Recent Trends in Organic Fertilizer Use in Belize: A Review

Gerardo O. Aldana[1]
Amsi Moralez[1]
Selvin Miranda[1]

Abstract

With the increasing prices of commercial fertilizers, smallholder Belizean farmers are finding it challenging to produce crop yields, enabling them to meet the country's food demand. In order to meet the country's food demands, alternative plant nutrition sources need to be obtained. The purpose of this review is to investigate the trends of organic fertilizers usage in Belize and their benefits. There are several methods for producing organic fertilizers – these include animal manure, food residue wastes, crop residue, vermicomposting, bocashi and biochar. Organic fertilizers are known to be environmentally friendly and cost effective for agricultural production. They can improve soil health and sequester carbon therefore helping to reduce climate change. Organic fertilizers and soil amendments like manure and biochar tend to be more promising. Several activities with regards to the application of organic fertilizers have been recorded in Belize. Organic fertilizers show to be an excellent choice for agricultural systems of Belize.

Keywords: Organic, fertilizers, smallholder farmers, agricultural systems, environmentally friendly

Introduction

According to the UN estimates, food demand is expected to increase anywhere between 59% to 98% by 2050 (Valin, 2014). To meet the global food demand, agriculture in 2050 will need to produce almost 50% more food, feed, and biofuel than it did in 2012 (FAO, 2017). If there is no proper guidance, farmers worldwide will be forced to increase crop production, either by increasing the amount of agricultural land to grow crops or by enhancing productivity on existing agricultural lands through the extensive use of fertilizers. Fertilizer use, increased land use, irrigation and agrochemicals played major roles in the growth of agricultural production during the Green Revolution. However, these gains were accompanied by negative effects on the natural environment. These negative effects include land degradation, over-extraction of groundwater, build-up of pest resistance and the erosion of biodiversity (FAO, 2017).

Fertilizers substitute the nutrients that crops remove from the soil. Without the addition of fertilizers crop productivity would significantly be reduced. According to the International Fertilizer Association, we would only be able to feed about half of the global population without fertilizer. Plants may not get the nourishment they need to result in the yields necessary to meet global demand without the use of fertilizers. Fertilizers are substances such as manure or chemical mixtures used to make soil more fertile. Fertilizers are grouped into two: organic or inorganic, supplying one or more than one trace element required for plant growth and development. Inorganic fertilizers are chemically manufactured materials containing one or

[1] University of Belize

Corresponding Author: Gerardo Aldana, Faculty of Science and Technology, Hummingbird Ave, Belmopan, Belize. email: galdana@ub.edu.bz

more of the primary nutrients (N-P-K) necessary for plant growth, while organic fertilizers are naturally occurring, compounds produced from waste matter or by-products, where only the physical extraction or processing steps are assisted by man (Huntley et al., 1997).

Although the use of mineral fertilizers has been a key tool to balance nutrient outputs and consequently achieving increased yields, it only has a short-term benefit and has severe long-term side effects on soil properties. These side effects are found to be soil toxicity and deterioration on soil fertility. Inorganic fertilizers are also known for their high cost and their negative environmental effect when managed improperly (Assefa & Tadesse, 2019). The inappropriate use of mineral fertilizers has thwarted the ability of productive soils to function, not only by chemical indicators but also by physical and biological ones. Improper fertilizing technology has also played a role in adding negative effects on soil health and soil-related ecosystem services. Inadequate use of chemical fertilizers alters soil pH, increase pests attack, acidification, and soil crust, which in turn decreases soil organic carbon and useful organisms, stunting plant growth and yield, and even leads to emission of greenhouse gasses (Krasilnikov et al., 2022).

In many countries, the agricultural sector plays a major part in sustaining population growth and reducing poverty. However, the lack of adequate nutrients, depletion of soil organic matter, and soil erosion avert the sector to sustain agricultural production. The use of organic fertilizers has advantages such as being low-cost, improving soil structure, texture and aeration – increasing the soil's water retention abilities, and stimulating healthy root development. Hence, it is recommended that using integrated nutrient management is a continuous improvement of soil productivity on a long-term basis. This will be carried out through adequate use of organic fertilizers and their management to increase optimum growth yields and quality of different crops. Today, many producers farm according to traditional methods that are similar to organic farming, these methods may not be certified nor included in the latest scientific advancements in organic agriculture giving farmers reasons to change to modern organic methods for economic purposes (Assefa, & Tadesse, 2019). The aim of this review is to discuss the use and status of different organic fertilizers being used in Belize.

