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SOIL ORGANIC CARBON MODELLING: A REVIEW

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Abstract

Organic carbon is one of the major components in the soil matrix. Due to ceaseless reactions (physical and chemical and biological), which define the soil's efficiency and characteristics. The use of conventional nonrenewable energy sources produces greenhouse gas resulting in global warming. Global warming is a major concern for many scientists as this is heading toward climate change resulting in dynamic changes in soil organic carbon stock. To control the alarming increase of greenhouse gas in our atmosphere we need to understand the dynamics and modeling of soil organic carbon. In present days continuous, monotonous conventional cropping method is the reason for the loss of soil organic carbon from the soil, a prominent reason for soil degradation and desertification. Proper knowledge of soil organic carbon dynamics helps us to manage our agronomical field and go towards sustainable agriculture.

Keywords: Carbon Pool, Caron Flux, Soil Organic Carbon, Global Warming and Climate Change, Soil Organic Carbon Model.

Introduction

Carbon is the basic and structural molecule of any living organism. The structural and functional unit of any organism is the cell, the main constituents of which are complex organic compounds composed of carbon. Cellulose and hemicellulose are for the higher plants while simple carbohydrates, protein, and lipid are dominated animal structure (Tan,2010). It is through carbon compounds that green plants store solar energy as static energy, this static energy flows through the food chain and provides life energy up to the highest level. We get our life force from the energy created by the oxidation of carbon-forming compounds inside the cell. So, carbon is equally necessary for everyone from microscopic microorganisms to large blue whales. These types of carbon are called organic carbon because they are derived from complex compounds produced by biological reactions (Tan,2010). Carbon is the fourth most abundant mineral in our environment (Brucato, *et al.,*2002), but carbon is not stored in a single form all around nature. Carbon is stored in different forms in different places in different physical structures. In our environment, there are 5 carbon pools or Stores present, oceanic pools, geologic pedological atmospheric, and biotic (Senapati, *et al*., 2014). Those carbon pools are interconnected with a continuous flow of carbon flux, which is the reason those carbon pools work as a source and receiver of carbon. In this universe the total amount of carbon is constant we can't increase or decrease the total value of carbon, the change is happening between one-carbon pool to another carbon pool. Each pool has its specific way to store carbon, in atmospheric cool carbon is stored in a gaseous form while the earth's crust stores carbon in a solid form.

Soil organic carbon is a complex and diversified mixture of different rates of decomposing plant and microorganism material. Its dynamics are a very important process of soil productivity and a sustainable environment. In soil, the carbon inputs come from the new plant material and animal material, and constant losses through Carbon mineralization or washing out leaching. In Most of the soil around1500 Pg of organic carbon is stored on the top surface layer of the soil (Batjes, 1996 & Smith, 2004). Soil organic carbon pool is smaller in front of earth crust reserve and ocean reserve, but this pool is affecting a lot of our sustainable development (Batjes,1996).

After the industrial revolution, because of the continuous use of fossil fuel as a source of energy the concentration of carbon is more than 400 ppm. Carbon is the most abundant and effective greenhouse gas which causes atmospheric temperature increases called global warming. Because of the global warming world, the climate is continuously changing. Global climate change is the main factor in dynamic changes in organic carbon stock. According to United Nations, up to 40% of world land is now completely degraded (Harvey, 27 April 2022). The basic reason for soil degradation is the lack of organic compounds in soil. If we are to feed the whole world, we must preserve the fertility, and health of the land.

Decomposition processes are continuously happening in soil and play an important role in soil organic carbon dynamics. The major factors controlling the size of soil organic carbon pool are management practicing, tillage operation, climate, and Soil (Wattenbach*, et al*.,2005). According to Ghosh, *et al.,* 2012, Agriculture land carbon pools are heavily affected by tillage and management. So, if we want to understand the soil organic carbon dynamics over continuous climate change we need an environmental model, called the soil organic carbon model. Those carbon turnover model helps to understand soil organic carbon reserve, its critical importance, and how soil organic carbon transportation is affected by different factors. For Such understanding, the concept of Soil organic carbon models represents different dynamics of soil organic carbon in different land use, management practices, and technology use climatic conditions for present-day and upcoming future scenarios (Smith, et al 2005).

Carbon Pool

A carbon pool is a reservoir of carbon. It is an environmental system that can accumulate or release carbon (IPCC[1] 2000). In general, there are the four-carbon pools that are the most effective and important in our environmental functioning. Each carbon Pool Stores organic carbon in any specific form like atmospheric carbon is stored in a gaseous form (carbon dioxide, methane), or Carbon stored in the Earth's crust as a solid form. The total amount of carbon on Earth is constant, there is an inter-changing between in carbon pool. This equilibrium maintains by Physical, chemical, and biological processes. The carbon stock or Pool is expressed by Gigatons

[1] *IPCC: Intergovernmental Panel on Climate Change,*

(Gt) or Petagrams of carbon (PgC). PgC and gigatons are equal, both units are equal to 10^{15} grams of carbon. The major four Carbon pools: -

Earth crust: The carbon storage in sedimentary rocks, and different forms of geological storage, for example, fossil fuel and carbonate rocks. The total amount of carbon stored in sedimentary rock is 100,000,000 PgC (The University of New Hampshire, 2008), and another 4 000 PgC each stored as a hydrocarbon form.

Ocean: Our Ocean contains 38000PgC and most of the carbon is dissolved in the ocean's water in inorganic form. Approximately 1000 PgC is available on the ocean surface and the rest of the carbon is stored in the deep sea (Melieres and Marechal, 2015).

Atmosphere: Earth's atmospheric reserve is the most important and broad category. Before the industrial revolution, its content was around 590 GtC (Donev *et al*. 2020), now it contains around 830GtC (Melieres and Marechal 2015). The increment of Carbon in this pool is because of Human activity Reason for Global warming.

Organic carbon: These carbon pools are the most important in our life for soil health, and soil productivity. This pool is containing microorganisms and macro-organisms and nonliving organic reschedule.

Carbon Flux

The transfer of carbon from one carbon pool to another carbon pool is called carbon flux (IPCC, 2001). Each carbon pool is interconnected with a pathway in this pathway carbon is added from one pool to another pool by changing its physical (solid, gas, liquid) and chemical structure. This continuous flow of carbon or Carbon flux is a physical-chemical and biological process (NASA. 2022).

