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# Environmental Pollution and Modern Agriculture: An Overview

**DR. DHIRENDRA SINGH**

PRINCIPAL, GOVT. GIRLS POST GRADUATE COLLEGE, SAWAI MADHOPUR, RAJASTHAN, INDIA

**ABSTRACT:** The environmental impact of agriculture is the effect that different farming practices have on the ecosystems around them, and how those effects can be traced back to those practices.[1] The environmental impact of agriculture varies widely based on practices employed by farmers and by the scale of practice. Farming communities that try to reduce environmental impacts through modifying their practices will adopt sustainable agriculture practices. The negative impact of agriculture is an old issue that remains a concern even as experts design innovative means to reduce destruction and enhance eco-efficiency.[2] Though some pastoralism is environmentally positive, modern animal agriculture practices tend to be more environmentally destructive than agricultural practices focused on fruits, vegetables and other biomass. The emissions of ammonia from cattle waste continue to raise concerns over environmental pollution

**KEYWORDS**- environmental, pollution, modern, agriculture, sustainable, impact

## I. INTRODUCTION

When evaluating environmental impact, experts use two types of indicators: "means-based", which is based on the farmer's production methods, and "effect-based", which is the impact that farming methods have on the farming system or on emissions to the environment. An example of a means-based indicator would be the quality of groundwater, which is affected by the amount of nitrogen applied to the soil. An indicator reflecting the loss of nitrate to groundwater would be effect-based.[4] The means-based evaluation looks at farmers' practices of agriculture, and the effect-based evaluation considers the actual effects of the agricultural system. For example, the means-based analysis might look at pesticides and fertilization methods that farmers are using, and effect-based analysis would consider how much $CO_2$ is being emitted or what the nitrogen content of the soil is.[4]

The environmental impact of agriculture involves impacts on a variety of different factors: the soil, water, the air, animal and soil variety, people, plants, and the food itself. Agriculture contributes to a number larger of environmental issues that cause environmental degradation including: climate change, deforestation, biodiversity loss,[5] dead zones, genetic engineering, irrigation problems, pollutants, soil degradation, and waste.[6] Because of agriculture's importance to global social and environmental systems, the international community has committed to increasing sustainability of food production as part of Sustainable Development Goal 2: “End hunger, achieve food security and improved nutrition and promote sustainable agriculture".[7] The United Nations Environment Programme's 2021 "Making Peace with Nature" report highlighted agriculture as both a driver and an industry under threat from environmental degradation.[8]

### By agricultural practice

#### Animal agriculture

The environmental impacts of animal agriculture vary because of the wide variety of agricultural practices employed around the world. Despite this, all agricultural practices have been found to have a variety of effects on the environment to some extent. Animal agriculture, in particular meat production, can cause pollution, greenhouse gas emissions, biodiversity loss, disease, and significant consumption of land, food, and water. Meat is obtained through a variety of methods, including organic farming, free-range farming, intensive livestock production, and subsistence agriculture. The livestock sector also includes wool, egg and dairy production, the livestock used for tillage, and fish farming.

Animal agriculture is a significant contributor to greenhouse gas emissions. Cows, sheep, and other ruminants digest their food by enteric fermentation, and their burps are the main source of methane emissions from land use, land-use change, and forestry. Together with methane and nitrous oxide from manure, this makes livestock the main source of greenhouse gas emissions from agriculture.[9] A significant reduction in meat consumption is essential to mitigate

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climate change, especially as the human population increases by a projected 2.3 billion by the middle of the century.[10][11]

Irrigation

The first environmental effect is increased crop growth, such as in the Rubaksa gardens in EthiopiaThe irrigation that grows crops, especially in dry countries, can also be responsible for taxing aquifers beyond their capacities. Groundwater depletion is embedded in the international food trade, with countries exporting crops grown from overexploited aquifers and setting up potential future food crises if the aquifers run dry.

The environmental effects of irrigation relate to the changes in quantity and quality of soil and water as a result of irrigation and the subsequent effects on natural and social conditions in river basins and downstream of an irrigation scheme. The effects stem from the altered hydrological conditions caused by the installation and operation of the irrigation scheme.

Amongst some of these problems is depletion of underground aquifers through overdrafting. Soil can be over-irrigated due to poor distribution uniformity or management wastes water, chemicals, and may lead to water pollution. Over-irrigation can cause deep drainage from rising water tables that can lead to problems of irrigation salinity requiring watertable control by some form of subsurface land drainage. However, if the soil is under irrigated, it gives poor soil salinity control which leads to increased soil salinity with the consequent buildup of toxic salts on the soil surface in areas with high evaporation. This requires either leaching to remove these salts and a method of drainage to carry the salts away. Irrigation with saline or high-sodium water may damage soil structure owing to the formation of alkaline soil.

Pesticides

Pesticides being sprayed onto a recently plowed field by tractor. Aerial spraying is a main source of pesticide drift and application on loose topsoil increases the chance of runoff into waterways.

The environmental effects of pesticides describe the broad series of consequences of using pesticides. The unintended consequences of pesticides is one of the main drivers of the negative impact of modern industrial agriculture on the environment. Pesticides, because they are toxic chemicals meant to kill pest species, can affect non-target species, such as plants, animals and humans. Over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species, because they are sprayed or spread across entire agricultural fields.[12] Other agrochemicals, such as fertilizers, can also have negative effects on the environment.