Current Organic Fertilizer Practices

In Belize, the organic fertilizers used include composted animal manure, compost, crop residues, food residue waste, bokashi, humus/vermicompost and biochar. The use of these organic fertilizers in agriculture is commonly known as organic farming. Organic farming is a production system that largely eliminates the use of synthetic fertilizers, pesticides, growth regulators, and livestock feed additives and relies on crop rotation, crop residues, animal manures, legumes, green manures, off-farm organic wastes, and mineral-bearing rocks. Due to the growing population and consequent pressure of soil use, agricultural soils must maintain adequate levels of quantity and quality to produce food, fiber, and energy, without falling victim to a negative impact on their balance of nutrients, health, or their ability to function (Krasilnikov, 2022). The U.S. Department of Agriculture defines soil health as the continued capacity of soil to function as a vital living ecosystem to sustain plants, animals, and humans. Soil sustains all this by performing its five essential functions: regulating water (soil helps control where rain, snowmelt, and irrigation water goes), sustain plant and animal life (diversity and productivity of living things depend on soil), filter and buffer potential pollutants (minerals and microbes in the soil are responsible for filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposits), cycling of nutrients (carbon, nitrogen, phosphorus, and many other nutrients are stored, transformed, and cycled in the soil), and providing physical stability and support (soil structure provides a medium for plant roots). Soils also provide support for human structures and protection for archeological treasures.

Crop Residues

The term agricultural residue is used to describe all the organic materials which are produced as by-products from harvesting and processing of agricultural crops. Crop residues encompasses all agricultural wastes such as straw, stem, stalk, leaves, husk, shell, peel, pulp, stubble, etc. which come from cereals (rice, wheat, maize or corn, sorghum, barley, millet), cotton, groundnut, jute, legumes (tomato, bean, soy) coffee, cacao, tea, fruits (banana, mango, coco, cashew) and palm oil (Zafar, 2021). Crop residues are carbon-rich materials that contain much nitrogen, phosphorus, potassium and microelements. Crop residue input is a sustainable way of improving soil quality without disturbing its biological balance. The decomposition of crop residues can increase the contents of organic carbon and available phosphorus, potassium in soils, which can provide nutrients for microorganisms and crops (Fu et al., 2021). In Belize, climate-smart agriculture practices include mulching. Mulching improves water holding capacity, soil organic matter (SOM), fertility, and stability, as well as reducing runoff and weed growth. Mulching can improve soil water-holding by adding crop residues and manure to soil which affects soil properties and nutrient cycling, as well as lowering emissions. Mulching has also been found to regulate surface temperatures, thus improving moisture and germination as well as other benefits for crop productivity. Practiced by about half of the milpa farmers in the Toledo District, Belize. Mulching has similar planting and harvesting timing and is beneficial because it restores degraded soils, provides shorter fallow periods, and stabilizes crop yield (Drexler, 2021).

Manure

Manures have been used as a beneficial soil amendment since the emergence of civilization, it was the primary soil amendment used in agriculture until the initiation of chemical fertilizers in the 1940's. Livestock manure is an important fertilizer in organic and sustainable soil management. Manure provides plant nutrients and can be an excellent soil conditioner. Properly managed manure applications recycle nutrients to crops, improve soil quality, and protect water quality. It is mostly effective when combined with crop rotation, cover cropping, green manuring, liming, and the addition of other natural or biologically-friendly fertilizers and amendments (Wander, 2019).