When we observe all the carbon fluxes it looks like a cycle, and it's called the carbon cycle. Soil organic carbon is also a part the of carbon pool, so it is also interlinked with carbon flux. Initial phase the atmospheric inorganic carbon molecules are absorbed by the plant, by this process inorganic carbon is converted into organic form and stored for some time as vegetation. The plant residue from the living plant and dead plant material is added to the soil, and microorganisms decompose those complex carbon materials into gaseous form and bring back them into the atmosphere (Tan, 2010). Soil respiration is a process where carbon dioxide is released from soil to the atmosphere by route or microorganisms (Högberg et al 2005). On a longer time, scale, the organic matter becomes stored in sedimentary rocks, and with time being it's slowly transformed into coal oil and natural gas which we use as conventional fossil fuels now a day. Fossil fuels are used as a conventional energy source, and here carbon flows from the earth's Crust pool to the Atmospheric pool. with the use of conventional fossil fuels and deforestation, the concentration of atmospheric carbon is increasing day by day. According to IPCC, 2001 CO_2 concentration in the atmosphere has increased by 31% since the beginning of the industrial era, from 280 ppm to 360 ppm (Forests and Climate Change, Fao.org). There are mostly 7 pathways or flux of carbon exchange from one reserve to another reserve.

Photosynthesis: during photosynthesis, plants use energy from sunlight to combine CO_2 from the atmosphere and take water from the soil to create carbohydrates. In such a way, carbon dioxide is removed from the atmosphere and stored as a structure of plant material. After the plant Death, the beast stores Carbon going into the soil as soil organic carbon. Current estimates suggest that photosynthesis removes 120 PgC/year.

Plant respiration: Plan also releases CO_2 back to the atmosphere through the process of respiration. During the generation of energy in plant cells carbon dioxide is produced. It is estimated that approximately half of CO_2 that returns to the atmosphere in the plant respiration, 60 PgC/ Year

Litterfall: living plants also added soil organic components to the soil every year in the form of leaves, roots, and branches. Another side dead plant component is also considered litter, all those components are made of carbon, and which are adding carbon to the soil.

Soil respiration: carbon dioxide is released through soil respiration when organic matter is broken down or decomposed by microorganisms CO_2 and other greenhouse gases are released into the atmosphere. Estimated that the average rate of releasing carbon is nearly 60PgC/ year.

Ocean atmosphere exchange: The ocean is a sink for approximately 25% of atmospheric CO2 emitted by human activity. It is estimated that approximately 2Pg of carbon per year sinks into the atmosphere into Ocean (Watson *et al,*2020).

Fossil fuel: Fossil fuel carbon flux is a man-made activity. The living organisms which are stored in the earth's crust are converted into fossil fuels like coal and mineral oil. Present-day fossil fuels are the most conventional source of energy and a concerning issue for global warming. Burning of fossil fuel, the carbon which is stored in Earth's crust for millions of years released into the atmosphere and increases the carbon concentration in the atmosphere.

Soil organic carbon and Estimation of Soil Organic

Soil contains carbon in both organic and inorganic forms. The term soil organic matter is used to describe the concentration of organic matter in soil with soil organic carbon each describes the carbon concentration in soil organic matter. Soil organic carbon and organic matter those two terms are used in a complimentary way because in soil organic matter the major percentage (57%) is soil organic carbon. Besides carbon, there are other

important contents that are present in soil organic matter like Oxygen, Nitrogen, and almost a similar amount of Potassium, Phosphorus, Magnesium, and Sulphur. Soil organic matter is a chemically and physically heterogeneous mixture. Different decomposition stages are present in soil organic Matter (Waksman,1938).

The soil organic carbon model divided soil organic matter into multiple conceptual pools. Those pools are based on their component, size, and turnover time. soil organic matter consists of a lot of complex substances (different organic molecules like polysaccharides, proteins, lipids, lignin, *etc.*). All those organic molecules are derived from flora, fauna, and microbial biomass (Totsche *et al.*2010). Because of such a variety of input, there are different microbial activities, and they are a variation of the carbon pools (Krull, 2003). In this Literature, we are focused on and discussing SOM Conceptual Pool.

Soil organic carbon plays a very important role in the growth of the plant by providing the essential nutrient and improving the soil's physical structure (Skjemstad *et al* 2013). Soil organic carbon function is classified into three major groups,

Biological: organic matter is a source of energy for many soil biota (GRDC[2], 2013). Initial large soil organic method particles are breakdown by the soil Fauna, which is easier to access for microorganisms. Soil microorganisms release carbon and other nutrients from soil organic matter during the time of decomposition. It is estimated that 95% of soil nitrogen and 2% of available Phosphorus and sulfur is coming from soil organic matter.

Chemical: soil organic carbon the chemical functions are mostly based on humans, which is finely divided stable organic matter. Humus has a large, exposed surface area that quick heal more contributing to the cation exchange site. About 32- 70% of cation exchange occurs through humus. Humus is a chelates agent of soil that help mobilize and update micronutrient. The exchange side of humus also helps in cleaning contamination of water and soil like heavy metals. Soil organic carbon meter is also working as a buffer substance against acidity and salinity at any kind of chemical change.

Physical: plan route microorganism creating polysaccharide, fungal hyphae, etc. reason behind improving the soil aggregates which help good aeration, rate of water infiltration and water holding capacity (Lal *et al*,2009). While mature organic carbon is the reason for the low percentage of Bulk density, in soil which help a proper root system improvement and low horsepower in the time of tillage (Meki *et al* 2014). Freshly adds organic matter or partially decompose organic method which present on the surface of soil each creates the focus of soil which reduced the run of rate and prevent the nutrient losses through runoff. In cold climatic conditions, the blanket layer of organic matter preserves soil heat.

Various studies on the measurement of organic carbon have been going on for a long time, as a result, now we have many types of techniques by which we can analyze organic carbon. And all those techniques are classified into two classes, ex-situ and in situ methods (Chatterjee *et al.,*2009). Ex-situ methods are mostly used as observing C sequestration programs using territorial systems (Mollitor et al 1980). Generally, carbon sequestration programs cause effective measurement. This method potentially monitors soil organic carbon stock. We need minimum replication. That's the reason for lower the cost involved with the sample processing measurement in the laboratory (Chatterjee et al., 2009). In-situ methods are developed on infrared spectroscopy. There are two kinds of infrared spectroscopy. Those methods are considered cost-effective. (Janik *et al.*2007). Soil organic carbon monitoring is a long-term process. While the method for analyzing the soil organic carbon concentration of a given soil sample are well established and easily carried out with high accuracy. Variability in soil carbon estimate can be due to several factors or conditions like uncertainty in bulk density measurement as impacted by above and below-ground biomass input (Miki *et al* 2014), Rock and stone composition, compaction of soil, sedimentary loss, deposition through soil and water activity. Those factors usually impact the

[2] *GRDC: Grains Research and Development Corporation*

estimation of soil organic carbon, for avoiding those errors and complexation we need to take a huge number of soil samples. It is estimated that 20 to 30 samples will be needed for the estimate of mean soil organic carbon of 95% accuracy (Mollitor *et al* 1980) or estimated that more than 100 samples are needed to detect a 2 - 3% change in soil carbon under switchgrass (Garten *et al* 2000). The small amount number of changes in soil organic carbon is impossible to detect by a conventional method. To determine a noticeable soil organic carbon change needs a long-term monitoring period of at least 20 years (Rasmussen *et al* 1998).

