry in Nigeria, possibly with a focus on mycorrhizal species that are native to Nigeria itself. Like with all universal problems a single solution is not feasible, however mycorrhizae can become a vital part in future agriculture and propel Nigeria into a future in which agriculture is sustainable.

Bibliography

"Nigeria Population (LIVE)." *Worldometers*, 2019, www.worldometers.info/world-population/nigeria-population/.

"WORLD DEVELOPMENT INDICATORS." *WDI - Home*, datatopics.worldbank.org/world-development-indicators/.

"NATIONAL BUREAU OF STATISTICS." *NATIONAL BUREAU OF STATISTICS*, www.nigerianstat.gov.ng/.

"FAO.org." *Nigeria at a Glance | FAO in Nigeria | Food and Agriculture Organization of the United Nations*, www.fao.org/nigeria/fao-in-nigeria/nigeria-at-a-glance/en/.

Agric, SENCE. "Farming in Nigeria – Crop Production Nigeria." *Agriculture Nigeria*, www.agriculturenigeria.com/farming-production/crop-production.

"Climate." *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., www.britannica.com/place/Nigeria/Climate.

"Nigeria - AgricultureNigeria - Agriculture." *Nigeria - Agriculture*, www.export.gov/article?id=Nigeria-Agriculture.

Unah, Linus. "Briefing: Nigerian Farmers Can't Fight Desertification Alone." *The New Humanitarian*, 16 Apr. 2019, www.thenewhumanitarian.org/analysis/2017/11/14/briefing-nigerian-farmers-can-t-fight-desertification-alone.

Olagunju, Temidayo Ebenezer. "Drought, Desertification and the Nigerian Environment: A Review." *Journal of Ecology and The Natural Environment*, vol. 7, no. 7, 2015, pp. 196–209., doi:10.5897/jene2015.0523.

"Nigerian Farmers Learn How to Increase Cowpea Production." *Voice of America*, www.voanews.com/archive/nigerian-farmers-learn-how-increase-cowpea-production.

Olomola, Aderibigbe S, and Manson Nwafor. "NIGERIA AGRICULTURE SECTOR PERFORMANCE REVIEW." *Fscluster.org*, Aug. 2018, fscluster.org/sites/default/files/documents/nigeria_agric_sector_review_report_august_2018.pdf.

Jeffries, et al. "The Contribution of Arbuscular Mycorrhizal Fungi in Sustainable Maintenance of Plant Health and Soil Fertility." *Biol Fertil Soils*, 5 Dec. 2002, doi: 10.1007/s00374-002-0546-5.

Giovannetti, M., et al. "Self Recognition and Non-Self Incompatibility in Mycorrhizal Networks." 2006.

Wang, B., and Y.-L. Qiu. "Phylogenetic Distribution and Evolution of Mycorrhizas in Land Plants." *Mycorrhiza*, vol. 16, no. 5, 2006, pp. 299–363., doi:10.1007/s00572-005-0033-

Redecker, D. “Glomalean Fungi from the Ordovician.” *Science*, vol. 289, no. 5486, 2000, pp. 1920–1921., doi:10.1126/science.289.5486.1920.

Finlay, R. D. “Ecological Aspects of Mycorrhizal Symbiosis: with Special Emphasis on the Functional Diversity of Interactions Involving the Extraradical Mycelium.” *Journal of Experimental Botany*, vol. 59, no. 5, 2008, pp. 1115–1126., doi:10.1093/jxb/ern059.

Marcel G. A. Van Der Heijden, et al. “The Unseen Majority: Soil Microbes as Drivers of Plant Diversity and Productivity in Terrestrial Ecosystems.” *Ecology Letters*, vol. 11, no. 3, 2008, pp. 296–310., doi:10.1111/j.1461-0248.2007.01139.x.

Marcel G. A. Van Der Heijden. “Mycorrhizal Fungi Reduce Nutrient Loss from Model Grassland Ecosystems.” *Ecology*, vol. 91, no. 4, 2010, pp. 1163–1171., doi:10.1890/09-0336.1.

“2. THE PROBLEM OF AGRICULTURE IN THE SEMI-ARID REGIONS.” *Soil and Water Conservation*, www.fao.org/3/t0321e/t0321e-08.htm.