Animal manures are solid, semi-solid and liquid by products generated by animals reared to produce meat, milk, eggs and other agricultural products for human use and consumption. They are mixtures of animal feces, urine, bedding materials (e.g., rice hulls, sawdust, etc.) and other materials associated with animal production such as waste feed, soil, or any amendment used during manure handling and storage. There are pros and cons of using manure as a soil amendment because different types of animal manure have different types of macronutrients and thus, must be adequately composted for effective use and be adequately incorporated at different rates to prevent plants from damage with too much of one nutrient or another. Animal Manure also carries a variety of human pathogens of great public health concern. For example, dangerous pathogens such as *E. coli* O157:H7, Listeria, and *Cryptosporidium* are found in cattle, sheep, and deer feces. Droppings from poultry, wild birds, and even pets are a potential source of *Salmonella* bacteria (LaBorde, 2022).

Du et al. (2020) performed a meta-analysis of 774 comparisons from 141 published studies and confirmed that manure application increased yield by an average of 7.6% when compared to mineral fertilizer. The effects of manure application were more pronounced in acidic soils, warm and/or humid climates, and longer experimental periods. Manure application increased soil pH (3.3%), water-stable aggregation (28.8%), soil organic carbon (17.7%), total (15.5%) and available nitrogen (16.0%), available phosphorus (66.2%), available potassium (19.1%), the activities of urease (23.5%), sucrase (18.3%), and catalase (16.1%), and the abundances of bacteria (60.0%), fungi (27.7%), and actinomyces (38.0%). Manure application also gave results of decreased soil bulk density (−3.9%). Increases in the nutrient pool and decomposition capacity of the soil explained the positive effects of manure application on yield. Overall, end results indicated that long-term manure application improved sustainable soil productivity and crop yield in China.

Food residue waste

The global volume of food wastage is estimated at 1.6 billion tons of primary product equivalents. Total food wastage for the edible part of this amounts to 1.3 billion tons (FAO, 2022). The increase in the global population has led to an increase in food consumption as well as food waste generation. Much of the food waste generated from unused consumable food products, household food waste, and waste products from the food manufacturing and processing industries end up in landfills. Other treatment methods for food waste widely applied are animal feeding, anaerobic digestion, composting, and incineration. The increasing food waste disposal has brought attention to the issues in environmental pollution, which will bring harm to both humans and animals. These organic food wastes can be converted into valuable organic matter through the implementation of microorganisms, which can naturally decompose the waste and transform them into usable compost. Food waste also contains high content of organic components such as carbohydrates, proteins, lipids, and organic acids, which makes it a potential source of fertilization. At the Chaa Creek Lodge Kitchen waste and other organic materials such as trimmings are composted and then used as fertilizers at the organic Maya farm. The Maya Organic Farm is 33 acres and it provides fresh products for the lodge at Chaa Creek and the Macal River Camp. Agro ecological Farming has been rapidly growing in the Cayo district. A series of training sessions and workshops were coordinated by the Agriculture Extension Department and funded by the GIZ Selva Maya Program executed by IP/ECO for farmers participating from three communities (Bullet Tree, Succotz and San Antonio). Some of the topics involved in the training were how to produce and manage *Bokash*i, Compost and Humus/Vermiculture (Garnett, 2015).

Bokashi

Bokashi is a Japanese term which means "Fermented organic matter". This type of fertilizer is high in nutrients and serves as a rapid effect fertilizer. Its main purpose is to improve soil fertility and supply crops with the necessary nutrients for them to produce effectively (Garnett, 2015). Currently, the Department of Agriculture (Belize District office) has an ongoing series of training sessions on how to prepare bokashi in Bomba for farmers in the Belize District. The *Bokashi* process allows farmers to convert food waste and similar organic matter into soil amendment which adds nutrients and improves soil texture. So far twenty-eight farmers have benefited from the program, the program is to be enclosed in December.

Compost

Compost is an organic material made from organic residues (grains, vegetables, manures, leaves etc.). It is a process that involves temperature, moisture, nutrients and aeration. It is used to improve the structure of the soil and provide nutrients to plants. Liquid Fertilizer - provides nutrients to plants through both leaves (foliar) and roots. In some cases, where the root system has been severely affected, liquid fertilizers are an excellent option when compared to other forms such as compost or *Bokashi*. The results are quicker, and it works effectively on crops grown in pots or bags (Garnett, 2015).

