OUTLOOK OF SUSTAINABLE AGRICULTURE THROUGH INNOVATED CARBON RECYCLING MODEL

Research Paper

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Abstract

Carbon is present in most living objects on earth, wherein carbon is necessary to live, grow, and reproduce. The carbon cycle is crucial as carbon makes life on earth possible. Nature tries to keep a balanced carbon level, implying that through natural process the amount of carbon released from reservoirs equals the amount that is absorbed by reservoirs. Sustaining this carbon balance is essential for life on our planet. But carbon cycle balance has been disrupted by various human activities, specially through traditional farming activities and burning fossil carbon as fuel. This has led to release of more carbon dioxide into the atmosphere than being absorbed by plants. Conventional agriculture, food production and distribution are major contributors of greenhouse gas emission. Agriculture is directly responsible for 14% of annual greenhouse gas (GHG) emissions and induces an additional 17% through land use change, mostly in developing countries. Agricultural intensification and expansion is expected to catalyze significant relative increases in agricultural GHG emissions over the next decade. Therefore, rising population and exponential demand of food with each day, it is of utmost importance to discover means of sustainable agriculture through carbon recycling for faster nutritious food generation and thereby the carbon cycle back into balance.

Keywords: Carbon, Recycling, Sustainbable Agriculture, Greenhouse Gas.

1 INTRODUCTION

1.1 INTRODUCTION

Agriculture is the art and science of cultivating the soil, growing crops, and raising livestock. It includes the preparation of plant and animal products for people to use and their distribution to markets. Food production must keep pace with population expansion and distribution systems. This is an enormous agricultural and political challenge. Overpopulation has pushed a rising number of farmers onto lands too fragile to sustain cultivation. Need for food has led to enhanced irrigation worldwide. In some places, irrigation have led water tables to drop, rivers to run, and wells to go empty. Agricultural chemicals that enhance production often pollute soil and groundwater and disturb food chains. All these complete agricultural processes accounts for almost one fourth of all the greenhouse gas emitted by humans. With the inclusion of food processing, this share rises to more than one third. Agriculture is also affected by changing climate – intense weather events, biodiversity loss and land degradation are weakening the sector's productivity and putting several businesses at risk.

With the right set of technology adoption, policies and investments, agriculture through carbon recycling can be a sustainable solution to reduce deforestation, restore degraded land, and promote sustainable agricultural practices and biodiversity conservation, along with helping to restore the carbon balance.

1.2 Research Problem

Cultivation soil cover half of the earth's livable land, and the global food system produces 21 percent -37 percent of the world's greenhouse gas emissions from human activity. When heavy machinery works on fields, the soil that store three times as much carbon dioxide as the atmosphere, releases trapped carbon back into the atmosphere. With ever rising population there is constant increase in demand of food, which is forcing for more food production and thereby more forest lands are being cleared for agriculture. But conventional food production techniques are causing increased greenhouse gas emissions, soil erosion, water pollution; thereby disrupting the carbon balance on the earth and posts a threat to sustainable human life.

1.3 Purpose of Research

Agriculture itself generates considerable amount of greenhouse gas emissions, which adversely leads to global warming and climate change. Agriculture is both a victim of and a contributor to climate change. On one side, agricultural activity adversely account for approximately 30 percent of total greenhouse gas emissions, mainly due to the use of chemical fertilizers, pesticides, and animal wastes. This rate will increase further because of rise in food demand by a growing global population, the stronger demand for dairy and meat products, and the intensification of agricultural practices. On the other side, these greenhouses gases include nitrous oxide (NO2), carbon dioxide (CO2) and methane (CH4), which are affecting towards climate change and global warming and thereby have a deep impact on the sustainability of agricultural production systems. This does not yet consider the greenhouse gas emissions associated with the use of pesticide, the environmental cost of which is largely unrecognized.

This research is to find methods of sustainable agriculture through carbon recycling, not only to help restore carbon cycle back to balance, but also for faster nutritious food generation. Reducing the use of coal, oil and natural gas is clearly important, but it’s not the only way to bring the carbon cycle back to balance. Using more fossil fuel in industrial production could be a significant factor behind high level of carbon emissions but it may not be the only reason. Financial development can be an important source as well (Gokmenoglu et Al 2015). One possibility is to capture the carbon in fuel either before or after combustion and then sequester it underground which is called carbon capture and sequestration (CCS). This approach can be used in power plants and other large stationary sources of carbon dioxide emissions. Another key area which requires major attention is to speed up the rate at which carbon dioxide is removed from the atmosphere and then sequester the resulting carbon, thereby balancing out the carbon dioxide. These carbon dioxide removal (CDR) mechanisms, sometimes called negative emissions, include reforestation; advanced agricultural practices that uses excess carbon to produce food; rebuilding wetlands, grasslands, peat bogs and other carbon-rich ecosystems; and restoring degraded lands.

1.4 Significance of the Study

All this extra carbon needs to be taken out. So far, land plants and the ocean have consumed about 55 percent of the extra carbon people have left into the atmosphere while about 45 percent has remained back in the atmosphere. In due course, the land and oceans will take up most of the extra carbon dioxide, but around 20 percent may linger in the atmosphere for thousands of years. The variations in the carbon cycle affects each reservoir. Carbon dioxide raises temperature and humidity, increasing the growing season. This leads to additional plant growth. But warmer temperature also strains plants. With a longer and warm growing season, plants require more water to stay alive. Excess carbon in the ocean makes the water more acidic, putting marine life in danger.