Table 1. Forms of soil organic matter or SOM Conceptual Pool (Victorian Govt report., 2010)

Form	Composition	Pool category
Surface plant residue	Fresh material on the surface of the soil. Leaf, crop, and pastor material	This is the fastest pool; decomposition occurs in a turnover time of about days to a year
	The plant material is greater than 2 mm in size.	This is the first pool labeled in which decomposing occurs over a time of decay into a year
Particulate organic matter (POC)	In this category, the materials are smaller than two mm and greater than 50 micrometers in size and they partially decompose	Fast food or level pool decomposition occurred for days to years
Humus	In this category, those materials come in sizes smaller than 50 micrometers. material is completely associated with the soil particles.	This is a slow pool or stable pool. It needs time to decompose for about a year to decades.
Resistance organic carbon (ROC)	This category includes elements that have been created as a result of burning organic carbon like charcoal.	It's a passive or recalcitrant pool decomposition that occurs at the time needed decades to thousand years.

Table 2. Techniques to determine the Soil organic Carbon (Chatterjee et al., 2009)

EX-situ	**IN – situ**
• Wet combustion This method is well known as the Walkley-Black method. • Dry combustion	• NIR And MIR-Method. • Inelastic Neutron Scattering Remote sensing.

The several reviews of different approaches to measurement and monitoring soil organic carbon stock show that the main challenge is designing an effective and cost-efficient sampling for the Soil organic carbon stock estimation system. conventional methods or *Ex-situ* methods are quite time effective and costly because they need a lot of sampling. If we want to apply such a method to the National level or regional level, we need a higher density sampling (Makipaa *et al* 2008) For that reason some scientists are finding different and alternative techniques for the measurement of soil organic carbon such as an infrared probe or Gamma-ray spectroscopy (Wielopolski *et al* 2008) Those methods allowed field-wide measurement of soil organic carbon stock, even though those instruments need extensive site-specific calibration.
To observe and share soil organic carbon data several soil monitoring networks (SMN) are present that target soil carbon and other related data. This network is interlinked with several countries throughout the world.
ENVASSO: It is a European ENVASSO (Environmental Assessment of Soil for monitoring), project. Which was founded as Scientific support to policy (SSP) under the European Commission6thFramework program. This project Has the main objective to define and document the soil Monitoring system for implementation in support of the soil framework for projecting soil in the EU (European Communities, 1995-2015). This Project has partners from 25 countries and a total of 3334 soil carbon monitoring sites (Kibblewhite *et al* 2013).
GEMCo: In Canada, this organization (Greenhouse Gas Emissions Management Consortium) working on recognizing the potential of soil carbon sequestration and eat also working on Carbon mirroring and verification protocol for carbon trading (Ellert et al 2000 & Izaurralde et al 1998)
STATSGO & SSURGO: State Soil Geographic (NRCS, 1994) & the Soil Survey Geographic (NRCS[3], 1995) both have a whole US Soil organic carbon stock database. STATSGO is a digital general soil map of the United State, which is a broad base in the history of soil and non-soil areas. SSURGO is content information about soil which is collected by the national co-operative soil survey all over the United State.
At the global level soil carbon stock has been made; the World bank global environmental funds sustainable development project is supporting similar soil monitoring initiatives in developing

[3] *NRCS: Natural Resources Conservation Service*

countries (Kern JS *et al* 1998.GSOC map is the first Global soil organic carbon map ever produced through a consultative and parties process involving member countries, under the guidance of the inter-governmental technical panel of soil and global soil partnership Secretariat. (FAO.org)

Soil organic carbon and global warming

Climate change and global warming are often used interchangeably, there is a subtle difference between these two terms. This difference is a lot like the weather and climate. We call the condition of the atmosphere of a particular day like weather, and the aggregate form of this weather we call climate. So, climate change is the primary component of climate change.

Global warming is the long-term heating of art climate system which is observe since the pre-industrial[4] period due to human activity, mostly fossil fuel burning (Climate Change: Vital Signs of the Planet, 2022) which increases heat-trapping greenhouse gas levels in the earth's atmosphere. The term is frequently used interchangeably with the term climate change through the letters refer to both human and natural produce warming, and the effects eat has on our planet it is commonly measured as the average increase at global surface temperature.

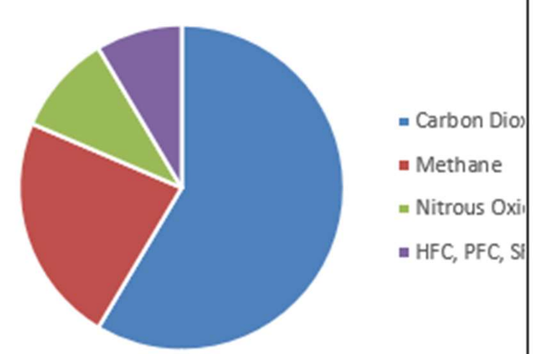

Fig2.Global Manmade Greenhouse Gas Emissions by Gas, 2015 (NONA 2017)

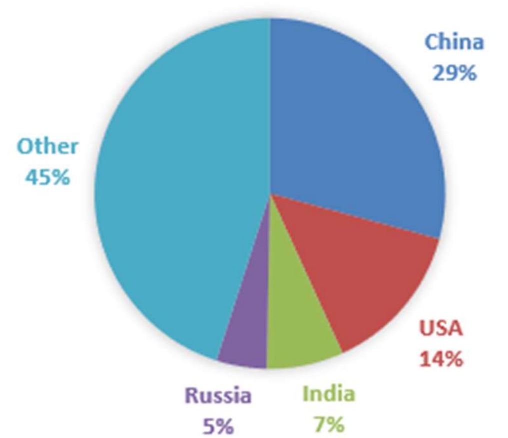

FIG 3 GREEN HOUSE GAS EMISSIONS BY COUNTRY

Since the pre-industrial period, because of human activity, it is estimated that the Earth's global average temperature is increased by 1 degree Celsius (1.8 degrees Fahrenheit) and it is estimated that every decade it increases by 0.2 degrees Celsius (Climate Change: Vital Signs of the Planet. 2022)