Blancaneaux Lodge does not offer accommodation for travelers but is also home to a 3.5-acre garden that supplies their own vegetables and fruits used in the property's two restaurants. The adequate climate in the region allows them to cultivate a wide range of produce all year long such as lettuce, herbs, beans, tomatoes, etc. Their team has been practicing vermicomposting since 1998. Today, they have a total of 6 rotating pits filled with 900lbs of horse manure, 250lbs of kitchen waste, 1200lbs of chicken manure and 1 gallon of molasses. Throughout the years, poultry had been reared in the farm with the purpose of egg production, now chicken manure is incorporated into the compost as a good source of nitrogen, phosphorus and potassium and are the nutrients required to be replenished in their soils. Additional manure is also collected from farms within the area. The farm also added vermicomposting as a practice of organic agriculture, the product is mainly used for vegetable seedlings since it's been noticed that it gives better yield from seeds and plants look a lot healthier.

Vermicomposting

Vermicomposting is the process by which earthworms are used to turn farm waste into a nutrient rich humus that assists to improve soil fertility and plant growth. Vermicomposting is an organic fertilizer that is produced by California Red Worms (*Eisenia foetida*). It is dark in color, homogeneous and the texture is usually soft and granular. Humus provides the soil with organic matter, nutrients, and rooting hormones in its natural form. It generally improves the retention of humidity, promotes aeration, and favors biological activity in the soil. Fertilizers used from vermiculture can be used as solid fertilizers or liquid fertilizers. The liquid fertilizers are obtained from the leachates that are derived from the solid fertilizers that are produced through vermiculture (Garnett, 2015).

Biochar

Biochar is produced by burning biomass (organic material) through a process known as pyrolysis. These materials are burned at specific temperatures in a low-oxygen environment. There are different types of biochar depending on the raw materials used and the temperature the feed material was heated to. Biochar does not act as a fertilizer per se, but it can be amended in the soil to boost the efficiency of organic fertilizers. For instance, biochar made from manure will have a greater nutrient content than that formed from wood chips. A wood-based biochar, on the other hand, will remain more stable for a longer time and will help to increase the efficiency of fertilizers. Higher firing temperatures will result in a greater amount of micro porosity and adsorptive capacity, therefore a better potential for adsorption of toxic substances and soil rehabilitation. Research interests for using biochar in agriculture have increased. It is reported that the addition of biochar to soils can bring about many benefits. Some of these benefits are to enhance soil carbon sequestration.

Biochar improves the soil through the reduction of bulk density, water holding capacity and nutrient retention, stabilization of organic matter, improvement of microbial activities, and heavy metal sequestration (Aldana et al., 2020). Furthermore, biochar application could enhance phosphorus availability in highly weathered tropical soils (Nair et al., 2017). The application of biochar to soils has been proposed as a strategy to reduce the concentration of CO2 in the atmosphere, as it serves as a carbon sink. Its resistance to degradation due to all the carbon present in its structure gives it the ability to remain in soils for years (Moreno & Herrera, 2020). Biochar is starting to be used in Belize. In 2008, John Missouri, a Silicon Valley entrepreneur arranged for three Mayan farmers to fly to Cornell University where Professor Johannes Lehmann gave them a 2-day intensive training in the production and use of biochar. The Mayan farmers returned to Belize and set about making biochar, with the help of Carbon Gold. Farmers applied biochar to their trees and to their nursery tree seedlings in the field and the results were healthier trees and improved yields from orchards where biochar had been applied. An application to the UNDP for funding to expand the biochar program was rewarded with a $50,000 grant. The UNDP also sees the potential for Belize's banana, citrus and sugar cane growers. Further success has led to an expansion of cocoa growing: 8 new nurseries are being established with a rural development grant from the Inter-American Development Bank (IDB), to raise 45,000 new cacao tree seedlings in biochar enriched soil. Biochar will be made from cacao pruning and other forest and agricultural waste (Sams, 2014).