So, every excess carbon needs to be removed from the ecosystem and that too at a faster speed, as compared to the rate at which new carbon is being added into the ecosystem. As conventional agriculture produces a substantial amount of greenhouse gas emissions, either directly or indirectly, we need to adopt ways of recycling carbon itself to produce food at a faster rate without giving back much of carbon to the atmosphere.

The study should further improve current state of thought and work by authors in the field of carbon free food production such as carbon emission avoidance and capture by producing in-reactor microbial biomass-based food, feed, and slow-release fertilizers (Pikaar, Ilje, et al. 2018), and others.

2 LITERATURE REVIEW

2.1 Carbon Cycle

Carbon is a vital element for all life forms on Earth. Whether these life forms take in carbon to help manufacture food or release carbon as part of respiration, the intake and output of carbon is an integral part of all plant and animal life. Carbon is in a continuous state of movement from place to place. It is stored in what are known as reservoirs, and it moves between these reservoirs through a variety of processes, including photosynthesis, burning fossil fuels, and simply releasing breath from the lungs. The movement of carbon from reservoir to reservoir is known as the carbon cycle.

Carbon is a finite element that cycles through the Earth in various forms. This is due to carbon's ability to readily form bonds with other atoms, giving flexibility to the form and function those biomolecules can take, such as DNA (Deoxyribonucleic acid) and RNA (Ribonucleic acid), which are essential to define characteristics of life: growth and replication. Hence, carbon molecules are therefore sought after by all organisms, which drives complex carbon cycles through all living systems. Carbon is found and is exchanged between global reservoirs: the atmosphere, the ocean, terrestrial plant biomass, and soil. The balance of carbon between these reservoirs is important for life.

Because Earth is a closed system, the amount of carbon on the planet never changes. However, the amount of carbon in a specific reservoir can change over time as carbon moves from one reservoir to another. Carbon can be stored in a variety of reservoirs, including plants and animals, which is why they are considered carbon life forms. For example, some carbon in the atmosphere might be captured by plants to make food during photosynthesis and to develop leaves and stems. This carbon can then be consumed by the animal world for their cellular growth and gets stored in animals. When the animals die, they decompose, and their remains become sediment, trapping the stored carbon in layers that eventually turn into rock or minerals. Some of this sediment might form fossil fuels, such as coal, oil, or natural gas, which release carbon back into the atmosphere as carbon dioxide and carbon monoxide when the fuel is burned. It is also available in oceans, trapped by various marine organisms. Some creatures, such as clams or coral, use the carbon to create shells and skeletons. Most of the carbon on the planet is present in rocks, minerals, and other sediment buried under the earth's surface.

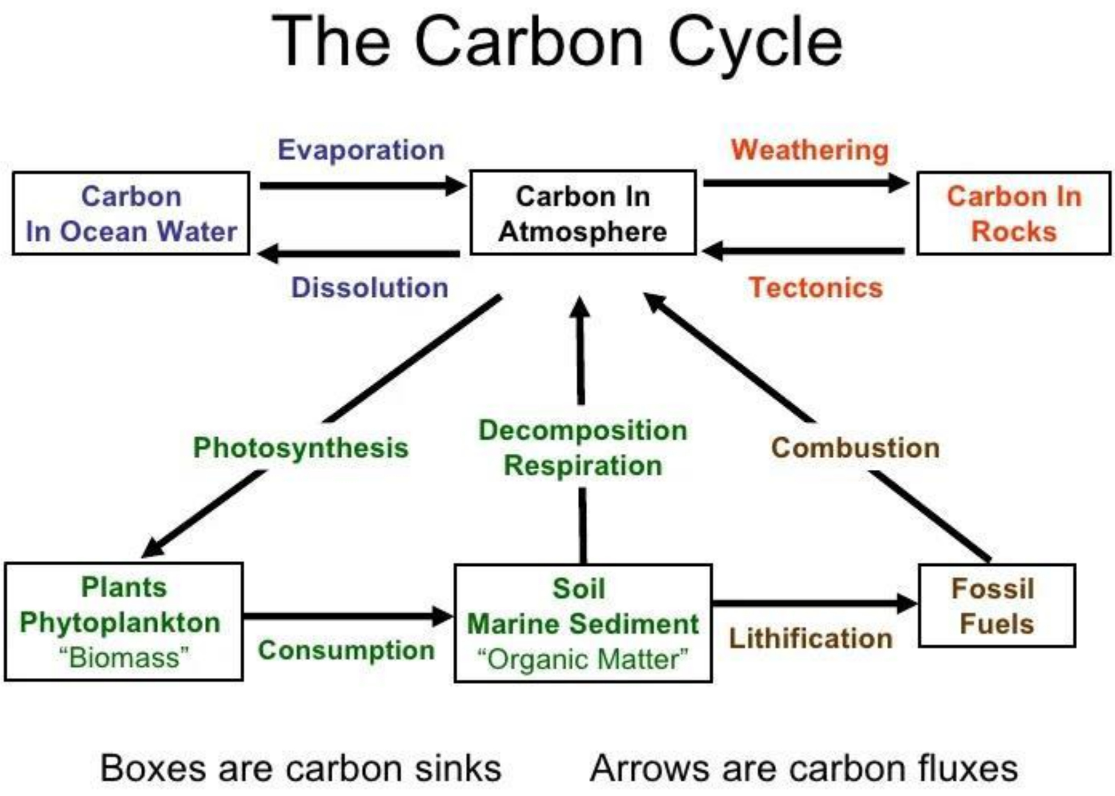


Figure 1. The carbon cycle.

