Old MacDonald had a microbe (more than one actually)

Evelyn Quek (evelyn_quek@u.nus.edu)

Year 3, Environmental Engineering

College of Design and Engineering, NUS

Introduction

Being a student in NUS is such a tough role and instead of thinking how to deal with such a demanding and hectic lifestyle, sometimes I pondered what it is like to live in an agricultural area in the countryside, nearer to where our food is cultivated and produced. Having lived in a bustling city and dealing with the immense stress from work demands, owning a farm when I retire next time may be a way for me to enjoy the peacefulness and appreciate a slower pace of life. Being in close contact with livestock animals and doing farm work have therapeutic effects to deal with human's modern life and improving mental wellness (Hlušičková, 2014), thus my own personal decision to possibly move into the countryside. Furthermore, cultivating agriculture and raising farm animals will bring me closer to nature and allow me to feed myself from my very own crops grown. That being said, we have also to consider improving our agricultural system not only to meet my dietary needs, but also the people worldwide.

The Food and Agriculture Organization (FAO) has estimated that by the year 2050, the global population will reach 9.3 billion and an additional 60% of the food production is needed to feed this global demand (Silva, n.d.). Eliminating global hunger and meeting the nutrition needs of humans is one of the sustainable development goals outlined by the United Nation, thereby putting in much pressure on the global agricultural sector to not only feed this global food demand, but also produce food in a sustainable manner.

I wonder what are some of the roles and functions that microorganisms have in our agricultural sector and would it be possible to utilise these microscopic creatures in our future sustainable food production. There are studies to prove the beneficial role of microorganisms in improving plant growth and livestocks production, yet we must note that there are some microorganisms that could destroy plant crops and reduce agricultural efficiency as well

(Vadakattu, 2012). With the urgency to increase global food production, we have to study and discuss the interactions between microorganism and agriculture, to achieve my retirement plan and the UN's sustainable development goals.

In this essay, I will explore how microorganisms can benefit crops and livestock animals in aiding food production, as well as some potential ways they can destroy our agricultural sector. I would like to engage the help of these microorganisms in growing healthy plant crops and raising happy farm animals for food in the rural areas. It would be interesting to analyse the types of relationships that these tiny creatures have with our food crops and animals.

Replacement of fertilisers with microorganisms

We always hear the necessity of adding fertilisers when growing a plant from our mothers or the science textbooks and how it helps in keeping the plants healthy. However, beyond this belief, the addition of fertilisers may cause adverse effects indirectly to us people and the environment.

In the year 2018, the European Union's use of Nitrogen fertilisers weighs 10.2 million tones in its agricultural sector (*Agri-environmental indicator - mineral fertiliser consumption*, 2020). This statistic highlights the vast amount of mineral fertilisers used for agricultural production to provide essential nutrients like nitrogen and potassium for crops to grow. While such fertilisers can optimise agricultural production to address the limited soil nutrients, there are drawbacks as well with their excessive uses.

Excessive uses of chemical fertilisers especially can have detrimental effects to the environment. This is because their presence in water bodies near agricultural areas due to surface runoff can cause eutrophication, which is the nutrients causing excess growth of plankton and other aquatic plants. Eventually, these excess growths block oxygen and sunlight from penetrating into the water bodies, causing them to die, thus upsetting the ecosystem in these water bodies (Buckler, 2018). Not only the environment will be affected, the health of people consuming food grown with fertilisers are compromised too. Studies have shown that consumption of chemical fertilisers has correlation in developing cancer among adults and children. Food crops produced using nitrate fertiliser can adversely affect the nervous, endocrine, and immune system (Buckler, 2018). While we see the necessity of using fertilisers in growing our food crops, we must not solely and overly depend on their uses as we ought to ensure the safety and sustainability production of our food.

Fortunately, we have the help from our tiny friends that offer alternative solutions to meet the nutrient needs of our food crops, instead of relying on fertiliser usage. Microbes can unlock micronutrients in the soil for plants to use them and many start-ups have begun commercialising the use of microbial technologies to replace chemical uses for crops (Wallenstein, 2017).