The negative effects of pesticides are not just in the area of application. Runoff and pesticide drift can carry pesticides into distant aquatic environments or other fields, grazing areas, human settlements and undeveloped areas. Other problems emerge from poor production, transport, storage and disposal practices.[13] Over time, repeat application of pesticides increases pest resistance, while its effects on other species can facilitate the pest's resurgence.[14] Alternatives to heavy use of pesticides, such as integrated pest management, and sustainable agriculture techniques such as polyculture mitigate these consequences, without the harmful toxic chemical application.

Environmental modelling indicates that globally over 60% of global agricultural land (~24.5 million $km^2$) is "at risk of pesticide pollution by more than one active ingredient", and that over 30% is at "high risk" of which a third are in high-biodiversity regions.[15][16] Each pesticide or pesticide class comes with a specific set of environmental concerns. Such undesirable effects have led many pesticides to be banned, while regulations have limited and/or reduced the use of others. The global spread of pesticide use, including the use of older/obsolete pesticides that have been banned in some jurisdictions, has increased overall.[17][18]

Plastics

Plasticulture is the practice of using plastic materials in agricultural applications. The plastic materials themselves are often and broadly referred to as "ag plastics". Plasticulture ag plastics include soil fumigation film, irrigation drip tape/tubing, plastic plant packaging cord, nursery pots and bales, but the term is most often used to describe all kinds of plastic plant/soil coverings. Such coverings range from plastic mulch film, row coverings, high and low tunnels (polytunnels), to plastic greenhouses.

Plastic used in agriculture was expected to include 6.7 million tons of plastic in 2019 or 2% of global plastic production.[19] Plastic used in agriculture is hard to recycle because of contamination by agricultural chemicals.[19] Moreover, plastic degradation into microplastics is damaging to soil health, microorganisms and beneficial organisms like earthworms.[19][20] Current science is not clear if there are negative impacts on food or once food grown in plasticulture is eaten by humans.[19] Because of these impacts, some governments, like the European Union under the Circular Economy Action Plan, are beginning to regulate its use and plastic waste produced on farms.

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By environmental issue

Climate change

The amount of greenhouse gas emissions from agriculture is significant: The agriculture, forestry and land use sector contribute between 13% and 21% of global greenhouse gas emissions.[22] Agriculture contributes towards climate change through direct greenhouse gas emissions and by the conversion of non-agricultural land such as forests into agricultural land.[23][24] Emissions of nitrous oxide and methane make up over half of total greenhouse gas emission from agriculture.[25] Animal husbandry is a major source of greenhouse gas emissions.[26]

The agricultural food system is responsible for a significant amount of greenhouse gas emissions.[27][28] In addition to being a significant user of land and consumer of fossil fuel, agriculture contributes directly to greenhouse gas emissions through practices such as rice production and the raising of livestock.[29] The three main causes of the increase in greenhouse gases observed over the past 250 years have been fossil fuels, land use, and agriculture.[30] Farm animal digestive systems can be put into two categories: monogastric and ruminant. Ruminant cattle for beef and dairy rank high in greenhouse-gas emissions; monogastric, or pigs and poultry-related foods, are low. The consumption of the monogastric types may yield less emissions. Monogastric animals have a higher feed-conversion efficiency, and also do not produce as much methane.[27] Furthermore, $CO_2$ is actually re-emitted into the atmosphere by plant and soil respiration in the later stages of crop growth, causing more greenhouse gas emissions.[31] The amount of greenhouse gases produced during the manufacture and use of nitrogen fertilizer is estimated as around 5% of anthropogenic greenhouse gas emissions. The single most important way to cut emissions from it is to use less fertilizers, while increasing the efficiency of their use.[32]

There are many strategies that can be used to help soften the effects, and the further production of greenhouse gas emissions - this is also referred to as climate-smart agriculture. Some of these strategies include a higher efficiency in livestock farming, which includes management, as well as technology; a more effective process of managing manure; a lower dependence upon fossil-fuels and nonrenewable resources; a variation in the animals' eating and drinking duration, time and location; and a cutback in both the production and consumption of animal-sourced foods.[27][33][34][35] A range of policies may reduce greenhouse gas emissions from the agriculture sector for a more sustainable food system.[36]:816–817

Deforestation

Deforestation is clearing the Earth's forests on a large scale worldwide and resulting in many land damages. One of the causes of deforestation is clearing land for pasture or crops. According to British environmentalist Norman Myers, 5% of deforestation is due to cattle ranching, 19% due to over-heavy logging, 22% due to the growing sector of palm oil plantations, and 54% due to slash-and-burn farming.[37]

Deforestation causes the loss of habitat for millions of species, and is also a driver of climate change. Trees act as a carbon sink: that is, they absorb carbon dioxide, an unwanted greenhouse gas, out of the atmosphere. Removing trees releases carbon dioxide into the atmosphere and leaves behind fewer trees to absorb the increasing amount of carbon dioxide in the air. In this way, deforestation exacerbates climate change. When trees are removed from forests, the soils tend to dry out because there is no longer shade, and there are not enough trees to assist in the water cycle by returning water vapor back to the environment. With no trees, landscapes that were once forests can potentially become barren deserts. The tree's roots also help to hold the soil together, so when they are removed, mudslides can also occur. The removal of trees also causes extreme fluctuations in temperature.[38]

In 2000 the United Nations Food and Agriculture Organisation (FAO) found that "the role of population dynamics in a local setting may vary from decisive to negligible," and that deforestation can result from "a combination of population pressure and stagnating economic, social and technological conditions."[39]

Genetic engineering

Pollutants

Agricultural pollution refers to biotic and abiotic byproducts of farming practices that result in contamination or degradation of the environment and surrounding ecosystems, and/or cause injury to humans and their economic interests. The pollution may come from a variety of sources, ranging from point source water pollution (from a single discharge point) to more diffuse, landscape-level causes, also known as non-point source pollution and air pollution. Once in the environment these pollutants can have both direct effects in surrounding ecosystems, i.e. killing local wildlife or contaminating drinking water, and downstream effects such as dead zones caused by agricultural runoff is concentrated in large water bodies.