This carbon cycle is vital to life on Earth. Nature tends to keep carbon levels balanced, meaning that the amount of carbon naturally released from reservoirs is equal to the amount that is naturally absorbed by reservoirs. Sustaining this carbon balance allows the planet to remain hospitable for life. Human activities, especially conventional farming activities and burning fossil carbon as fuel, have disturbed the carbon cycle's balance, leading to more carbon dioxide being released into the atmosphere than is being consumed by plants. Carbon dioxide in the atmosphere acts like insulation. It traps a fraction of the sun's heat – therefore, more carbon dioxide means more heat being trapped, leading to climbing temperatures and changing weather patterns around the globe and all these are leading to global warming consequences.

2.2 Carbon loss in conventional agriculture

Human population and economic growth have led to an exponential rise in use of soil resources. Roughly 50 million km2 of soils are currently being managed in various ways by humans for food, fiber, and livestock production, leading to the affirmation that we live on a "used planet". The concerns of human domination on soil resources are of various types : accelerated erosion, desertification, salinization, acidification, compaction, biodiversity loss, nutrient depletion, and loss of soil organic matter (SOM). The agriculture sector contributes 30 percent of greenhouse gases. The three main greenhouse gases emitted by agricultural practices are carbon dioxide, methane, and nitrous oxide. Airborne greenhouse gases are responsible for the effects of climate change.