[4] *Pre-industrial: between 1850 and 1900*

When we are talking about greenhouse gas, the first gas that comes on the list is carbon dioxide. 75% of total greenhouse gases are carbon dioxide (Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2015, EPA, 2017). This percentage of carbon dioxide in the atmosphere really matters because carbon dioxide is important for arts long leave greenhouse gas. It absorbs less heat per molecule than the greenhouse gas methane or nitrous oxide but it's more abundant and stays in the atmosphere much longer. Increasing in atmospheric carbon dioxide is responsible for two-thirds of the total energy imbalance that is causing the earth's temperature to rise (Lindsey, Climate Change: Vital Signs of the Planet 2020) other hand carbon dioxide dissolves into the ocean and reacts with water molecules and producing carbonic acid and creating lower ocean water pH. Since the start of the industrial revolution, the pH of ocean surface water is decreasing from 8.21 to 8.10. This acidification of the ocean damages the Marine ecosystem and mostly reacts with calcium from shells and Skeleton. Based on the bubble trapped In Miles of thick ice, we know that during the ice age the cycle of past millions of yards of carbon dioxide never crossed the 300-ppm limit in the atmosphere but after the industrial revolution start meeting the 1700s Global average amount of carbon dioxide was increasing continuously. In 2015 the Global amount of carbon dioxide in the atmosphere increased by 400 ppm for the first time. It is estimated that if Global energy demand continuously grows and is met mostly with fossil fuels the average atmospheric carbon dioxide is projected to be more than 900 ppm by the end of the century (Climate Change: Vital Signs of the Planet, 2022)

Earth's warming and climate are slowly changing because of the continuous increase in carbon dioxide in the atmosphere. We are previously discussing soil organic carbon and its importance in soil health, If the carbon dioxide in the environment has to be stored for a long time, the simplest and most reliable way is to convert the carbon into organic form and keep it transmitted to the soil. global warming and climate change have created an imbalance in the Earth's organic carbon stock. Climate change has profoundly affected the seasons and rainfall, which has led to the arrival of vegetation in areas that were not previously vegetated. Due to the continuous rise in temperature, the decomposition of organic carbon has increased for that reason soil organic carbon stocks are declining rapidly, and this carbon is released into the environment as a gaseous form causing a greenhouse effect. It is estimated that they are 2000 Giga tone Carbon is trapped in organic form (Landmark et al, 2015) and because of climate change some places are warm and you made which provoking the microbial activity and rapid decomposition of soil organic matter. The microbial population converts soil organic carbon into the gaseous form of carbon like methane carbon dioxide which increases the concentration of carbon in the atmosphere and decreases soil health.

If we want to protect our soil health and restrict the transmission of soil organic carbon to atmospheric carbon, we need to understand the dynamic and environmental correlation with organic carbon decomposition. To understand the management practices, land-use practices, and environmental factors and how they affect soil organic carbon in the present day and in the upcoming future we use the environmental model or soil, organic carbon model.

Those models are helping us to make the decision for our future activities and planning by understanding soil organic carbon dynamics. We can't see our future scenario of soil organic carbon stock for a specific reason but with the help of the soil organic carbon model, we can estimate a scenario for the next 50 or 100 years.

Soil Organic Carbon Modeling

A model is a specific representation of a real scenario (Smith et al, 2007). Soil organic carbon models represent the turnover or decompositions of organic matter and their transformation in between soil- plant -atmosphere Systems (Jenny,.1941). One of the Initial soil organic carbon models to describe Carbon accumulation or losses was (Sanapati et al 2014)

$$\frac{dx}{dt} = -Kt + A$$

Where,
dx = change in soil carbon.
K = first-order kinetics reaction constant
A = addition rate

There are mainly Three types of Soil organic carbon model

1. Process-Oriented Model
2. Organism-oriented/food-web model.
3. Cohort Model

a) **Process-Oriented Model:** Process-oriented soil organic carbon model mostly dominated to simulate a change in soil organic matter because of management practices. The process-oriented model represents soil organic matter dynamics based on different conceptual carbon pool which is altered in size, decomposition rate, and stabilization mechanism. Process-oriented soil organic carbon model is divided into three groups.

1. **Single compartmental model:** in a single compartmental model, we consider Soil organic carbon as a homogeneous pool. (Jenny, 1941). In this model, changes are calculated using relative comparison or slim ply by calculating the net balance between input and output with a linear humidification coefficient and mineralization rates on annual basis. Intergovernmental panel on climate change IPCC 2004 is one of example this kind of model. IPCC estimated changes in carbon stock in soil based on soil geographic database and land use and management gave countries over the world. This model includes three tiers of methodologies, tier 1 calculates soil organic carbon response to a management change using default parameter and reference carbon stock. In Tier 2 replace the default country-specific estimate. Tier 2 approach to the analysis of soil il organic carbon stock changes for Major soil and crop management practices across Canada (VandenBygaart *et al,*.2003). The tier 3 approach of IPCC utilizes an estimate of soil organic carbon change derived from the multi-compartmental model. (Bolinder *et al.,* 2005)

2. **Two-compartmental model**: in this model, we consider organic carbon as two different Pools or compartments (Jenkinson,1977). To or multi compartmental soil organic carbon model or

nonlinear and more dynamic base upon fast order kinetics. Those approaches parameterize using isotopic measurement to provide decay rate for the individual soil organic carbon pool (Bolinder et al., 2005). Two compartmental models mostly estimate crop residue carbon input with a sub-model using simple physiological relationships and parameters. In the sub-model above grounded crop residue for serials are calculated from harvested index data (Bolinder 2004; Izaurralde *et al.* 2001) and related regression relationships (Campbell *et al.* 2000). The below ground crop residue carbon inputs are calculated using locally selected estimates of shoots (straw or grain) to root ratio at the approximate time of peak above-ground biomass (almost harvesting time). (Izaurralde *et al.* 2001)

3. **Multi compartmental model:** In the multi-compartmental model soil, organic Carbon considers part of a multiple carbon pool. For the first two types of soil organic carbon model is mostly static which means environmental variation remains constant. Another hand the third type of soil organic carbon model environmental variation change with time. Long-term field data or control studies (eg: incubation), as well as climatic variables, are added to this model. Most of the soil organic carbon models are processed-oriented multi-compartmental models. In the multi-compartmental SOM model soil organic carbon describes as a finite number of soil organic carbon pools, each pool is homogeneous and properly characterized by its position in the model structure and its decade rate (Falloon & Smith,.2000). Multi-compartmental soil organic carbon model estimated of crop ratio carbon input is obtained from dynamic process base crop production sub-model that will be calibrated with a number of crops specific parameters for the different environment (Metherell et al. 1993). That sub-model is not always easy to calibrate particularly for rotation involving two or more crops (Green Plan 1993)

In two compartmental and multi-compartmental model carbon input is quantity manner and the sub-model estimate crop residue carbon input needs to be calibrated to reflect a different kind of crop growth with given soil and climatic region. Physical disturbance such as tillage and other agronomical factor affect soil organic carbon dynamics (Paustian *et al*. 1997) and most models generally deal with this factor. Two multi-compartment models usually include parameters that follow the first-order decay rate when soil is tilled. ICBM (two- compartmental model) and CENTURY (multi-compartmental model) have a cultivation factor that affects the decomposition rate of each soil organic carbon pool (Andrén *et al.* 2004). This factor can be modified and calibrated for specific environmental conditions. Physical disturbance like soil erosion is also considered some of the soil organic carbon models.
Each compartment or soil organic matter conceptual pool within a model is characterized by its position in the model structure and its decay rate. The decay rate is expressed by the first order of kinetic reaction[5] with the concentration of Carbon in the carbon pool.