Chen, et al. “Beneficial Services of Arbuscular Mycorrhizal Fungi – From Ecology to Application.” *Frontiers*, Frontiers, 10 Aug. 2018, www.frontiersin.org/articles/10.3389/fpls.2018.01270/full.

“Mycorrhizal Colonization and Soil Health.” *EcoFarming Daily*, 2 Mar. 2019, www.ecofarmingdaily.com/mycorrhizal-fungi/.

Ruth, Bernhard, et al. “Quantification of Mycorrhizal Water Uptake via High-Resolution on-Line Water Content Sensors.” *Plant and Soil*, vol. 342, no. 1-2, 2011, pp. 459–468., doi:10.1007/s11104-010-0709-3.

Huising, Jerome, et al. “STATUS OF INTEGRATED SOIL FERTILITY MANAGEMENT (ISFM) IN SOUTHWESTERN NIGERIA.” *International Journal of Sustainable Agricultural Research*, vol. 4, no. 2, 2017, doi:10.18488/journal.70.2017.42.28.44.

Priyadharsini, Perumalsamy, and Thangavelu Muthukumar. “Arbuscular Mycorrhizal Fungus Influence Maize Root Growth and Architecture in Rock Phosphate Amended Tropical Soil.” *Anales De Biología*, no. 39, 2017, pp. 211–222., doi:10.6018/analesbio.39.22.

Sanni, Sheriff O. “Vesicular-Arbuscular Mycorrhiza In Some Nigerian Soils And Their Effect On The Growth Of Cowpea (Vigna Unguiculata), Tomato (Lycopersicon Esculentum) And Maize (Zea Mays).” *New Phytologist*, vol. 77, no. 3, 1976, pp. 667–671., doi:10.1111/j.1469-8137.1976.tb04659.x.

Mukhongo, R.w., et al. “Production and Use of Arbuscular Mycorrhizal Fungi Inoculum in Sub-Saharan Africa: Challenges and Ways of Improving.” *International Journal of Soil Science*, vol. 11, no. 3, 2016, pp. 108–122., doi:10.3923/ijss.2016.108.122.

Ijdo, Marleen, et al. “Methods for Large-Scale Production of AM Fungi: Past, Present, and Future.” *Mycorrhiza*, vol. 21, no. 1, 2010, pp. 1–16., doi:10.1007/s00572-010-0337-z

Chen, Min, et al. “Beneficial Services of Arbuscular Mycorrhizal Fungi – From Ecology to Application.” *Frontiers in Plant Science*, vol. 9, 2018, doi:10.3389/fpls.2018.01270.

Oyewole, B.o., et al. “Influence of Arbuscular Mycorrhiza Fungi (AMF) on Drought Tolerance and Charcoal Rot Disease of Cowpea.” *Biotechnology Reports*, vol. 14, 2017, pp. 8–15., doi:10.1016/j.btre.2017.02.004.

Séry, D. Jean-Marc, et al. “Selecting Native Arbuscular Mycorrhizal Fungi to Promote Cassava Growth and Increase Yield under Field Conditions.” *Frontiers in Microbiology*, vol. 7, 2016, doi:10.3389/fmicb.2016.02063.

Stephen, et al. “Assessment of the Effects of Arbuscular Mycorrhizal Fungi (Glomus Clarum) and Pigeon Pea Hedgerow on the Yield of Maize and Soil Properties in Degraded Ultisols.” *Journal of Biology, Agriculture and Healthcare* , vol. 3, no. 15, 2013, doi: 2225-093X .

Hoseinzade, H, et al. “Rice (Oryza Sativa L.) Nutrient Management Using Mycorrhizal Fungi and Endophytic Herbaspirillum Seropedicae.” *Journal of Integrative Agriculture*, vol. 15, no. 6, 2016, pp. 1385–1394., doi:10.1016/s2095-3119(15)61241-2.

Sanni, Sheriff O. “Vesicular-Arcuscular Mycorrhiza In Some Nigerian Soils: The Effect Of Gigaspora Gigantea On The Growth Of Rice.” *New Phytologist*, vol. 77, no. 3, 1976, pp. 673–674., doi:10.1111/j.1469-8137.1976.tb04660.x.