Management practices, or ignorance of them, play a crucial role in the amount and impact of these pollutants. Management techniques range from animal management and housing to the spread of pesticides and fertilizers in global agricultural practices, which can have major environmental impacts. Bad management practices include poorly managed animal feeding operations, overgrazing, plowing, fertilizer, and improper, excessive, or badly timed use of pesticides.

Pollutants from agriculture greatly affect water quality and can be found in lakes, rivers, wetlands, estuaries, and groundwater. Pollutants from farming include sediments, nutrients, pathogens, pesticides, metals, and salts.[40] Animal agriculture has an outsized impact on pollutants that enter the environment. Bacteria and pathogens in manure can make their way into streams and groundwater if grazing, storing manure in lagoons and applying manure to fields is not properly managed.[41] Air pollution caused by agriculture through land use changes and animal agriculture practices have an outsized impact on climate change, and addressing these concerns was a central part of the IPCC Special Report on Climate Change and Land.[42] Mitigation of agricultural pollution is a key component in the development of a sustainable food system.[43][44][45]

Soil degradation

Soil degradation is the decline in soil quality that can be a result of many factors, especially from agriculture. Soils hold the majority of the world's biodiversity, and healthy soils are essential for food production and adequate water supply.[46] Common attributes of soil degradation can be salting, waterlogging, compaction, pesticide contamination, a decline in soil structure quality, loss of fertility, changes in soil acidity, alkalinity, salinity, and erosion. Soil erosion is the wearing away of topsoil by water, wind, or farming activities.[47] Topsoil is very fertile, which makes it valuable to farmers growing crops.[47] Soil degradation also has a huge impact on biological degradation, which affects the microbial community of the soil and can alter nutrient cycling, pest and disease control, and chemical transformation properties of the soil.[48]

Soil erosion

Large scale farming can cause large amounts of soil erosion. 25 to 40 percent of eroded soil ends up in water sources. Soil that carries pesticides and fertilizers pollutes the bodies of water it enters.[49] In the United States and Europe especially, large-scale agriculture has grown and small-scale-agriculture has shrunk due to financial arrangements such as contract farming. Bigger farms tend to favour monocultures, overuse water resources, and accelerate deforestation and soil quality decline. A study from 2020 by the International Land Coalition, together with Oxfam and World Inequality Lab, found that 1% of land owners manage 70% of the world's farmland. The highest discrepancy can be found in Latin America, where the poorest 50% own just 1% of the land. Small landowners, as individuals or families, tend to be more cautious in land use compared to large landowners. As of 2020, however, the proportion of small landowners has been decreasing since the 1980s. Currently, the largest share of smallholdings can be found in Asia and Africa.[50]

Tillage erosion

Tillage erosion is a form of soil erosion occurring in cultivated fields due to the movement of soil by tillage.[51][52] There is growing evidence that tillage erosion is a major soil erosion process in agricultural lands, surpassing water and wind erosion in many fields all around the world, especially on sloping and hilly lands[53][54][55] A signature spatial pattern of soil erosion shown in many water erosion handbooks and pamphlets, the eroded hilltops, is actually caused by tillage erosion as water erosion mainly causes soil losses in the midslope and lowerslope segments of a slope, not the hilltops.[56][51][53] Tillage erosion results in soil degradation, which can lead to significant reduction in crop yield and, therefore, economic losses for the farm.[57][58]

Waste

Plasticulture is the use of plastic mulch in agriculture. Farmers use plastic sheets as mulch to cover 50-70% of the soil and allow them to use drip irrigation systems to have better control over soil nutrients and moisture. Rain is not required in this system, and farms that use plasticulture are built to encourage the fastest runoff of rain. The use of pesticides with plasticulture allows pesticides to be transported easier in the surface runoff towards wetlands or tidal creeks. The runoff from pesticides and chemicals in the plastic can cause serious deformations and death in shellfish as the runoff carries the chemicals toward the oceans.[59]

In addition to the increased runoff that results from plasticulture, there is also the problem of the increased amount of waste from the plastic mulch itself. The use of plastic mulch for vegetables, strawberries, and other row and orchard crops exceeds 110 million pounds annually in the United States. Most plastic ends up in the landfill, although there are

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other disposal options such as disking mulches into the soil, on-site burying, on-site storage, reuse, recycling, and incineration. The incineration and recycling options are complicated by the variety of the types of plastics that are used and by the geographic dispersal of the plastics. Plastics also contain stabilizers and dyes as well as heavy metals, which limits the number of products that can be recycled. Research is continually being conducted on creating biodegradable or photodegradable mulches. While there has been a minor success with this, there is also the problem of how long the plastic takes to degrade, as many biodegradable products take a long time to break down.[60]

Issues by region

The environmental impact of agriculture can vary depending on the region as well as the type of agriculture production method that is being used. Listed below are some specific environmental issues in various different regions around the world.

- Hedgerow removal in the United Kingdom.
- Soil salinisation, especially in Australia.
- Phosphate mining in Nauru
- Methane emissions from livestock in New Zealand. *See Climate change in New Zealand.*
- Environmentalists attribute the hypoxic zone in the Gulf of Mexico as being encouraged by nitrogen fertilization of the algae bloom.
- Coupled systems from agricultural trade leading to regional effects from cascading effects and spillover systems. Environmental factor (Socioeconomic Drivers Section)

Sustainable agriculture

Sustainable agriculture is the idea that agriculture should occur in a way such that we can continue to produce what is necessary without infringing on the ability for future generations to do the same.