[5] *A chemical reaction in which the reaction rate is linearly dependent on the concentration of only one reactant. In this kind of reaction, the changes in reaction rate are only variable with*

$$\frac{dy}{dx} = -KC$$

Where t is time, and K is the constant of first-order Kinetic reaction.

The carbon pool's half-life[6] (h= (ln 2)/k) or turnover time (1/k) is sometimes used in place of K to explain the dynamics of the pool. With a lower decay rate constant (K), the stability of the organic pool is higher with a higher half-life and turnover time. In a process-oriented model different conceptual carbon pool is taken with similar chemical and physical characteristics which are differentiated by decomposition rate. Soil biodata is only used as microbial biomass (SOMM) they don't count as an active part. There are different soil organic carbon pools present for degradation as biota (multi-compartmental model

In this model, we are taking the top 30 cm of soil and the scalability of this model is the small plot to the regional level. We can easily apply a wide range of ecosystems like grassland, arable land, grass arable relationship, and forest area.

GIS tool can be added with is model as example CANDY (Carbon and Nitrogen Dynamics), CENTURY (Parton,1996), and Roth C (Coleman and Jenkinson, 1996) are widely used in soil organic carbon modeling. We are discussing Different soil organic carbon models comparatively in *Table Number 4*.

b) **Organism-oriented/food-web model**.

Organism oriented model focuses on the flow of carbon and nitrogen through the food web of the soil organism. In this model soil organic carbon dynamics represent through the different pools of soil biota. This model is working on the mechanism of microbial-specific death rate and consumption rate, applying energy conversion efficiency and the carbon-nitrogen ratio of the organisms (Smith *et al* 1998). Organism-oriented models are taken for small plots. This model is mostly applied to edible land and grassland. Because of changes in the soil biota community in the modeling of SOM dynamics that's why we don't use GIS software in this model.

Cohort Model

This type of model is for additional fresh organic addition. In this model, each fresh addition of organic matter is considered a separate group. The word cohort means group, in this model it is a separate group of phrase organic addition which is decay continually.

This model is dynamic, and the Decay process is continuous.

In this model, there is no concept of a conceptual organic carbon pool. We consider whole organic carbon as a single pool.

- ✓ This model divided soil organic carbon into an infinity number of components.
- ✓ This kind of model is quality dependent and hole model mechanisms represent by a single rate equation.

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only one reagent concentration. In the SOM model scenario, the concentration of soil organic carbon is the Determining factor. (Chemical Kinetics by Keith J. Laidler)

[6] Half-time is the time taken for the initial concentration of the reactant (SOM) to reach half of its original value. (Chemical Kinetics by Keith J. Laidler)

- ✓ That single rate equation represents the whole dynamics of soil organic carbon components. (Bosatta, *et al* 1994)

MILLENNIA, in this soil carbon model We are Considering the Store carbon of peatland. Globally. That peatland has Significant. Roll. In the carbon cycle. Normal Globally, soil organic carbon models do not accurately represent. Peat land carbon stock and dynamics Current Model. Are mostly focusing on. Decomposition of carbon pool. Which is Lacking Representation of the long-term soil organic carbon accumulation. Where, Carbon models are commonly powered up to equilibrium over several years using an average climate, In nature, Soil actually evolves many thousands of years with associated changes in little amount and quality with the effect of soil organic carbon accumulation, And hence pit formation (Heinemeyer *et al*.,2011). Peat soil has a different hydrological cycle. And. Different soil organic carbon dynamics are normal. Soil organic carbon models Can't properly define those hydrological parameters.

Heinemeyer *et al,* choose England peatland with a weak net carbon source and highly climatic sensitive. They developed this Cohort model. Based on the Variable of Water table depth. They use a realistic variable of water table depth Driving carbon dynamics during Holocene peat land accumulation. With Peat, age data, and Testing of realistic Water table depth dependent Pate Soil organic carbon stock response to the climate change scenario.

Table No 4. Most frequent use models (Smith et al., 1997; Grace et al., 2006; Krull et al., 2003)

Name of Model	Scientist
CANDY	Franko (1996)
CENTURY	Parton (1996)
DAISY	Mueller *et al*. (1996)
DNDC	Li et al (1992)
ITE	Thornly and Verbene (1996)
NC SOIL	Molina (1996)
Roth C	Jenkinson and Coleman (1994)
Socrates	Grace *et al*. (2006)
SOMM	Chertov and Komarov (1996)
Struc-C	Malamoud *et al.* (2009)
Verbene	Verbene *et al*. (1990)

SOMKO is a new simulation model of soil organic matter dynamics and aimed to predict long-term and short-term soil organic matter dynamics. This model works on a mechanistic approach that mostly focuses on microbes as the key agent of decomposition. Soil organic matter is partitioned into cohorts and chemical quality pools. (Gignoux *et* al. 2001)
Computer simulation soil organic carbon model can complement and extend the application of information collected in field trials (Meki, *et al* 2013). The data which we obtain from field trials are implemented in the Soil organic carbon model to get a realistic view of Carbon stock and dynamics. Soil organic carbon models are widely used in many different fields with different parameters like soil science, agronomy, and environmental science. Those model helps to understand the Carbon turnover process and give a clear idea about the underground Carbon sterilization mechanism (Smith, *et al* 2019). Nowadays the models of soil organic carbons are extensively used to understand soil organic carbon dynamics for future projects (Smith, *et al*.2005) and place oriented from nation to global Scale.

- Lee et al worked on the effect of trends in tillage practices on erosion and carbon content of soils in the US corn belt in 1993.Falloon, et al work on regional estimates of carbon sequestration potential: linking the Rothamsted carbon model to GIS databases in 1998.

- King, et al worked-on Soil organic matter models and global estimates of soil organic carbon in 1996.In agronomy, we can use the soil organic carbon model to improve the environmental systems' quality and agronomic efficiency. From an agronomical perspective, there are some beneficial models,

- McCown et al developed a novel software system for model development, and simulation in agricultural research in 1996, This model is called APSIM (Agricultural Production Systems simulator).