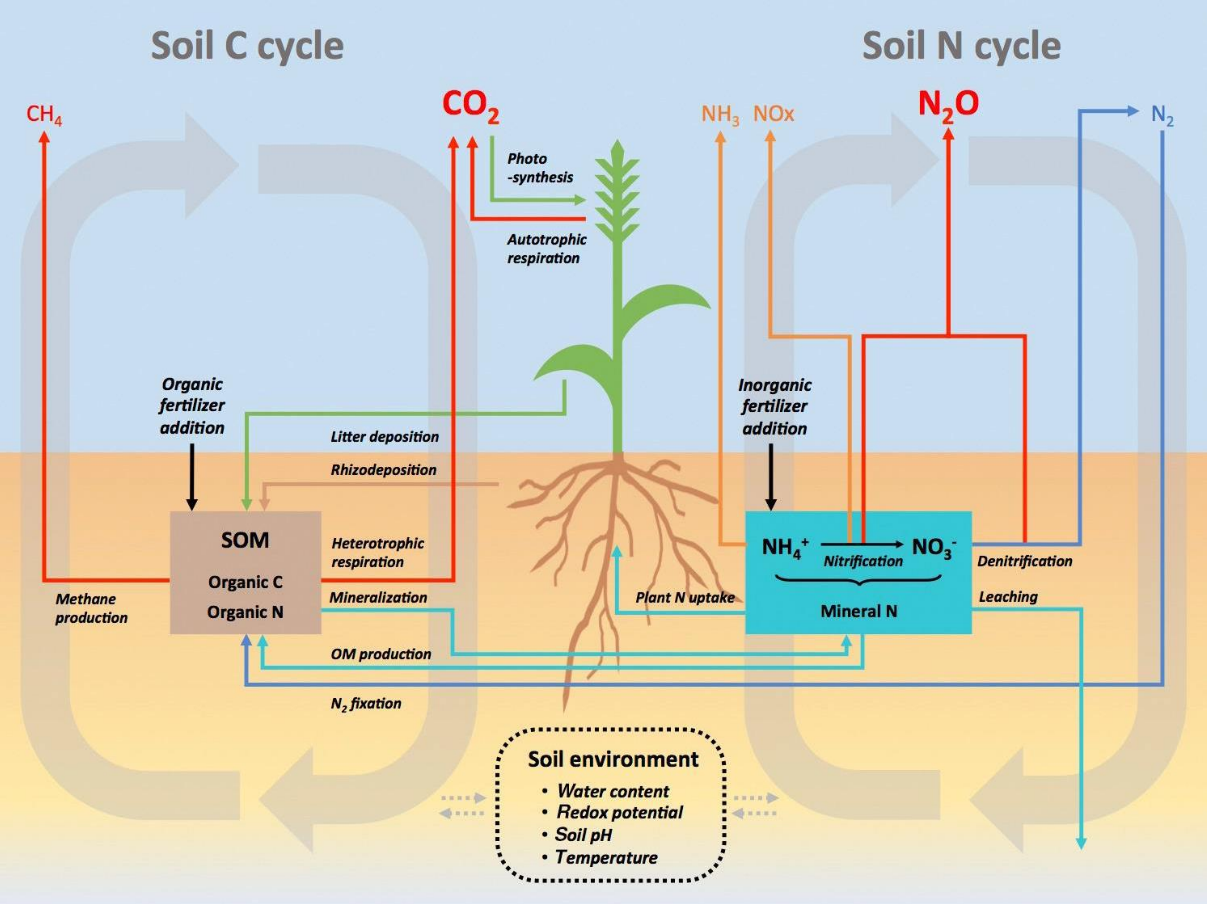


Figure 2. Soil environment

Carbon dioxide

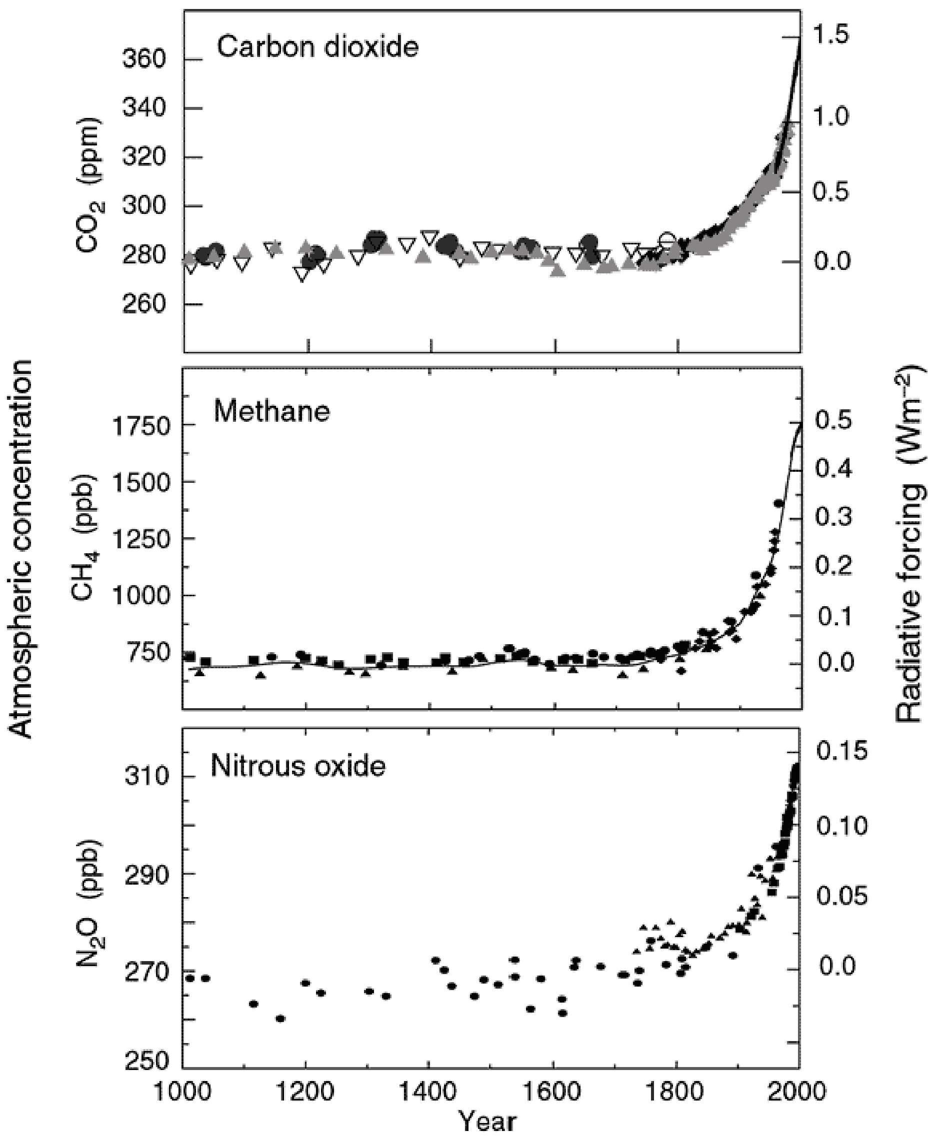
Carbon dioxide (CO2) is released when farm equipment moves across the farm's fields during tilling, planting, application of pesticides and fertilizers and harvest. The more these happen across the farm field, the more carbon gets emitted. Another source of carbon dioxide is the freight movement of foods and grains from the fields to the markets.

Methane

Methane (CH4) is emanated from the digestive tracks of ruminant animals (cattle, sheep, goats, buffalo, antelopes, deer, giraffes, etc.) in a process called enteric fermentation. Manure is another cause of methane. Composted manure and animals that are allowed to pasture, produce little methane. Deep bedding of animals also produces less methane. The largest source of animal-produced methane is in the liquid manure stored in lagoons, manure storage structures and holding pits used in swine concentrated animal feeding operations (CAFOs).

Nitrous Oxide

Nitrous Oxide (NO2) is discharged particularly from soils not covered with plants. The largest source of nitrous oxide is from synthetic fertilizer. Legumes are also responsible for nitrous oxide emissions. Likewise, livestock manure, particularly from confinement operations, is a source of nitrous



Graph 1. Atmospheric concentration of gases over a time period

2.3 Sustainable Agriculture

Sustainable agriculture is way of farming that aims at producing long-term crops and livestock while leaving least effects on the environment. This type of agriculture provides a good balance between the need for food production and the conservation of the ecological system within the environment. In addition to food production, there are various other goals linked with sustainable agriculture, including water conservation, reduced use of fertilizers and pesticides, and encouraging biodiversity in crops grown and the ecosystem. Sustainable agriculture also focuses on providing economic stability of farms and helping farmers improve their techniques and quality of life. Sustainability lies on the principle that the needs of the present should be met without compromising the ability of future generations to meet their own needs.