The exponential population increase in recent decades has increased the practice of agricultural land conversion to meet the demand for food which in turn has increased the effects on the environment. The global population is still increasing and will eventually stabilize, as some critics doubt that food production, due to lower yields from global warming, can support the global population.

## II. DISCUSSION

Agriculture can have negative effects on biodiversity as well.[5] Organic farming is a multifaceted sustainable agriculture set of practices that can have a lower impact on the environment at a small scale. However, in most cases organic farming results in lower yields in terms of production per unit area.[61] Therefore, widespread adoption of organic agriculture will require additional land to be cleared and water resources extracted to meet the same level of production. A European meta-analysis found that organic farms tended to have higher soil organic matter content and lower nutrient losses (nitrogen leaching, nitrous oxide emissions, and ammonia emissions) per unit of field area but higher ammonia emissions, nitrogen leaching and nitrous oxide emissions per product unit.[62] It is believed by many that conventional farming systems cause less rich biodiversity than organic systems. Organic farming has shown to have on average 30% higher species richness than conventional farming. Organic systems on average also have 50% more organisms. This data has some issues because there were several results that showed a negative effect on these things when in an organic farming system.[63] The opposition to organic agriculture believes that these negatives are an issue with the organic farming system. What began as a small scale, environmentally conscious practice has now become just as industrialized as conventional agriculture. This industrialization can lead to the issues shown above such as climate change, and deforestation.

Regenerative agriculture

Regenerative agriculture is a conservation and rehabilitation approach to food and farming systems. It focuses on topsoil regeneration, increasing biodiversity,[64] improving the water cycle,[65] enhancing ecosystem services, supporting biosequestration,[66] increasing resilience to climate change, and strengthening the health and vitality of farm soil.

Regenerative agriculture is not a specific practice itself. Rather, proponents of regenerative agriculture use a variety of sustainable agriculture techniques in combination.[67] Practices include recycling as much farm waste as possible and adding composted material from sources outside the farm.[68][69][70][71] Regenerative agriculture on small farms and gardens is often based on philosophies like permaculture, agroecology, agroforestry, restoration ecology, keyline design, and holistic management. Large farms are also increasingly adopting regenerative techniques and often use "no-till" and/or "reduced till" practices.

As soil health improves, input requirements may decrease, and crop yields may increase as soils are more resilient against extreme weather and harbor fewer pests and pathogens.[72]

Regenerative agriculture mitigates climate change through carbon dioxide removal, i.e. it draws carbon from the atmosphere and sequesters it. Along with decreasing carbon emissions, carbon sequestration practices are gaining popularity in agriculture, and individuals and groups are taking action to fight climate change.[73]

Techniques

Conservation tillage

Conservation tillage is an alternative tillage method for farming which is more sustainable for the soil and surrounding ecosystem.[74] This is done by allowing the residue of the previous harvest's crops to remain in the soil before tilling for the next crop. Conservation tillage has shown to improve many things such as soil moisture retention, and reduce erosion. Some disadvantages are the fact that more expensive equipment is needed for this process, more pesticides will need to be used, and the positive effects take a long time to be visible.[74] The barriers of instantiating a conservation tillage policy are that farmers are reluctant to change their methods, and would protest a more expensive, and time-consuming method of tillage than the conventional one they are used to.[75]

Biological pest control

Biological control or biocontrol is a method of controlling pests, whether pest animals such as insects and mites, weeds, or pathogens affecting animals or plants by using other organisms.[76] It relies on predation, parasitism, herbivory, or other natural mechanisms, but typically also involves an active human management role. It can be an important component of integrated pest management (IPM) programs.

There are three basic strategies for biological control: classical (importation), where a natural enemy of a pest is introduced in the hope of achieving control; inductive (augmentation), in which a large population of natural enemies are administered for quick pest control; and inoculative (conservation), in which measures are taken to maintain natural enemies through regular reestablishment.[77]

Natural enemies of insects play an important part in limiting the densities of potential pests. Biological control agents such as these include predators, parasitoids, pathogens, and competitors. Biological control agents of plant diseases are most often referred to as antagonists. Biological control agents of weeds include seed predators, herbivores, and plant pathogens.

Biological control can have side-effects on biodiversity through attacks on non-target species by any of the above mechanisms, especially when a species is introduced without a thorough understanding of the possible consequences.

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## Abiotic sources

### Pesticides

Pesticides and herbicides are applied to agricultural land to control pests that disrupt crop production. Soil contamination can occur when pesticides persist and accumulate in soils, which can alter microbial processes, increase plant uptake of the chemical, and are toxic to soil organisms. The extent to which the pesticides and herbicides persist depends on the compound's unique chemistry, which affects sorption dynamics and resulting fate and transport in the soil environment.[7] Pesticides can also accumulate in animals that eat contaminated pests and soil organisms. In addition, pesticides can be more harmful to beneficial insects, such as pollinators, and to natural enemies of pests (i.e. insects that prey on or parasitize pests) than they are to the target pests themselves.[8]

### Pesticide leaching

Pesticide leaching occurs when pesticides mix with water and move through the soil, ultimately contaminating groundwater. The amount of leaching is correlated with particular soil and pesticide characteristics and the degree of rainfall and irrigation. Leaching is most likely to happen if using a water-soluble pesticide, when the soil tends to be sandy in texture; if excessive watering occurs just after pesticide application; if the adsorption ability of the pesticide to the soil is low. Leaching may not only originate from treated fields, but also from pesticide mixing areas, pesticide application machinery washing sites, or disposal areas.[9]

### Fertilizers

Fertilizers are used to provide crops with additional sources of nutrients, such as nitrogen, phosphorus, and potassium, that promote plant growth and increase crop yields. While they are beneficial for plant growth, they can also disrupt natural nutrient and mineral biogeochemical cycles and pose risks to human and ecological health.