- DSSAT stands for Decision Support System for Agrotechnology Transfer. DSSAT develop by the International Benchmark Sites Network for Agrotechnological Transfer (IBSNAT) in the 1980s. Jones JW et al developed The DSSAT cropping system model VI version in 2003.

The soil organic carbon model is used for exploration and investigation of soil organic carbon dynamics in different management and environmental scenario, and sometimes we are forecasting some experimental scenarios, for example, Montanarella *et al,* Projected changes in mineral soil carbon of European forests in between 1990–2100. Nowadays soil organic carbon models are widely used by policymakers at the National, regional, and global levels as example In the Post-Kyoto[7] debate high-level talks attempted to address the capacity of a terrestrial ecosystem model to store Carbon (IPCC,2000) Land use, land-use change, and forestry (Watson, *et al*, A special report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge).

[7] *Post-Kyoto: A negotiation refers to high-level talks attempting to address global warming by limiting greenhouse gas emissions (Wikipedia)*

There are many factors for evaluating the performance of the soil organic matter model. Model evolution shows how a given model can be implemented and performed in each situation. Model evolution helps to improve a proper understanding of the system, mostly the reason for model failure, and provides confidence in the model's ability to credit future soil organic carbon changes. There are very different levels to evaluating the file organic carbon model. Soil organic carbon model can be evaluated at the individual process level, level of a subset of process, or the model's overall output (Fallon&Smith 2009). The model can be also evaluated on its applicability in site-specific to a regional level (Izarraulde *et al*., 1996).

Smith *et al* (1997) complicated the most comprehensive evolution of the soil organic matter model, they classified 9 models which are tested against 12 data sets from 7 long-term experiments based on arable rotation, managed, and managed grassland, a forest plantation, and natural Woodland regeneration.

Out of the 9 models, 6 models have a significantly lower overall other than the other group of 3 models.

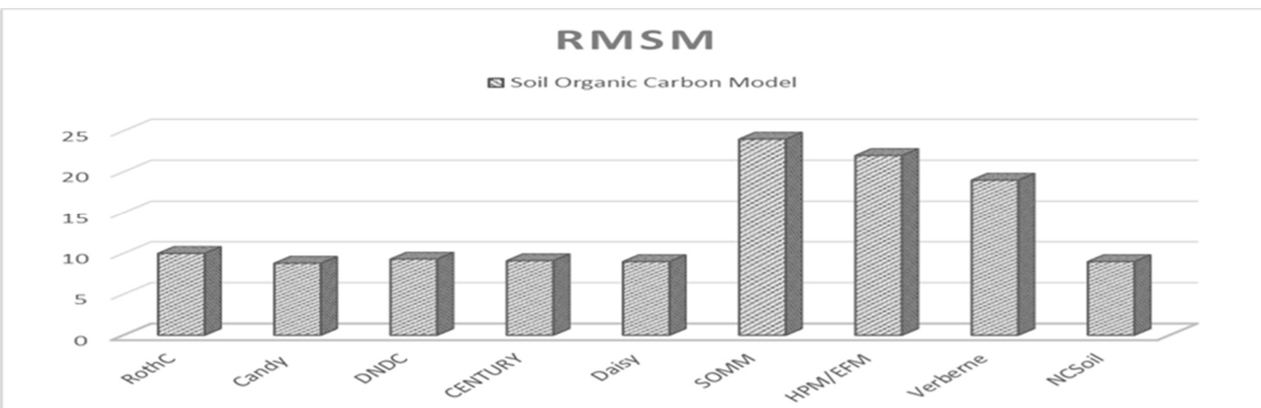


Fig 6 Overall RMSE value for nine SOM models (Fallon & Smith, 2009)

CENTURY

The century is an agro-ecosystem model which was developed by Parton *et al.1987* to simulate carbon, nitrogen, phosphorus, and sulfur dynamics through an annual cycle over the time scale of centuries or millennia (Hollis and Sakrabani) its aim is to get a proper understanding about soil biochemistry of carbon-nitrogen Phosphorus and sulfur. Century has compressed with a series of sub-model which may be grassland/crop forest aur savanna ecosystem. With the flexibility and specifying potential primary production curve representing the site Pacific plant community. This model was developed to deal with a wide range of cropping systems and tillage practices to understand and analyze the effect of management and global change on productivity and sustainability of the agro-ecosystem.

Every ecosystem has different sub-models which are linked to common soil organic matter some models for example Savanna model used for grassland or cropland. The model run with a monthly time step the major input variable for the model include,

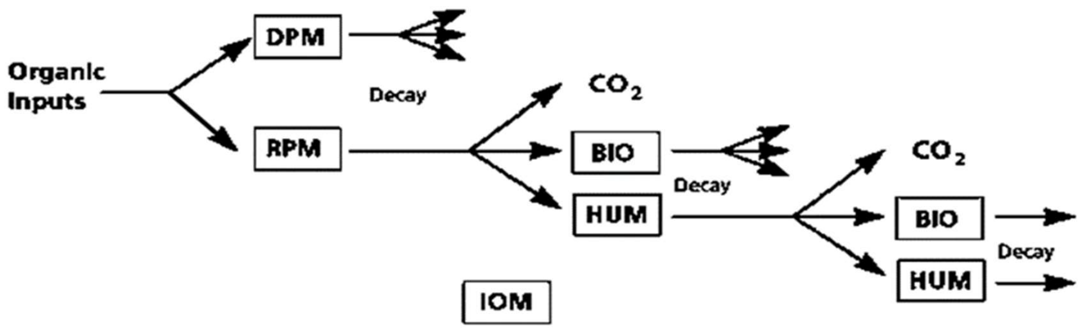
- Monthly average maximum and minimum temperature
- Monthly precipitation and transpiration
- Lignin content of plant material
- Planned nitrogen phosphorus and sulfur input.
- Initial soil carbon nitrogen Phosphorus and sulfur amount.

For the time being the model is developed in version 4 of the model to integrate the effect of climate and soil-dependent variables and Agriculture management to simulate carbon nitrogen and the water dynamics in the soil-plant system. Simulation of complex agricultural management systems including crop rotation teenage practice fertilization irrigation grazing and harvesting method is now added to those parameters.
In Version 5 we are adding the various layers of soil physical structure and new erosion and deposit sub-model.