Smith, et al. (2007) and Bellarby, et al. (2008) have proposed mitigation options for GHG emissions, finding that both farmers and policymakers will face challenges from the GHG-related changes needed in agriculture (Niggli et Al 2009).

2.4 Carbon Recycling

The constant emission of anthropogenic, non-biogenic carbon dioxide in the air is accountable for the irregular climate-change and constant increase in the atmospheric temperature. In our opinion, such negative impact must be more correctly ascribed to the general scarce efficiency (Aresta and Dibenedetto, 2020) in the use of the fossil carbon chemical energy we do [only an average 32 percent of the fossil energy is transformed into usable energy (electrical-, mechanical, thermal-energy), remaining portion heats the atmosphere and our planet]. In fact, direct heating of the atmosphere is causing an increase of water transfer from soil to air (Dai, 2006) with water vapor having a stronger Green House Effect-GHE (at least twice) than carbon dioxide (Dessler et al., 2008). The constant increase in carbon dioxide atmospheric level since the inception of the industrial era, has been a serious concern about inefficient use of fossil carbon and of our lavishness in the use of any form of energy (electric, thermal, mechanical). Irrespective of the atmospheric content of carbon dioxide being the primary concern for climate change or has lesser adverse effect, whatever is actually responsible for the impact on climate, the reduction of use of fossil carbon is the need of the hour and an open opportunity.

A necessity for preserving natural resources that are limited (Table 1), an opportunity for making the best use (direct and indirect) of perennial (solar, wind, hydro, geothermal-SWHG) and renewable energy (biomass) in conjunction with carbon dioxide use and carbon recycling, are crucial steps toward a circular carbon economy.

Carbon recycling represents developing a man-made carbon cycle that can integrate the natural one and make available at a superior rate than natural processes, and with a higher selectivity towards a single product, goods that are in our common use and will continue to be used for next generations. The implementation of such capability will ensure longer usability of the limited natural resources (Table 1).

Region		Europe	Russia	N America	S America	China	India	Middle East	Africa	Australia	Total
Fossil-C reserves, Gt_{oe}	Coal	40	152	170	13	76	62	0	34	60	607
	Oil	2	19	8	15	2	1	101	17	2	167
	Gas	6	52	8	6	2	1	68	14	10	167
	Total	48	223	186	34	80	64	169	65	72	941

Table 1. Estimated worldwide fossil carbon availability (Gtoe, toe = tons oil equivalent)

2.5 Carbon Farming

Carbon farming (also known as carbon sequestration) is agriculture's solution to climate change. The objective is to take surplus carbon from the atmosphere, that causes global warming and store it in the soil, where carbon aids the growth of plants. Carbon farming practices refer to those agricultural activities that can sequester carbon and/or reduce GHG emissions (Tang, Kai, et al. 2016).

Land management is one of the biggest contributors to climate change. Agriculture has the capacity to transform from a carbon dioxide emitter to a carbon dioxide sequester. There is no other human managed process with this ability. Common agricultural practices, including driving a tractor, tilling the soil, over-grazing, using fossil fuel-based fertilizers, pesticides and herbicides result in substantial carbon dioxide release. Alternatively, carbon can be stored for a very long duration (for decades or centuries or more) beneficially in soils through a process called soil carbon sequestration. Carbon Farming involves implementing practices that are known to improve the rate at which carbon dioxide is eliminated from the atmosphere and converted to plant material and/or soil organic matter.

Carbon sequestration in the agriculture sector refers to the capacity of agriculture lands and forests to remove carbon dioxide from the atmosphere. Carbon dioxide is absorbed by trees, plants and crops through photosynthesis and stored as carbon in biomass in tree trunks, branches, foliage and roots and soils (EPA, 2008b). Forests and fixed grasslands are referred to as carbon sinks because they can store large amounts of carbon in their vegetation and root systems for long periods of time. Soils are the largest terrestrial sink for carbon on the planet. The ability of agriculture lands to store or sequester carbon depends on several factors, including climate, soil type, type of crop or vegetation cover and management practices.

The amount of carbon stored in soil organic matter depends on the addition of carbon from dead plant material and carbon losses from respiration, the decomposition process and both natural and human disturbance of the soil. By exercising farming practices that includes least disturbance of the soil and encourage carbon sequestration, farmers can slow or even reverse the loss of carbon from their fields. In the United States, forest and croplands currently sequester 12 percent of U.S. carbon dioxide emissions from the energy, transportation, and industrial sectors (EPA, 2008b).

Carbon sequestration and reductions in greenhouse gas emissions can occur through a variety of agriculture practices. Sustainable agriculture can be accomplished by encouraging carbon capture on working landscapes by implementing methods that are known to improve the rate at which carbon dioxide is eliminated from the atmosphere and stored in plant material and/or soil organic matter. Carbon Farming acts as a framework to engage the agroecosystem processes to enforce system change. Carbon farming clearly recognizes that it is solar energy that drives farm ecosystem dynamics, and that carbon is the carrier of that energy within the farm system. Carbon farming can be termed equal to ”regenerative agriculture” when it gets explicitly rooted in an understanding of the underlying system dynamics and positive feedback processes that make a “regenerative” upward spiral of soil fertility and farm productivity possible. Recognizing that carbon is the energy currency of living systems – as the medium through which solar energy enters and radiates throughout the food web and the farm system – carbon farming focuses on opportunities for increasing the capacity of the farm system to “receive, store and release” that energy; as work, as system processes, and as biological and structural diversity within the farm ecosystem, particularly recognizing the critical role of soil organic matter as both a sink for solar energy and as driver of both soil and overall agroecosystem dynamics. Carbon farming is effective when carbon gains, resulting from increased land management and/or conservation practices exceed carbon losses.