### Nitrogen

Nitrogen fertilizers supply plants with forms of nitrogen that are biologically available for plant uptake; namely $NO_3^-$ (nitrate) and $NH_4^+$ (ammonium). This increases crop yield and agricultural productivity, but it can also negatively affect groundwater and surface waters, pollute the atmosphere, and degrade soil health. Not all nutrient applied through fertilizer are taken up by the crops, and the remainder accumulates in the soil or is lost as runoff. Nitrate fertilizers are much more likely to be lost to the soil profile through runoff because of its high solubility and like charges between the molecule and negatively charged clay particles.[10] High application rates of nitrogen-containing fertilizers combined with the high water-solubility of nitrate leads to increased runoff into surface water as well as leaching into groundwater, thereby causing groundwater pollution. Nitrate levels above 10 mg/L (10 ppm) in groundwater can cause "blue baby syndrome" (acquired methemoglobinemia) in infants and possibly thyroid disease and various types of cancer.[11] Nitrogen fixation, which converts atmospheric nitrogen ($N_2$) to more biologically available forms, and denitrification, which converts biologically available nitrogen compounds to $N_2$ and $N_2O$, are two of the most important metabolic processes involved in the nitrogen cycle because they are the largest inputs and outputs of nitrogen to ecosystems. They allow nitrogen to flow between the atmosphere, which is around 78% nitrogen) and the biosphere. Other significant processes in the nitrogen cycle are nitrification and ammonification which convert ammonium to nitrate or nitrite and organic matter to ammonia respectively. Because these processes keep nitrogen concentrations relatively stable in most ecosystems, a large influx of nitrogen from agricultural runoff can cause serious disruption.[12] A common result of this in aquatic ecosystems is eutrophication which in turn creates hypoxic and anoxic conditions – both of which are deadly and/or damaging to many species.[13] Nitrogen fertilization can also release $NH_3$ gases into the atmosphere which can then be converted into $NO_x$ compounds. A greater amount of $NO_x$ compounds in the atmosphere can result in the acidification of aquatic ecosystems and cause various respiratory issues in humans. Fertilization can also release $N_2O$ which is a greenhouse gas and can facilitate the destruction of ozone ($O_3$) in the stratosphere.[14] Soils that receive nitrogen fertilizers can also be damaged. An increase in plant available nitrogen will increase a crop's net primary production, and eventually, soil microbial activity will increase as a result of the larger inputs of nitrogen from fertilizers and carbon compounds through decomposed biomass. Because of the increase in decomposition in the soil, its organic matter content will be depleted which results in lower overall soil health.[15]

Mitigation

Changes in global N budget in croplands with the best adoption of the 11 selected measures [16]

A study identified "11 key measures" that can reduce nitrogen chemicals pollution of air and water from croplands. Its prioritized measures include use of enhanced-efficiency fertilizers (EEFs), soil amendments, crop legume rotation and application of buffer zones. As a meta-measure, the study proposes "innovative policies such as a nitrogen credit system (NCS) could be implemented to select, incentivize and, where necessary, subsidize the adoption of these measures".[16]

One alternative to standard nitrogen fertilizers are Enhanced Efficiency Fertilizers (EEF). There are several types of EEFs but they generally fall within two categories, slow release fertilizers or nitrification inhibitor fertilizers. Slow release fertilizers are coated in a polymer that delays and slows the release of nitrogen into agricultural systems. Nitrification inhibitors are fertilizers that are coated in a sulfur compound that is very hydrophobic, this help to slow the release of nitrogen. EEFs provide a lower and more steady flow of nitrogen into the soil and may reduce nitrogen leaching and volatilization of $NO_x$ compounds, however the scientific literature shows both effectiveness and ineffectiveness at reducing nitrogen pollution.[17][18]

Phosphorus

The most common form of phosphorus fertilizer used in agricultural practices is phosphate ($PO_4^{3-}$), and it is applied in synthetic compounds that incorporate $PO_4^{3-}$ or in organic forms such as manure and compost.[19] Phosphorus is an essential nutrient in all organisms because of the roles it plays in cell and metabolic functions such as nucleic acid production and metabolic energy transfers. However, most organisms, including agricultural crops, only require a small amount of phosphorus because they have evolved in ecosystems with relatively low amounts of it.[20] Microbial populations in soils are able to convert organic forms of phosphorus to soluble plant available forms such as phosphate. This step is generally bypassed with inorganic fertilizers because it is applied as phosphate or other plant available forms. Any phosphorus that is not taken up by plants is adsorbed to soil particles which helps it remain in place. Because of this, it typically enters surface waters when the soil particles it is attached to are eroded as a result of precipitation or stormwater runoff. The amount that enters surface waters is relatively low in comparison to the amount that is applied as fertilizer, but because it acts as a limiting nutrient in most environments, even a small amount can disrupt an ecosystem's natural phosphorus biogeochemical cycles.[21] Although nitrogen plays a role in harmful algae and cyanobacteria blooms that cause eutrophication, excess phosphorus is considered the largest contributing factor due to the fact that phosphorus is often the most limiting nutrient, especially in freshwaters.[22] In addition to depleting oxygen levels in surface waters, algae and cyanobacteria blooms can produce cyanotoxins which are harmful to human and animal health as well as many aquatic organisms.[23]