Nitrogen fixing with the use of rhizobia in legume plants

Before we dive deep into understanding the roles of microbes in keeping our plants healthy, we have to understand the concept of the Nitrogen Cycle. Like a complicated life cycle of the Anopheles mosquitoes, but much simpler, the Nitrogen cycle describes the interaction of the element Nitrogen with our environment.

The Nitrogen describes how the element nitrogen is constantly transformed from one form to another throughout its life cycle, while interacting with both living and non-living things. A part of this cycle is called the Nitrogen Fixation, which involves the changing of nitrogen from the atmosphere into a form, typically ammonia (NH3), that can readily be taken in by our plants (Aczel, 2019). This process is carried out by bacteria and now, let's take a look at how these microorganisms do their work.

Legumes are plant-based protein including soybeans, chickpeas and peanuts, containing high amounts of health fibres, several vitamins and other nutrients (Lawler, 2021). Legume plants have nodules found in their roots which are homes of nitrogen fixing bacteria, known as the rhizobia. Nitrogen from the atmosphere is supplied to these legume plants as ammonia, the biological form of nitrogen for plant nutrients (Mendoza-Suárez, 2020). Throughout history, rhizobia proves its ability to replace the need for chemical fertilisers and increase the legume crop yields.

In Indonesia, farmers in soybean plantations have utilised Rhizobium inoculation to establish the rhizobia bacteria and improve nodulation in the soybean plants' root system to increase their production. This is done by inoculating the bacteria into the soybean seeds before plantation. This report mentions that the inoculation of Rhizobia has increased 25.75% to 52% soybean harvest, meanwhile increasing the soybeans' seeds amount and protein content as well (Fuskhah, 2019).

The above highlights Rhizobia's high nitrogen fixing efficiency, which paves ways for farmers and myself, a potential farmer, to make use of bacteria to replace the need of chemicals for more sustainable agricultural practices and saving money too!

Enhancement of plants' biomass with the help of microorganisms

While we see the importance of having nutrients to grow our food crops, having microorganisms in the soil allows farmers to have better harvest! In this section, I will be highlighting the microorganism, protozoa, and its role in plant growth.

Protozoa are single celled microorganisms that feed on bacteria, thus controlling bacteria population in the ecosystem (Horan, 2003). This process is called protozoan grazing and it decreases the bacteria population in the soil ecosystem, increasing the mineralization of nutrients in it that allows plants easier for uptake (Ronn, 2020). The consumption of bacteria by protozoa allows nitrogen from the bacteria to be released in the form of ammonium nitrogen that is taken in by plants. Furthermore, the presence of protozoa in the soil enhances microbial activities that convert nitrogen in the soil for nutrients (Kuikman, 1990). The research also proves that nitrogen mineralization contributed indirectly from protozoa is more significant than the direct intake of nitrogen nutrients from the roots, with the help of rhizobia bacteria.

<u>Effects of protozoa in growing barley</u>

By conducting experiments on the growth of barley plants in the presence and absence of the protozoa, naked amoeba, the research showed a 40% increase in biomass of the barley, with protozoa. Meaning, the amount and size of barley grains harvested by farmers are greater with the help of the protozoa. Not only increasing the barley grains, the reproduction of the plants in terms of the number of seeds produced and their sizes are enhanced as well (Bonkowski, 2004).

In the previous section, we noted the importance of having bacteria in enhancing soil nutrients in plants for better growth and productivity. However, this section explains the introduction of protozoa that reduces bacteria population and is in fact more effective in cultivating better growth of crops. Considering how different microorganisms can help in achieving the same intended purposes, it is indeed a headache for me and fellow farmers in determining the best microorganisms to help plants grow better.

Feeding microorganisms for a happier livestock

Moving on from crop plants, let us now discuss the role of microorganisms in benefitting our furry cute livestock animals, where children get excited looking at them, to obtain our food needs from them. Sounds cruel, but no choice, beef is too yummy.

Like us humans, animals also have microbiota in their various body parts for their health and body functions (Hontecillas, 2018). Rumens which aid the digestion of animal feed are found in livestock animals such as sheep, cattle and goats (Quain, 2017). The rumen biota aids in digesting and converting organic plant matter into nutrients for the production of animal protein in the form of meat and milk (Liu, 2021). The author also highlights the importance of understanding the various roles of these microorganisms residing in these animals to improve their productivity. The rumen is home to trillions of bacteria, fungi, archaea and protozoa that have diverse roles in building a healthy rumen and avoiding diseases, especially for digestion purposes. These rumen microorganisms can ferment the organic matter consumed by the animals and convert them into simpler compounds including the volatile organic acids for their energy and nutrients purposes (Liu, 2021).