The value of organic fertilizers to combat climate change

In the last century, synthetic fertilizers have greatly enhanced crop production, allowing farmers to produce more food on less land. Nevertheless, the increase in fertilizer use has come at a great cost with global warming (e.g., greenhouse gas emissions). Worldwide, the agricultural industry is the second-largest source of climate change pollution; having both the manufacturing and application of fertilizer with a heavy emission inventory (Manthiram & Gribkoff, 2021).

Although soil may not be the first thing that comes to mind when contemplating climate change, they are both relentlessly linked. Climate change affects soil functions directly and indirectly. The direct effects comprise soil process changes in organic carbon transformations and nutrient cycling by altering moisture and temperature regimes in the soil or increasing soil erosion rates due to an increased frequency of high-intensity rainfall events. For example, in organic-rich soils in the UK, temperature increase and reduction in soil moisture was linked to warming or drought, where both were observed to reduce carbon storage capacity. Another effect of climate change includes extreme weather events such as heavy rainfall, droughts, frosts, storms, and rising sea levels in coastal areas; these effects increased the threats to soil such as soil erosion and soil compaction, reduced soil fertility, and lowered agricultural productivity, deteriorating food security and environmental sustainability (Lal et al., 2011). These climate-related risks raise major concerns regarding the future role of soils as a sustainable resource for food production (Hamidov et al., 2018).

While modern agriculture is justifiably proud of feeding the world, the unintended consequences of the new systems create problems. Climate change along with soil management practices have also changed the ability of soils to perform soil functions. The activity that has subsidized this has been the overuse of fertilizers, contributing nitrous oxide to the atmosphere as well as polluting surface and groundwater supplies (Lewotsky, 2022). Worldwide, one-third of the Earth's soil is at least moderately degraded, and over half of the land used for agriculture has some level of degradation (Melville, 2020). Due to intense and mismanaged farming, soil nutrients keep declining; nitrogen storage decreases by 42 percent, phosphorus by 27 percent, and sulfur by 33 percent. For plants to reach their optimum growth they require these nutrients for photosynthesis, enzymes, protein synthesis, and more (Kopittke et al., 2017).

For many years, soil nutrient depletion and degradation have also been considered serious threats to agricultural productivity and have been identified as major causes of decreased crop yields and per capita food production (Sisay & Sisay, 2019). This issue is connected with the overuse of fertilizers that have contributed to the deterioration of soil fertility, soil acidification, and soil crust, reducing the content of organic matter, humus content, beneficial species, stunting plant growth, altering the pH of the soil, growing pests, and even leading to the release of greenhouse gasses (Bisht & Chauhan, 2020). Preventing the loss of organic matter and nutrients will help plants grow plentiful for an expanding population of humans. This can be done through well-managed organic systems with better nutrient retentive abilities, and significantly reduce the risk of groundwater pollution, thus conversion to organic agriculture is highly encouraged as a restorative measure (FAO, 2022).

According to new research published in a special issue of Waste Management & Research, applying organic fertilizers (those resulting from composting) to agricultural lands could increase the amount of carbon stored in these soils and contribute significantly to the reduction of greenhouse gas emissions. Practicing organic agriculture helps mitigate greenhouse effects and global warming through its ability to sequester carbon in the soil. Many management practices used by organic agriculture can increase the return of carbon to the soil, raising productivity and favoring carbon storage. In addition to the carbon storage benefits – of adding compost to agricultural soils, composting can lead to improved soil quality, improved productivity, and cost savings. For example, nutrients in compost tend to foster soil fertility. Combinations of plants and animals can also optimize nutrient and energy cycling for agricultural production. The establishment of structures providing food and shelter, and the lack of pesticide use, will attract new or recolonize species to the area, including wild flora and fauna (e.g., birds) and organisms beneficial to the organic system such as pollinators and pest predators (Sisay & Sisay, 2019).

Other studies carried out with various fertilization treatments also showed to have had a significant effect on the structure of soil microbial biomass and the community. Different applications of fertilizers changed the physical and chemical properties of the soil, which in turn affected the structure of the soil's bacterial community. Other significant soil factors that influenced the structure of the microbial community were pH, nitrate, and available potassium and phosphates. Therefore, the application of fertilizers without the recommendation of soil testing can lead to implications such as soil degradation, nutrient imbalance, soil structure destruction, and bulk density increase. The excessive and continuous use of fertilizers is threatening our climate, ecosystems, and biodiversity. The adverse effects of these synthetic chemicals on human health and the environment can be reduced or eliminated by adopting new agricultural technological practices (changing to organic farming) for example the use of organic inputs such as manure and moving away from chemical-intensive cultivation (Bisht et al., 2020).