The concentration of cadmium in phosphorus-containing fertilizers varies considerably and can be problematic. For example, mono-ammonium phosphate fertilizer may have a cadmium content of as low as 0.14 mg/kg or as high as 50.9 mg/kg. This is because the phosphate rock used in their manufacture can contain as much as 188 mg/kg cadmium (examples are deposits on Nauru and the Christmas islands). Continuous use of high-cadmium fertilizer can contaminate soil and plants. Limits to the cadmium content of phosphate fertilizers has been considered by the European Commission. Producers of phosphorus-containing fertilizers now select phosphate rock based on the cadmium content.[24] Phosphate rocks contain high levels of fluoride. Consequently, the widespread use of phosphate fertilizers has increased soil fluoride concentrations. It has been found that food contamination from fertilizer is of little concern as plants accumulate little fluoride from the soil; of greater concern is the possibility of fluoride toxicity to livestock that ingest contaminated soils. Also of possible concern are the effects of fluoride on soil microorganisms.[25]

Radioactive elements

The radioactive content of the fertilizers varies considerably and depends both on their concentrations in the parent mineral and on the fertilizer production process. Uranium-238 concentrations range can range from 7 to 100 pCi/g in phosphate rock and from 1 to 67 pCi/g in phosphate fertilizers. Where high annual rates of phosphorus fertilizer are used, this can result in uranium-238 concentrations in soils and drainage waters that are several times greater than are normally present. However, the impact of these increases on the risk to human health from radionuclide contamination of foods is very small (less than 0.05 mSv/y).

Organic contaminants

Manures and biosolids contain many nutrients consumed by animals and humans in the form of food. The practice of returning such waste products to agricultural land presents an opportunity to recycle soil nutrients. The challenge is that manures and biosolids contain not only nutrients such as carbon, nitrogen, and phosphorus, but they may also contain contaminants, including pharmaceuticals and personal care products (PPCPs). There is a wide variety and vast quantity of PPCPs consumed by both humans and animals, and each has unique chemistry in terrestrial and aquatic environments. As such, not all have been assessed for their effects on soil, water, and air quality. The US Environmental Protection Agency (EPA) has surveyed sewage sludge from wastewater treatment plants across the US to assess levels of various PPCPs present.[26]

Metals

The major inputs of heavy metals (e.g. lead, cadmium, arsenic, mercury) into agricultural systems are fertilizers, organic wastes such as manures, and industrial byproduct wastes. Inorganic fertilizers especially represent an important pathway for heavy metals to enter soils.[27] Some farming techniques, such as irrigation, can lead to accumulation of selenium (Se) that occurs naturally in the soil, which can result in downstream water reservoirs containing concentrations of selenium that are toxic to wildlife, livestock, and humans. This process is known as the "Kesterson Effect", eponymously named after the Kesterson Reservoir in the San Joaquin Valley (California, US), which was declared a toxic waste dump in 1987.[28] Heavy metals present in the environment can be taken up by plants, which can pose health risks to humans in the event of consuming affected plants.[29] Some metals are essential to plant growth, however an abundance can have adverse effects on plant health.

Steel industry wastes, which are often recycled into fertilizers due to their high levels of zinc (essential to plant growth), can also include the following toxic metals: lead, arsenic, cadmium, chromium, and nickel. The most common toxic elements in this type of fertilizer are mercury, lead, and arsenic. These potentially harmful impurities can be removed during fertilizer production; however, this significantly increases cost of fertilizer. Highly pure fertilizers are widely available, and perhaps best known as the highly water-soluble fertilizers containing blue dyes. Fertilizers such as these are commonly used around households, such as Miracle-Gro. These highly water-soluble fertilizers are used in the plant nursery business and are available in larger packages at significantly less cost than retail quantities. There are also some inexpensive retail granular garden fertilizers made with high purity ingredients, limiting production.[*citation needed*]

Land management

Agriculture contributes greatly to soil erosion and sediment deposition through intensive management or inefficient land cover.[30] It is estimated that agricultural land degradation is leading to an irreversible decline in fertility on about 6 million ha of fertile land each year.[31] The accumulation of sediments (i.e. sedimentation) in runoff water affects water quality in various ways. Sedimentation can decrease the transport capacity of ditches, streams, rivers, and navigation channels. It can also limit the amount of light penetrating the water, which affects aquatic biota. The resulting turbidity from sedimentation can interfere with feeding habits of fishes, affecting population dynamics. Sedimentation also affects the transport and accumulation of pollutants, including phosphorus and various pesticides.[32]

Tillage and nitrous oxide emissions

Natural soil biogeochemical processes result in the emission of various greenhouse gases, including nitrous oxide. Agricultural management practices can affect emission levels. For example, tillage levels have also been shown to affect nitrous oxide emissions.[33]

## III. RESULTS

Organic farming in mitigation

From an environmental perspective, fertilizing, overproduction and the use of pesticides in conventional farming has caused, and is causing, enormous damage worldwide to local ecosystems, soil health,[34][35][36] biodiversity, groundwater and drinking water supplies, and sometimes farmers' health and fertility.[37][38][39][40][41]

Organic farming typically reduces some environmental impact relative to conventional farming, but the scale of reduction can be difficult to quantify and varies depending on farming methods. In some cases, reducing food waste and dietary changes might provide greater benefits.[41] A 2020 study at the Technical University of Munich found that the greenhouse gas emissions of organically farmed plant-based food were lower than conventionally-farmed plant-based food. The greenhouse gas costs of organically produced meat were approximately the same as non-organically produced meat.[42][43] However, the same paper noted that a shift from conventional to organic practices would likely be beneficial for long-term efficiency and ecosystem services, and probably improve soil over time.[43]