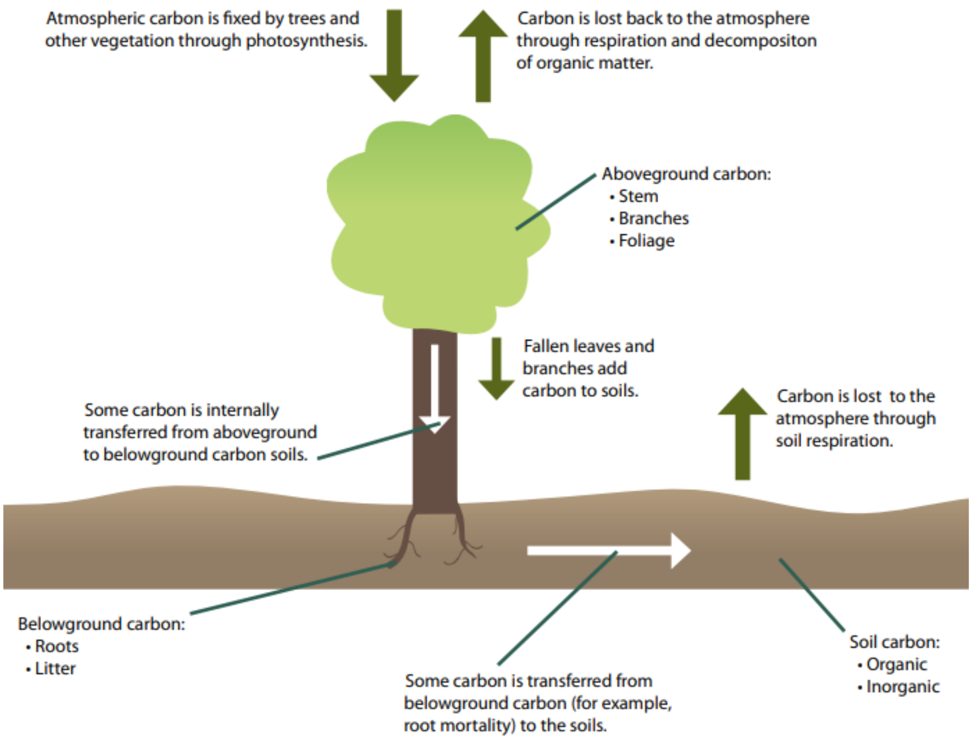


Figure 3. Carbon pools in forestry and agriculture. Source: EPA.

3 RESEARCH METHODOLOGY

3.1 Overview of Research Problem

Rising carbon dioxide concentrations are affecting the climate and use of fossil fuel is the main reason for excess carbon dioxide emissions. But standalone fossil fuels are not causing the issue; rather, it's how we utilize them. One of the foundations of climate science is the global carbon cycle, the largest part of which is the uptake of carbon dioxide through photosynthesis and the subsequent release, when the carbon in organic matter is consumed, or metabolized, to produce food for plants. Chemically speaking, carbon is the fuel of life. Over eons, a slow accumulation of unmetabolized carbon accrued and became the coal, oil, and natural gas resources that we consume today. Burning fossil fuels emits carbon dioxide into the atmosphere faster than photosynthesis and other practices that can cleanse it back. The damage is caused by the imbalance in the carbon cycle rather than the carbon itself.

All known life on earth is carbon based. Today, what we hear about carbon, is related to emissions, or idea of capturing and storing those emissions. Deep in the geologic past, atmospheric carbon dioxide was 10 times higher than today, wherein ancient ocean life began to use it. Today, the burning of fossil fuels is shifting ancient carbon stored in the earth back into the atmosphere. To balance this impact of carbon dioxide emissions, critical steps need to be taken up to drastically reduce its reliance on fossil carbon, upscale carbon farming to store more carbon in nature, and promote industrial solutions to sustainably and verifiably remove and recycle carbon. Removing and storing more carbon, from the atmosphere, oceans, and coastal wetlands, is essential to become climate neutral by 2050.

3.2 Research Purpose and Questions

Sustainable agriculture is a basic needed for sustainable development. Given the forecast in population increase, sustainable agriculture must accomplish goals like food security in combination with economic viability, social responsibility and have least effect on biodiversity and natural ecosystems as possible.

The concentration of carbon dioxide in the atmosphere has increased by 49 percent, from approximately 277 parts per million (ppm) in 1750 (Joos and Spahni, 2008), the beginning of the Industrial Era, to 418 ppm in January 2022. This is more than what had happened naturally over a 20,000-year period (from the Last Glacial Maximum to 1850, from 185 ppm to 280 ppm). Since the late 19th century, humans have mined fossil carbon to burn for energy. The release of carbon dioxide into the atmosphere causes an increase in carbon fluxes from the atmosphere to photosynthetic organisms and the oceans. Although this limits the overall increase of carbon dioxide in the atmosphere, the increase is enough to have contributed to recent significant increases in global temperature, which affects all life. In addition, dissolution of excess carbon dioxide acidifies the oceans, which can affect oceanic biosystems. Carbon dioxide is by far the main contributor to anthropogenic global warming (Myhre et al., 2013). Anthropogenic influences, for example from agricultural practices, habitat loss, and climate change mean that approximately 1 million species are now at risk of extinction globally. We therefore need to drastically limit carbon dioxide emissions to mitigate the impacts we are having on our planet via the carbon cycle.