<u>Rumen Microbiome in cows</u>

As estimated by the Food and Agriculture Organization (FAO), the global milk production and demand increases by 2.4% per year, whereas that for meat has increased by 1.3%. Thus, we see the growing need of milk and meat production to meet this demand, and thereby pushing us for solutions to increase our livestock production (Matthews, 2018). However, doing so comes at a great cost in increasing the global greenhouse gas emissions, noting that the livestock sector has already contributed between 9% to 11% of this total emission (Matthews, 2018).

Particularly cows, each of these animals produce 220 pounds of methane gas annually, a significant greenhouse gas that causes more destruction than carbon dioxide (Quinton, 2019). Therefore, we note that increasing the number of livestock animals for food production is not a sustainable way. Studies have proven that there exists a strong correlation between rumen microbiome and milk yield, together with other production traits in dairy cows (Schären, 2018). Moreover, the types of microorganisms found in the rumen of cows can determine the end products produced during digestion. This means that we can reduce the methane emission from these animals by introducing different microbes in its rumen biota (Doyle, 2019).

A study was done by the University of Florida to determine the effectiveness of fermentative lactic acid bacteria (LAB) on the performance of dairy cows. The LAB, particularly, *Lactobacillus plantarum* was inoculated at a rate greater than 10^5 cfu/g in silage, consisting of grass or other green fodder, which was then used to feed the cows. The statistics showed that the silage LAB inoculation has increased milk yield, milk fat and milk protein as there is an enhancement in the ruminal microbial synthesis of protein (Oliveira, 2017). This highlights the benefits of bacteria in increasing the food yield and its quality from dairy cows.

Not only does lactic acid bacteria (LAB) aid in improving the production efficiency from our cows, it can also reduce the methane production from them. Methane is produced from the rumen of cows due to enteric fermentation, the conversion of plant material into nutrients in the rumen for protein production by methanogenesis. LAB releases lactic acid during fermentation in the cows' rumens and it is used as direct fed microbials (DFMs) in dairy farms. LAB have the ability to influence rumen methanogenesis, thereby reducing methane production and this is proven by the data indicating a reduction of 13% of methane production from a sheep, dosed with 6×10^{10} cfu/animal/day of LAB (Yanez-Ruiz, 2019).

Although the author mentioned this study is not intensive enough, this paves a potential way farmers can help in reducing the global greenhouse gas emission from the agricultural sector and practise more sustainable farming.

Not your typical farm

Apart from the traditional forms of farming, we youngsters like to innovate, and I too can foresee the possibility of introducing living organisms that aren't found typically in the agricultural sector. Algae, which are eukaryotic microorganisms that are capable of photosynthesizing, and they come in various shapes, sizes and colours (Shukla, 2021). They are the green gooey stuff we sometimes find in our fish tank, rocks near a water body or floating on water itself. Instead of creating the lean green algae ball for tomorrow's meatball, there are commercial algae farms established globally for our energy needs. Algae farming or named algaculture are commercially grown microalgae used for myriad applications including making fuel and bioplastics under controlled conditions and environment before harvesting (Walker, 2013).

<u>The Algae Biofuel</u>

As the world aims to be more sustainable especially in our energy usage considering our anthropogenic activities that have exacerbated climate change, algae can be commercially farmed to harness biofuel to replace crude oil. This is done by taking algae with water, carbon dioxide and sunlight, then refining them either in a bioreactor or the open ponds. These smart microorganisms convert light to energy, which is kept as oil in the cells. This biofuel is later harnessed by using physical or chemical methods to break the cell walls, then releasing the oil for harvest (*Biofuel Production*, 2018). Depending on the dry to fresh biomass ratio, it determines the amount of lipid and wet or dry mass of algae needed to harvest 1kg of oil. For a unit of land area, microalgae are capable of generating 30 times more the amount of oil, which makes them very efficient compared to other biofuel generating crops (Soos, 2012).