A 2019 life-cycle assessment study found that converting the total agricultural sector (both crop and livestock production) for England and Wales to organic farming methods would result in a net increase in greenhouse gas emissions as increased overseas land use for production and import of crops would be needed to make up for lower organic yields domestically.[44]

## Biotic sources

### Greenhouse gases from fecal waste

The United Nations Food and Agriculture Organization (FAO) predicted that 18% of anthropogenic greenhouse gases come directly or indirectly from the world's livestock. This report also suggested that the emissions from livestock were greater than that of the transportation sector. While livestock do currently play a role in producing greenhouse gas emissions, the estimates have been argued to be a misrepresentation. While the FAO used a life-cycle assessment of animal agriculture (i.e. all aspects including emissions from growing crops for feed, transportation to slaughter, etc.), they did not apply the same assessment for the transportation sector.[45]

Alternate sources [46] claim that FAO estimates are too low, stating that the global livestock industry could be responsible for up to 51% of emitted atmospheric greenhouse gasses rather than 18%.[47] Critics say the difference in estimates come from the FAO's use of outdated data. Regardless, if the FAO's report of 18% is accurate, that still makes livestock the second-largest greenhouse-gas-polluter.

A PNAS model showed that even if animals were completely removed from U.S. agriculture and diets, U.S. GHG emissions would be decreased by 2.6% only (or 28% of agricultural GHG emissions). This is because of the need replace animal manures by fertilizers and to replace also other animal coproducts, and because livestock now use human-inedible food and fiber processing byproducts. Moreover, people would suffer from a greater number of deficiencies in essential nutrients although they would get a greater excess of energy, possibly leading to greater obesity.[48]

### Biopesticides

Biopesticides are pesticides derived from natural materials (animals, plants, microorganisms, certain minerals).[49] As an alternative to traditional pesticides, biopesticides can reduce overall agricultural pollution because they are safe to handle, usually do not strongly affect beneficial invertebrates or vertebrates, and have a short residual time.[49] Some concerns exist that biopesticides may have negative impacts on populations of nontarget species, however.[50]

In the United States, biopesticides are regulated by EPA. Because biopesticides are less harmful and have fewer environmental effects than other pesticides, the agency does not require as much data to register their use. Many biopesticides are permitted under the National Organic Program, United States Department of Agriculture, standards for organic crop production.[49]

### Introduced species

The increasing globalization of agriculture has resulted in the accidental transport of pests, weeds, and diseases to novel ranges. If they establish, they become an invasive species that can impact populations of native species[51] and threaten agricultural production.[8] For example, the transport of bumblebees reared in Europe and shipped to the United States and/or Canada for use as commercial pollinators has led to the introduction of an Old World parasite to the New World.[52] This introduction may play a role in recent native bumble bee declines in North America.[53] Agriculturally introduced species can also hybridize with native species resulting in a decline in genetic biodiversity[51] and threaten agricultural production.[8]

Habitat disturbance associated with farming practices themselves can also facilitate the establishment of these introduced organisms. Contaminated machinery, livestock and fodder, and contaminated crop or pasture seed can also lead to the spread of weeds.[54]

Quarantines (see biosecurity) are one way in which prevention of the spread of invasive species can be regulated at the policy level. A quarantine is a legal instrument that restricts the movement of infested material from areas where an invasive species is present to areas in which it is absent. The World Trade Organization has international regulations concerning the quarantine of pests and diseases under the Agreement on the Application of Sanitary and Phytosanitary Measures. Individual countries often have their own quarantine regulations. In the United States, for example, the United States Department of Agriculture/Animal and Plant Health Inspection Service (USDA/APHIS) administers domestic (within the United States) and foreign (importations from outside the United States) quarantines. These quarantines are enforced by inspectors at state borders and ports of entry.[49]

Biological control

The use of biological pest control agents, or using predators, parasitoids, parasites, and pathogens to control agricultural pests, has the potential to reduce agricultural pollution associated with other pest control techniques, such as pesticide use. The merits of introducing non-native biocontrol agents have been widely debated, however. Once released, the introduction of a biocontrol agent can be irreversible. Potential ecological issues could include the dispersal from agricultural habitats into natural environments, and host-switching or adapting to utilize a native species. In addition, predicting the interaction outcomes in complex ecosystems and potential ecological impacts prior to release can be difficult. One example of a biocontrol program that resulted in ecological damage occurred in North America, where a parasitoid of butterflies was introduced to control gypsy moth and browntail moth. This parasitoid is capable of utilizing many butterfly host species, and likely resulted in the decline and extirpation of several native silk moth species.[55]

International exploration for potential biocontrol agents is aided by agencies such as the European Biological Control Laboratory, the United States Department of Agriculture/Agricultural Research Service (USDA/ARS), the Commonwealth Institute of Biological Control, and the International Organization for Biological Control of Noxious Plants and Animals. In order to prevent agricultural pollution, quarantine and extensive research on the organism's potential efficacy and ecological impacts are required prior to introduction. If approved, attempts are made to colonize and disperse the biocontrol agent in appropriate agricultural settings. Continual evaluations on their efficacy are conducted.[49]

Genetically modified organisms (GMO)

Genetic contamination and ecological effects

GMO crops can, however, result in genetic contamination of native plant species through hybridization. This could lead to increased weediness of the plant or the extinction of the native species. In addition, the transgenic plant itself may become a weed if the modification improves its fitness in a given environment.[8]

There are also concerns that non-target organisms, such as pollinators and natural enemies, could be poisoned by accidental ingestion of Bt-producing plants. A recent study testing the effects of Bt corn pollen dusting nearby milkweed plants on larval feeding of the monarch butterfly found that the threat to populations of the monarch was low.[8]

The use of GMO crop plants engineered for herbicide resistance can also indirectly increase the amount of agricultural pollution associated with herbicide use. For example, the increased use of herbicide in herbicide-resistant corn fields in the mid-western United States is decreasing the amount of milkweeds available for monarch butterfly larvae.[8]

Regulation of the release of genetic modified organisms vary based on the type of organism and the country concerned.