General Conclusions

The use of synthetic fertilizers is beneficial for only a short-term period and tends to give rise to negative long-term effects which result in a decline in soil fertility. Although organic fertilizers may have a slow process of releasing their nutrients, it is beneficial as it sustains microorganisms in the soil, reduces soil acidity, and does not cause nutrient leaching or plant damage. Pollution caused by plant protection products can be reduced by good management and by applying organic fertilizers such as manure, vermicomposting, etc. Therefore, Belize is on a good path when it comes to organic farming systems that can assist farmers to improve soil quality and health. Proper organic fertilizer use is therefore vital for Belizean agricultural systems to aim towards climate-smart agriculture.

References

Aldana, G.O., Hazlerigg, C., Lopez-Capel, E. & Werner, D. (2020). Agrochemical leaching reduction in biochar-amended tropical soils of Belize. European Journal of Soil Sciences, doi: https://doi.org/10.1111/ejss.13021. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/ejss.13021.

Assefa, S., & Tadesse, S. (2019). The principal role of organic fertilizer on soil properties and agricultural productivity -A Review. Agricultural Research & Technology.: Open Access Journal, 22(2): 556192. DOI: 10.19080/ARTOAJ.2019.22.556192

Bisht, N., & Chauhan, P. (2020). Excessive and disproportionate use of chemicals cause soil contamination and nutritional stress. IntechOpen. Retrieved August 19, 2022, from https://www.semanticscholar.org/paper/Excessive-and-Disproportionate-Use-of-Chemicals-and-Bisht-Chauhan/53f76f9f7361a8bae2920b85619c099d6505a6d4

Drexler, K. Climate-Smart Adaptations and Government Extension Partnerships for Sustainable Milpa Farming Systems in Mayan Communities of Southern Belize. (2021). Sustainability, 13, 3040. https://doi.org/10.3390/su13063040

Du, Y., Cui, B., Zhang, Q., Wang, Z., Sun, J., & Niu, W. (2020). Effects of manure fertilizer on crop yield and soil properties in China: A meta-analysis. Catena. Retrieved August 14, 2022, from https://www.sciencedirect.com/science/article/abs/pii/S0341816220301673

FAO. (2017). The Future of Food and Agriculture – Trends and challenges. summary version. Food and Agriculture Organization of the United Nations . Retrieved August 22, 2022, from https://www.fao.org/3/I6881e/I6881e.pdf

FAO. (2022). What are the environmental benefits of organic agriculture? Organic Agriculture: What are the environmental benefits of organic agriculture? Retrieved August 19, 2022, from https://www.fao.org/organicag/oa-faq/oa-faq6/en/

Fu, B., Chen, L., Huang, H., qu, P., & Wei, Z. (2021). Impacts of crop residues on Soil Health: A Review. Taylor & Francis. Retrieved August 21, 2022, from https://www.tandfonline.com/doi/full/10.1080/26395940.2021.1948354#

Garnett, F. I. (2015). Agro-ecological Farming: A practical guide for the production of safe and healthy fruits and vegetables within the Selva Maya Region. Retrieved September 10, 2022, from https://selvamaya.info/wp-content/uploads/2016/06/Agroecological-Farming.-Practical-guide-for-the-production-of-safe-and-healthy-fruits-and-vegetables-within-the-Selva-Maya-Region.pdf

Hamidov, A., Helming, K., Bellocchi, G., Bojar, W., Dalgaard, T., Ghaley, B. B., Hoffmann, C., Holman, I., Holzkämper, A., Krzeminska, D., Kværnø, S. H., Lehtonen, H., Niedrist, G., Øygarden, L., Reidsma, P., Roggero, P. P., Rusu, T., Santos, C., Seddaiu, G.Schönhart, M. (2018, August). Impacts of climate change adaptation options on soil functions: A review of European case-studies. Land Degradation & Development, 29 (8): 2378-2389, doi: 10.1002/ldr.3006.