Currently, Hutt Lagoon in Western Australia is home to the largest commercial algae farm in the world with a total pond size of 740 hectares. By assessing the viability of this algae facility, research has proven that for every 1 tonnes of algae biofuel production, this reduces 1.5 tonnes of carbon dioxide (Tamburic, n.d.).

While more studies and research are needed to be conducted to upscale algae farming in order for this microalgae to be a significant source for our fuel needs, we must not forget these microorganisms' role in the agricultural sector. Who knows by the time I retire, my farm may be used to grow microalgae that can power your cars and houses.

Agricultures can fail due to microorganisms too

As we witness how microorganisms can lend a helping hand to farmers in taking better care for their crops and animals, we must not forget that these tiny creatures may be an enemy for farmers as well. Plants like us humans can get sick as well!

Food crops too can get diseases from plant pathogens, incurring devastating losses for farmers who sell them for a living. Globally, an estimated 20 - 40% of crop losses are due to diseases and pests, highlighting this threat that hinders the sustainable development goal of ensuring food security for all (Godwin, 2019). Plant pathogens used their plant host for food or reproduction, at the same time damaging these plants. This poses a great challenge managing and eliminating plant diseases as pathogens are continuously evolving to attack the plant defence system. Hence, even with science and technology being put in place to enhance agriculture productivity, a significant portion of crops are still lost due to diseases annually (He, 2016).

Not only humans and plants get sick, farm animals too! A study done in Ghana, Africa estimated that about 78% of cattle are lost due to animal diseases (Nuvey, 2020), being one of the leading factors causing livestock losses to farmers. Livestock diseases contribute to a great number of issues including agriculture productivity loss, food security reduction and potential public human health risks (*Livestock disease management*, n.d.).

As farmers, they have the responsibility in understanding the mechanisms of potential disease spread among their crops and animals and being aware of preventive measures to prevent crop failure and their livestock deaths. Definitely, I do not wish to see how these tiny creatures can destroy my farmland:(

Irish Potato Famine

Round and starchy potatoes, also known as the "Irish Lumper", were a staple food in Ireland, especially for the poor due to its relatively easy to grow type of food, nutrition and high calorie content. In the early 1840s, nearly half of the Irish population became dependent fully on potato farming for their diet. However, solely reliant on this food source, meant the population is susceptible to famine as monoculture, which is the plantation of a single food crop on the farmland, increases the chance of crop failure due to diseases and pests. This is because diseases in plants can spread rapidly throughout the farmland among this single type of plant (Kroeze, n.d.)

Introducing the predominant cause of The Irish Potato Famine or the great hunger, a fungus-like organism called *Phytophthora infestans (Irish Potato Famine*, 2019). This potato energy was accidentally introduced from North America, causing late potato blight, which are brownish/blackish spots on the potatoes, when the fungi grows and reproduces on their surface (Fry, 1998). Eventually, the edible part of the potato became rotten, causing consecutive crop failure annually from 1846 to 1849. Millions of deaths and hunger were attributed to this famine, with a significant population migrated. From 1844 to 1851, the Irish population was reduced by 1.8 million (Mokyr, 2021).

This microorganism is currently the most destructive potato pathogen worldwide and a major threat to the global potato supply, causing an annual loss of $6 billion (Gosss, 2014). Not only does it infect potatoes, it infects other food crops such as tomatoes and has the ability to infect the entire tomato plantation in just days (Kankolongo, 2018). Next time when you eat your mashed potato and tomato ketchup from KFC, remember to be thankful.

African Swine Fever

Imagine putting a thermometer in a pig's mouth to check its temperature. Yes, pigs can get higher fever like us and sadly to say, it cannot be cured by simply putting an ice bag on our forehead like how our mum's took care of us when we were ill.

Between August 2018 to July 2019, China, as the largest producer of pork, faced the African Swine Fever outbreak among their pigs, killing millions of them (You, 2021). As reported, there were a total of 162 outbreaks during this time period.