GMO as a tool of pollution reduction

While there may be some concerns regarding the use of GM products, it may also be the solution to some of the existing animal agriculture pollution issues. One of the main sources of pollution, particularly vitamin and mineral drift in soils, comes from a lack of digestive efficiency in animals. By improving digestive efficiency, it is possible to minimize both the cost of animal production and the environmental damage. One successful example of this technology and its potential application is the Enviropig.

The Enviropig is a genetically modified Yorkshire pig that expresses phytase in its saliva. Grains, such as corn and wheat, have phosphorus that is bound in a naturally indigestible form known as phytic acid. Phosphorus, an essential nutrient for pigs, is then added to the diet, since it can not be broken down in the pigs digestive tract. As a result, nearly all of the phosphorus naturally found in the grain is wasted in the feces, and can contribute to elevated levels in the soil. Phytase is an enzyme that is able to break down the otherwise indigestible phytic acid, making it available to the pig. The ability of the Enviropig to digest the phosphorus from the grains eliminates the waste of that natural phosphorus (20-60% reduction), while also eliminating the need to supplement the nutrient in feed.[56]

Animal management

One of the main contributors to air, soil and water pollution is animal waste. According to a 2005 report by the USDA, more than 335–million tons of "dry matter" waste (the waste after water is removed) is produced annually on farms in the United States.[57] Animal feeding operations produce about 100 times more manure than the amount of human sewage sludge processed in US municipal waste water plants each year. Diffuse source pollution from agricultural fertilizers is more difficult to trace, monitor and control. High nitrate concentrations are found in groundwater and may reach 50 mg/litre (the EU Directive limit). In ditches and river courses, nutrient pollution from fertilizers causes eutrophication. This is worse in winter, after autumn ploughing has released a surge of nitrates; winter rainfall is heavier increasing runoff and leaching, and there is lower plant uptake. EPA suggests that one dairy farm with 2,500 cows produces as much waste as a city with around 411,000 residents.[58] The US National Research Council has identified odors as the most significant animal emission problem at the local level. Different animal systems have adopted several waste management procedures to deal with the large amount of waste produced annually.

The advantages of manure treatment are a reduction in the amount of manure that needs to be transported and applied to crops, as well as reduced soil compaction. Nutrients are reduced as well, meaning that less cropland is needed for manure to be spread upon. Manure treatment can also reduce the risk of human health and biosecurity risks by reducing the amount of pathogens present in manure. Undiluted animal manure or slurry is one hundred times more concentrated than domestic sewage, and can carry an intestinal parasite, *Cryptosporidium,* which is difficult to detect but can be passed to humans. Silage liquor (from fermented wet grass) is even stronger than slurry, with a low pH and very high biological oxygen demand. With a low pH, silage liquor can be highly corrosive; it can attack synthetic materials, causing damage to storage equipment, and leading to accidental spillage. All of these advantages can be optimized by using the right manure management system on the right farm based on the resources that are available.

Manure treatment

Composting

Composting is a solid manure management system that relies on solid manure from bedded pack pens, or the solids from a liquid manure separator. There are two methods of composting, active and passive. Manure is churned periodically during active composting, whereas in passive composting it is not. Passive composting has been found to have lower green house gas emissions due to incomplete decomposition and lower gas diffusion rates.

Solid-liquid separation

Manure can be mechanically separated into a solid and liquid portion for easier management. Liquids (4–8% dry matter) can be used easily in pump systems for convenient spread over crops and the solid fraction (15–30% dry matter) can be used as stall bedding, spread on crops, composted or exported.

## IV. CONCLUSION

Anaerobic digestion and lagoons

Anaerobic digestion is the biological treatment of liquid animal waste using bacteria in an area absent of air, which promotes the decomposition of organic solids. Hot water is used to heat the waste in order to increase the rate of biogas production.[59] The remaining liquid is nutrient rich and can be used on fields as a fertilizer and methane gas that can be burned directly on the biogas stove[60] or in an engine generator to produce electricity and heat.[59][61] Methane is about 20 times more potent as a greenhouse gas than carbon dioxide, which has significant negative environmental effects if not controlled properly. Anaerobic treatment of waste is the best method for controlling the odor associated with manure management.[59]

Biological treatment lagoons also use anaerobic digestion to break down solids, but at a much slower rate. Lagoons are kept at ambient temperatures as opposed to the heated digestion tanks. Lagoons require large land areas and high dilution volumes to work properly, so they do not work well in many climates in the northern United States. Lagoons also offer the benefit of reduced odor and biogas is made available for heat and electric power.[62]

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Studies have demonstrated that GHG emissions are reduced using aerobic digestion systems. GHG emission reductions and credits can help compensate for the higher installation cost of cleaner aerobic technologies and facilitate producer adoption of environmentally superior technologies to replace current anaerobic lagoons.[63]

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