Huntley, E.E., Baker, A.V., and Stratton, M.L. (1997) Composition and uses of organic fertilizers. In: Recheigl JE and MacKinnon HC (eds.) Agricultural uses of by-products and wastes. ACS Symposium Series 668, pp. 120–139, Washington, DC: American Chemical Society.

Kopittke, P. M., Dalal, R. C., Finn, D., & Menzies, N. W. (2017). Global changes in soil stocks of carbon, nitrogen, phosphorus, and sulphur as influenced by long-term agricultural production. National Library of Medicine. Retrieved August 19, 2022, from https://pubmed.ncbi.nlm.nih.gov/27670741/.

Krasilnikov, P., Taboada, M. A., & Amanullah. (2022). Fertilizer use, Soil Health and Agricultural Sustainability. Agriculture, 12(4), 462; doi: 10.3390/agriculture12040462

LaBorde, L. (2022). Reducing risks from animals and manure. Penn State Extension. Retrieved August 14, 2022, from https://extension.psu.edu/reducing-risks-from-animals-and-manure.

Lal, R. , Delgado, J. A. , Groffman, P. M. , Millar, N. , Dell, C. , & Rotz, A. (2011). Management to mitigate and adapt to climate change. Journal of Soil and Water Conservation, 66, 276–285, doi: 10.2489/jswc.66.4.276

Lewotsky, K. (2022). Climate change and agriculture: How are they connected and what's to be done? Oregon Environmental Council. Retrieved August 19, 2022, from https://oeconline.org/climate-and-agriculture/

Manthiram, K., & Gribkoff, E. (2021). Fertilizer and climate change. MIT Climate Portal. Retrieved August 18, 2022, from https://climate.mit.edu/explainers/fertilizer-and-climate-change

Melville, K. (2020). How Does Nutrient-Depleted Soil Impact Our Food, and What Can We Do to Fix It? Chris Kresser. Retrieved August 19, 2022, from https://chriskresser.com/depletion-of-soil-and-what-can-be-done/

Moreno-Riascos, S., & Ghneim-Herrera, T. (2020). Impact of biochar use on agricultural production and climate change. A Review. Agronomía Colombiana. Retrieved August 13, 2022, from http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0120-99652020000300367#B78

Nair, V. D., Nair, P. K. R., Dari, B., Freitas, A. M., Chatterjee, N., & Pinheiro, F. M. (2017). Biochar in the agroecosystem–climate-change–sustainability nexus. Frontiers. Retrieved August 13, 2022, from https://www.frontiersin.org/articles/10.3389/fpls.2017.02051/full

Sams, C. (2014). Biochar is 'carbon gold' for Belize's Cacao Farmers. The Ecologist. Retrieved August 13, 2022, from https://theecologist.org/2014/apr/05/biochar-carbon-gold-belizes-cacao-farmers

Sisay, A. & Sisay, T. (2019). The Principal Role of Organic Fertilizer on Soil Properties and Agricultural Productivity -A Review. Agri Res & Tech: Open Access J. 2019; 22(2): 556192. DOI: 10.19080/ARTOAJ.2019.22.556192

Valin, H., Mensbrugghe, D., Nelson, G. C., Ahammad, H., Blanc, E., Bodirsky, B., Fujimori, S., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Mason-D'Croz, D., Paltsev, S., Rolinski, S., Tabeau, A., Meijl, H. V., Lampe, M. V., & Willenbockel, D. (2014). The future of food demand: Understanding differences in global economic models. Agricultural Economics, 45 (1), p. 51-67, doi: https://doi.org/10.1111/agec.12089

Wander, M. (2019). Managing manure fertilizers in organic systems. eOrganic. Retrieved August 10, 2022, from https://eorganic.org/node/3132

Zafar , S. (2021). Everything You Should Know About Agricultural Residues. BioEnergy Consult. Retrieved August 21, 2022, from https://www.bioenergyconsult.com/agricultural-residues/