The African Swine Fever is caused by a highly contagious haemorrhagic virus, with nearly 100% mortality. The African Swine Fever Virus (ASFV), a large DNA virus of the As Farviridae, can be transmitted among wild and domestic pigs (African swine fever, n.d.). First identified in Kenya, Africa, this virus becomes endemic in Africa, infecting warthogs and Ornithodoros soft ticks, being a vector and hosts for it. The ASFV tends to settle in the burrows of warthogs or pens and shelters of domestic pigs, making the virus highly transmissible and contagious to rapidly infect the entire swine population. Due to the lack of vaccine for this ASFV, its complexity and high morbidity, this virus poses serious threats to the global swine industry and production, affecting countries' economies (Werling, 2020). Pigs typically infected with the virus, experience high fever, loss of appetite, weakness and are most likely to die once contracted with the disease (*African Swine Fever*, 2018).

In the case of the outbreak in China, raising the pigs in small scale farms makes it easier for the ASFV to spread among its pigs due to the lack of hygiene and proper sanitation. Consequently, about 43.5 million pigs died due to this ASFV outbreak, with an economic loss of US$111.2 billion. Not only does it affect the economy, the livelihood of pig farmers, public health and food security are being threatened too (You, 2021). I sound like an economist, but really the economic loss of this ASFV outbreak is huge and I may need to file for bankruptcy if this were to happen to my future piglets.

Conclusion and Reflection

This long-winded essay explains the myriad roles of bacteria, protozoa, virus, fungi and microalgae in shaping and influencing the agricultural sectors. We see how these microscopic creatures can make the lives of farmers much easier, as well as potentially destroy their livelihood. There is much exploration to be made in studying the functions of microorganisms in a wide range of topics, uncovering the opportunities that microbes have to offer for us. The use of microbes may in fact help in resolving some of the most pressing issues we face globally among mankind. Bearing this in mind, I am inspired to convert my future farm into a “laboratory”, where I can study and make use of microbes to benefit my crops and animals but also be wary of the danger they can bring too. Let us not forget the role of microorganisms in ensuring our refrigerator, kitchen cabinet and dining table are packed with food and with that, I conclude this series of “Old Macdonald had a microbe (more than one actually)”

References

Gupta Vadakattu. (2012, January). *Beneficial microorganisms for sustainable agriculture*. https://www.researchgate.net/publication/265511476_Beneficial_microorganisms_for_sustainable_agriculture.

Agri-environmental indicator - mineral fertiliser consumption. (n.d.). eurostat. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_mineral_fertiliser_consumption

Fuskhah. (n.d.). *Inoculation of rhizobium bacteria and nutrient of seawater to increase soybean production and quality as food*. https://iopscience.iop.org/article/10.1088/1755-1315/292/1/012058/pdf

Hlušičková and Gardiánová. (2014, March 18). *Farming therapy for therapeutic purposes*. https://www.sciencedirect.com/science/article/abs/pii/S1212411714000026#!

Buckler. (2018, April 1). *The Hidden Dangers of Chemical Fertilizers*. Occupational Health & Safety. https://ohsonline.com/Articles/2017/12/07/The-Hidden-Dangers-of-Chemical-Fertilizers.aspx?Page=3

Leech, J. (2019, July 29). *Legumes: Good or bad?* https://www.healthline.com/nutrition/legumes-good-or-bad#fiber

Mendoza-Suárez et al. (2019, December 3). *Optimizing Rhizobium-legume symbioses by simultaneous measurement of rhizobial competitiveness and N2 fixation in nodules*. PNAS. https://www.pnas.org/doi/10.1073/pnas.1921225117

United Nations. (n.d.). *Feeding the world sustainably*. https://www.un.org/en/chronicle/article/feeding-world-sustainably

Wallenstein, M. (2017, January 25). *From flask to field: How tiny microbes are revolutionizing big agriculture*. The Conversation. https://theconversation.com/from-flask-to-field-how-tiny-microbes-are-revolutionizing-big-agriculture-67041

Quain. (2017, September 26). *What are the functions of a rumen?* Pets on Mom.com. https://animals.mom.com/what-are-the-functions-of-a-rumen-12582195.html

Quinton. (2019, June 27). *Cows and climate change*. UC Davis. https://www.ucdavis.edu/food/news/making-cattle-more-sustainable

Global burden of crop loss. (2021, June 17). CABI.org. https://www.cabi.org/projects/global-burden-of-crop-loss/