On the other hand, world population has reached 7.7 billion and is expected to increase by 2 billion persons in the next 30 years; from 7.7 billion currently to 9.7 billion in 2050 and could peak at nearly 11 billion around 2100. This growth, along with rising incomes in developing countries (which cause dietary changes such as eating more protein and meat) are driving up global food demand. Food demand is expected to increase anywhere between 59 percent to 98 percent by 2050. Humans have cleared 19.4 million square miles for crops and livestock. This is almost the size of South America and Africa combined. As an example, in Indonesia an amount of virgin rain forest was cleared totaling the size of Ireland between 2000 and 2012 to make way for palm plantations.

All these deforestations have serious negative effect on carbon balance as it eliminates many species, impacts the diversity of plant life and animal life and removes natural carbon sink. All these deforestations are being done to achieve some human need. In other sense, human beings become directly responsible for the degradation of the carbon balance. For instance, the clearing of the rain forest in Ind0onesia for palm plantations was meant to grow palm trees to manufacture palm oil, which will be used to produce daily need products like cooking oils, detergents, soaps, cookies, ice cream, etc. Thereby human beings become direct beneficiaries of removed rain forest.

Sustainable agriculture is farming in sustainable ways meeting society's present food and textile needs, without compromising the ability for current or future generations to meet their needs. It can be based on an understanding of ecosystem services. “Sustainable agriculture” as legally defined in U.S. Code Title 7, Section 3103 means an integrated system of plant and animal production practices having a site-specific application that will over the long term:

• Satisfy human food and fiber needs.

• Enhance environmental quality and the natural resource base upon which the agricultural economy depends.

• Make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.

• Sustain the economic viability of farm operations.

• Enhance the quality of life for farmers and society as a whole.

The basic goals of sustainable agriculture are environmental health, economic profitability, and social and economic equity (sometimes referred to as the “three legs” of the sustainability stool (UC Sustainable Agriculture Research and Education Program. 2021. This will shape agricultural markets in ways we have not seen before, as modern agriculture simply cannot sustainably scale to meet the above demand.

The research is intended to derive means and provide more food for thought on various ways of carbon recycling technologies to help reduce the greenhouse gas emissions and support the intensification of crop and food production, thereby preserving the natural resources.

• How to produce food with limited space and minimal resources?

• Can we grow crop in a reduced time, then conventional time needed?

• Can we produce food without carbon emission?

• Why carbon recycling is important?

• Can we use carbon to produce food at a faster rate than carbon emission rate?

• Will the process remove more carbon from the atmosphere than they put back?

• What will those changes look like?

4 RESULTS

Modern agriculture is one of the largest emitters of greenhouse gases. It emits more greenhouse gases than our cars, trucks, planes, trains combined. To feed 9.7 billion population by 2050, agriculture needs huge size of land to produce food. But with ever increasing population, land available for agriculture will constantly decrease. Here farmers have a critical role in restoring ecosystems and ensuring climate resilience in agriculture. Carbon farming is setting the path for more climate-conscious practices in agriculture by becoming a green business model that rewards land managers for taking up improved land management practices, resulting in the increase of carbon sequestration in living biomass, dead organic matter, and soils - by enhancing carbon capture and reducing the release of greenhouse gases to the atmosphere, in respect of ecological principles favorable to biodiversity. Carbon recycling can save the environment, increase productivity, and render social benefits, such as diversification of rural and regional economies and incomes, introduction of new or restored habitats for native species and improved air and water quality.

Carbon farming involves implementing practices that are known to improve the rate at which carbon dioxide is removed from the atmosphere and converted to plant material and/or soil organic matter

(Creque & Estrada 2015). Recent studies demonstrate the efficiency of several carbon-beneficial, agricultural practices in increasing soil carbon sequestration such as:

• Afforestation and reforestation.

• Agroforestry.

• Protecting soils and enhancing soil organic carbon.

• Conversion of cropland to fallow/permanent grassland.

• Restoration of peatlands and wetland.

5 DISCUSSION

5.1 Discussion of Research Questions

Let's assume a group of astronauts are travelling to Mars or some remote planet. The travel time can take a year or even longer. The space onboard and available resources will be limited. So, the crew members have to figure out how to produce food with minimal inputs. Here, it will be great if a few packets of seeds can be grown into crops in a matter of hours. And what if those crops would then make more seeds enabling you to feed the entire crew with just those few packets of seeds for the entire duration of the trip. This research was conducted in NASA way back in 1960's-1970's. They came with a concept of microorganisms, which are single celled organisms. They use hydrogen from water. The types of microbes that they used are called hydrogenotrophs. With these hydrogenotrophs you can create a closed loop carbon cycle that can nurture life through sustainable agriculture process onboard a spacecraft or a closed ecosystem. Astronauts will exhale carbon dioxide. This carbon dioxide will be captured by the microbes and get transformed into a nutritious carbon-rich crop. The astronauts will then eat that carbon-rich crop and exhale the carbon out in the form of carbon dioxide, which will then be captured by the microbes to create a nutritious carbon-rich crop, which then will be exhaled out in the form of carbon dioxide by the astronauts. So, in this way, a closed loop carbon cycle is created.