ROTH C

This is a model of turnover of organic carbon in non-water lodging soil that allow for the effect of soil type temperature moisture content and Vegetation to cover on the turnover process. It's use a monthly time step to calculate the total organic carbon and microbial biomass carbon on the year to centuries timescale. ROTHC was written by IACR (Institute of Arable Crops Research)-Rothamsted (formerly known as Rothamsted Experimental Station), UK.The input data required to run this model are average monthly rainfall (mm), average monthly evaporation (mm), average monthly air temperature, click content of soil, an estimate of the decomposability of incoming plan material (decomposition rate) , soil vegetation cover monthly input a plant residue and monthly input of farm yard manure and the death of soil sample.
Roth C model is derived from the decomposition of plant material and resistance plant material, both are decomposed by the first order of kinetics and give carbon dioxide and microbial biomass and humified organic matter. BOI and HUM decompose at they are characteristics rates by the first order of kinetics and give more carbon dioxide biomass and humified matter. It was assumed that there was a small compartment in soil organic carbon which is not affected by the decomposition called IOM (inter organic matter).

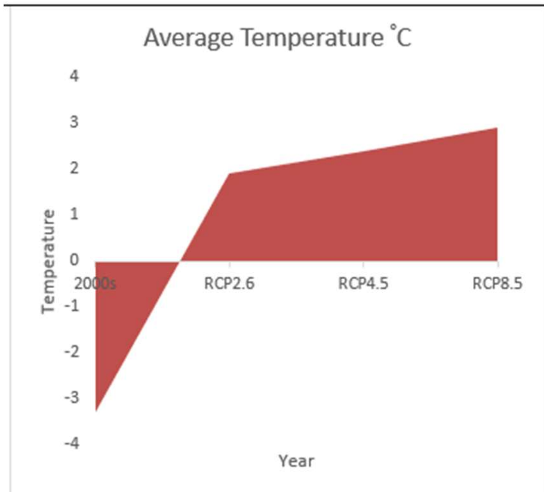
Fig 4. Simple Diagram of Roth C carbon model



Estimation of soil organic carbon under Climate Change

Several studies have been examining that soil carbon sequestration for climate change is affected heavily (Smith, 2004). Climate change is the key factor of change in soil carbon stock in the 21st century (Wattenbach *et al* 2005). Because of the greenhouse effect the environmental temperature is increasing and which accelerates soil organic carbon decomposition and losses of soil organic carbon. There are some recent studies on the projection of soil organic carbon under climate change across arable forests and grassland. Grassland is one of the most important and widely spread ecosystems, which is covering approximately 40% of the global land surface and continues the largest share (39%) of terrestrial soil carbon stock (~580Gt C) (White *et al* 200). Any change in the soil organic carbon storage in grassland will have a significant and long-term effect on the global carbon cycle (Parton *et al* 1995). Under the climatic change, the grassland carbon stock is changing rapidly. Smith and others projected in loss of 6 to 10% of European grassland soil organic carbon stock over 90 years (1990-2080) (Moncrieff *et al* 2008). Xu and others estimated losses of 2-6% of grassland soil organic carbon stock in Ireland over the 40 years (2021-2060) across different emissions scenarios. Similarly, Senapati and others estimated a loss of grassland soil organic carbon by 10 to 11% in Australia because of climate change (Senapati, *et al* 2013).

Liu *et al* 2021 working on the Middle Qilian Mountains and trying to understand the SOM dynamics over climate change. The Qilian Mountains, as a typical semiarid alpine region in northwestern China. They are trying to estimate SOM stock from the 2000s to the next 50 years. Because of global warming and climate change they observe a huge change in soil organic carbon in a specific region. Since the 2000s atmospheric temperature and average rainfall is continually increased in Middle Qilian Mountains.



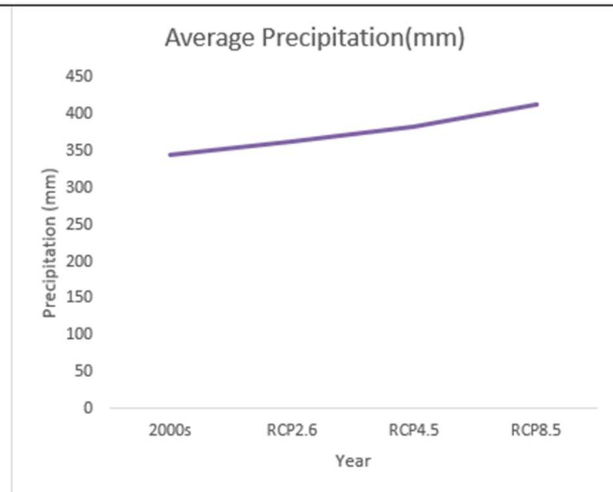


Fig 5 Graph of Average Temperature and Average Precipitation

The temperature from the 2000s to the 2050s is predicted that temperature continuously increased because of global warming and climate change. 2000 temperature was minus 3.3 degrees centigrade it continuously increased by 1.9°C, 2.4º C, and 2.9º C to the 2050s under the RCP 2.6 RCP 4.5 and RCP 8.5 scenario. for the climate change the rate of precipitation also change in 2000s it was 344.70 mm while it increases by 28.37, 19.80, 30.80 mm (Liu et al 2021). Because of climate changes the variation in vegetation was decreased some vegetation is expanding its area on the other hand some vegetation is shrinking, which we can see in **Table Number 5.**