Oliveira et al. (2017, June). *Meta-analysis of effects of inoculation with homofermentative and facultative heterofermentative lactic acid bacteria on silage fermentation, aerobic stability, and the performance of dairy cows*. https://www.sciencedirect.com/science/article/pii/S0022030217302515

He et al. (2016, April). *Problems, challenges and future of plant disease management: from an ecological point of view*. ScienceDirect. https://www.sciencedirect.com/science/article/pii/S2095311915613004?via%3Dihub

Liu et al. (2021, March). *Ruminal microbiota–host interaction and its effect on nutrient metabolism*. https://www.sciencedirect.com/science/article/pii/S2405654520301220

Doyle et al. (n.d.). *Use of lactic acid bacteria to reduce methane production in ruminants, a critical review*. https://www.frontiersin.org/articles/10.3389/fmicb.2019.02207/full

African swine fever. (n.d.). WOAH - World Organisation for Animal Health. https://www.woah.org/en/disease/african-swine-fever/

Kroeze. (n.d.). *Do's and don'ts of variety mixing*. CANNA. https://www.canna-uk.com/variety_mixing

Barratt et al. (2019, June 18). *Framework for estimating indirect costs in animal health using time series analysis*. Frontiers. https://www.frontiersin.org/articles/10.3389/fvets.2019.00190/full

Great Famine. (n.d.). Encyclopedia Britannica. https://www.britannica.com/event/Great-Famine-Irish-history/additional-info#history

Fry. (1998). *Late blight of potatoes and tomatoes fact sheet*. Vegetable Diseases Cornell. https://vegetablemdonline.ppath.cornell.edu/factsheets/Potato_LateBlt.htm

Livestock disease management. (n.d.). Climate Technology Centre & Network. https://www.ctc-n.org/technologies/livestock-disease-management

Hernandez Nopsa et al. (2014). *Phytophthora infestans*. ScienceDirect. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/phytophthora-infestans

Nuvey et al. (2020, June 1). *Poor mental health of livestock farmers in Africa: A mixed methods case study from Ghana*. BioMed Central. https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-020-08949-2

Kuikman. (1990, January). *Mineralization of nitrogen by protozoan activity in soil*. ResearchGate. https://www.researchgate.net/publication/40178260_Mineralization_of_nitrogen_by_protozoan_activity_in_soil

African Swine Fever. (2018, November). CFSPH - The Center for Food Security and Public Health. https://www.cfsph.iastate.edu/FastFacts/pdfs/african_swine_fever_F.pdf

Shukla et al. (2021). *Microbial fouling in water treatment plants*. https://www.sciencedirect.com/topics/immunology-and-microbiology/alga

Bonkowski. (2004, April 13). *Protozoa and plant growth: the microbial loop in soil revisited*. https://nph.onlinelibrary.wiley.com/doi/10.1111/j.1469-8137.2004.01066.x

Ronn et al. (2002, December 1). *Impact of Protozoan Grazing on Bacterial Community Structure in Soil Microcosms*. ASM Journal Platform. https://journals.asm.org/doi/10.1128/AEM.68.12.6094-6105.2002

Taylor & Sanders. (2010). *Protozoan*. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/protozoan

Aczel. (2019, March 12). *What is the nitrogen cycle and why is it key to life?* Frontiers for Young Minds. https://kids.frontiersin.org/articles/10.3389/frym.2019.00041

You et al. (2021, September 27). *African swine fever outbreaks in China led to gross domestic product and economic losses*. Nature. https://www.nature.com/articles/s43016-021-00362-1

Algae farm power. (2013, November 8). Sustainable Footprint. https://sustainablefootprint.org/algae-farm-power/

Biofuel production with algae. (2019, July 24). The Origin Blog. https://www.originenergy.com.au/blog/biofuel-production-with-algae/

Tamburic, B. (2015, July 29). *Sustainable oil from algae: The technology is ready, but what about the politics?* The Conversation. https://theconversation.com/sustainable-oil-from-algae-the-technology-is-ready-but-what-about-the-politics-44969

Walker. (2019, July 5). *What are algae farms?* AZoCleantech.com. https://www.azocleantech.com/article.aspx?ArticleID=448