The significance of carbon cycle lies is that carbon is essential for human survival, and we get our carbon from food. On a long space journey, the astronauts would not be able to pick up any carbon along the way. So, we need to figure out how to recycle carbon onboard in a closed environment. Our earth is like the spacecraft in the universe and we humans on this earth are the astronauts. Earth has limited space, limited resources and on earth its high time we find out how to recycle our carbon better for a better tomorrow. Hence the same concept of carbon recycling can be applied on the earth to address issues like climate change, improve carbon balance, faster food production and to have a sustainable agriculture.

To bring about a revolution in the goal to meet the rising food demand and hence the necessity to grow more crops, microbes can play a very crucial role. These unicellular organisms act as supercharged carbon recyclers. These supercharged carbon recyclers are present in few specific ecosystems on this earth like hydrothermal vents and hot springs. In these environments they capture carbon and recycle it into the nutrients needed for those ecosystems. The nutrient composition comprises of oils, proteins, minerals, and carbohydrates. Microbes are already an integral part of our daily life. Microbes are already being utilized to produce food items like bread, cheese, yogurt, beer, pinot noir, etc. But the ultimate beauty and power of these supercharged carbon recyclers, the microbes, lie in the below aspects:

- They can produce food in few hours as compared to conventional requirement of months to grow crops.
- They can grow in the dark, which makes things very convenient to grow in any season and in any geography.

- They can grow in containers that requires minimal space. This promotes vertical farming, instead of conventional horizontal agriculture. This drastically can save land space and give more product yield per land area.

There are other microbes called “acetogens” which can use carbon dioxide as their input to make several chemicals including ethanol. Acetogens are believed to be one of the first life-forms on Earth. The ancient Earth’s atmosphere was very different to the atmosphere today; there was no oxygen, yet plentiful carbon dioxide. Acetogens were able to recycle this carbon using chemical energy sources, such as hydrogen, through a process called gas fermentation. Today, acetogens are found in many anaerobic environments, such as in animals’ guts. Not being able to use oxygen makes acetogens less efficient at building biomass; they are slow growers. But interestingly, it makes them more efficient producers. For example, a typical food crop’s energy efficiency (where sunlight is converted into a product) may be around 1 percent. On the other hand, if solar energy was used to provide renewable hydrogen for use in gas fermentation (via acetogens), the overall energy efficiency in this process will be 10-15 percent. This implies acetogens are potentially up to twice as efficient as compared to other current industrial processes, which makes them a cheaper and more environment friendly option.

Few countries like, Australia, has a competitive advantage and could be a leader in this technology. As host to the world’s largest green-hydrogen projects, it has the capacity to produce low-cost renewable hydrogen. Underused renewable waste streams could also enable carbon recycling with acetogens. For instance, large amounts of biogas are produced at wastewater treatment plants and landfills. Currently it’s either burned as waste, or to generate heat and power. Past research shows us biogas can be converted (or “reformed”) into renewable hydrogen and carbon in a carbon-neutral process. And we found this carbon and hydrogen could then be used in gas fermentation to make carbon-neutral products. This would provide as much as 12 times more value than just burning biogas to generate heat and power. The IPCC report shows carbon dioxide removal is required to limit global warming to less than 2°C. Carbon capture and storage is on most governments’ agendas.

Sustainable agriculture through carbon recycling can become a new source of income for the agriculture sector players, such as land managers, food product buyers and supply chain companies that could, in many cases, benefit from advantages related to carbon reuse.

5.2 Improving Carbon Balance

The microbes or the hydrogenotrophs which are nature’s supercharged carbon recyclers are a formidable set of microbes capable of producing very valuable products. These microbes can assist to make essential amino acids from carbon dioxide, to make protein rich meal that has amino acid profile like what is found in some animal proteins. These microbes can also be used to produce cooking oils for commercial purposes. Utilizing microbes on large scale can really help in addressing multiple issues with agriculture and allow us to create a type of agriculture which is sustainable, and which can allow us to scale up to meet the demands of tomorrow.

If we can implement this kind of approach of using these carbon recyclers, then we would never have to remove any rain forest to make the food and the goods we consume, because on a large scale we can make 10,000 times more output per land area. This is what can be a new type of agriculture than can allow us to sustainably scale to meet the demands of 10 billion.

6 SUMMARY, IMPLICATIONS AND RECOMMENDATIONS

6.1 Summary

Ever increasing rise of population and constant urbanization are eating away the agriculture fields. Agricultural lands are getting converted to residential and commercial lands. Ideally the rise of population and food production should be directly proportional. But if both needs to grow simultaneously, carbon balance is getting seriously affected, which will at the end shorten the life span of this earth and human life. We run the risk of robbing a beautiful planet from our next generations.

But by using microbe as the supercharged carbon recyclers, we can optimize the carbon recycling to promote sustainable agriculture to make a future of abundance. If we change our mindset from viewing carbon as a waste product, then we can change our economic incentive from carbon disposal to carbon reuse. Carbon dioxide stored underground has no value. If we harness its full potential by using it to manufacture products, this could support numerous industries as they move to sustainable production.

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