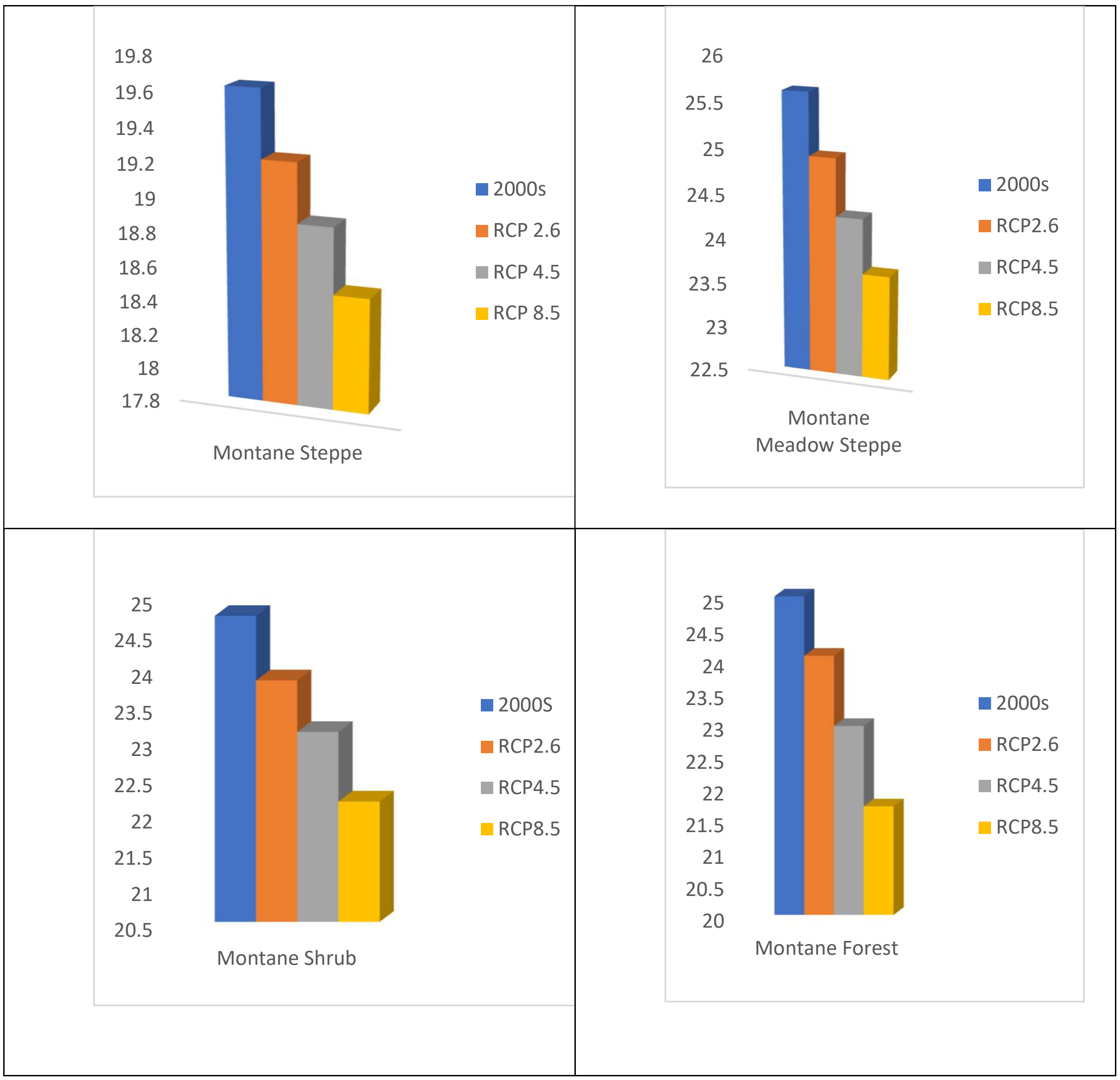
Table No. 5: Change around different vegetation types under different climate change scenarios (Liu et al 2021)

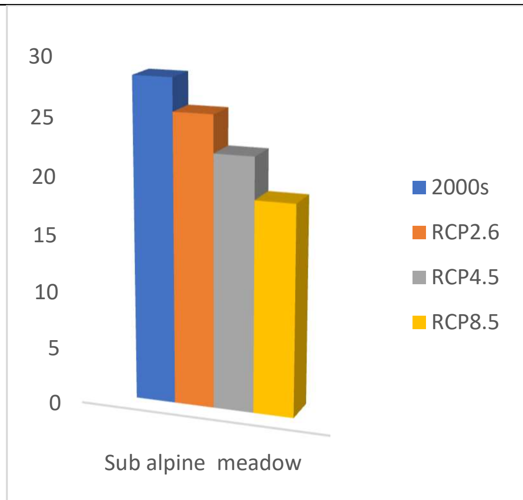
Vegetation Type	Area (km^2)	Change In Area(km2)		
	2000s	RCP2.6	RCP4.5	RCP8.5
Montane Desert Steppe	101	-10	-15	-24
Montane Steppe	745	13	12	18
Montane Meadow steppe	267	-29	-18	-34
Montane Shrub	447	40	37	56
Montane Forest	776	32	63	100
Subalpine meadow	1564	199	216	250
Subalpine Shrub	1002	-63	-37	234
Alpine Meadow	3676	124	-185	-577
Alpine Desert	1875	-57	-72	-22

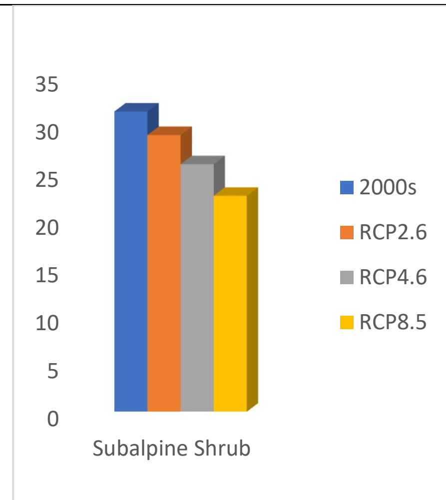
No Vegetation	46	0	0	0

If we observe this chart, we can see that a lot of places where new vegetation enters like mountain forests and sub-alpine meadows, and sub-alpine shrubs are continuously expanding because of climate change. Changes in vegetation reflect in our future soil organic carbon stock. Due to temperature and precipitation increase, soil microbial activity increases effectively, and the place where our previous organic carbon stock is quickly decomposed because of the humid climate. As we can observe in Table 6

Table No 6, SOM decreasing in different vegetation populations because of climate change (the 2000s to 2050s)

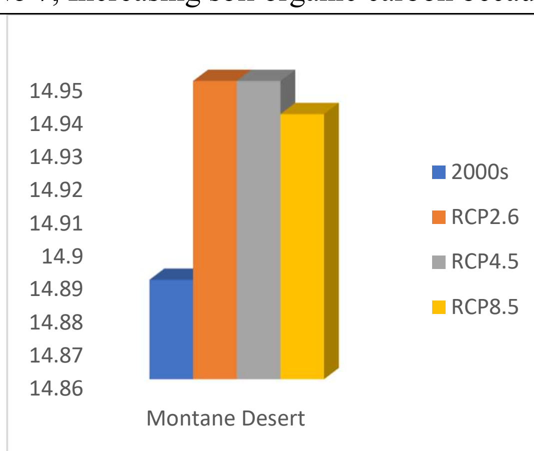


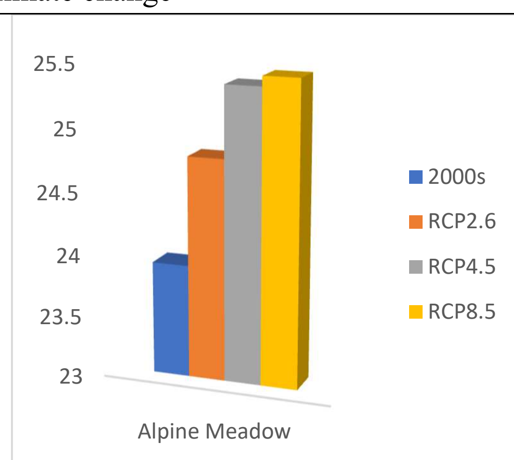


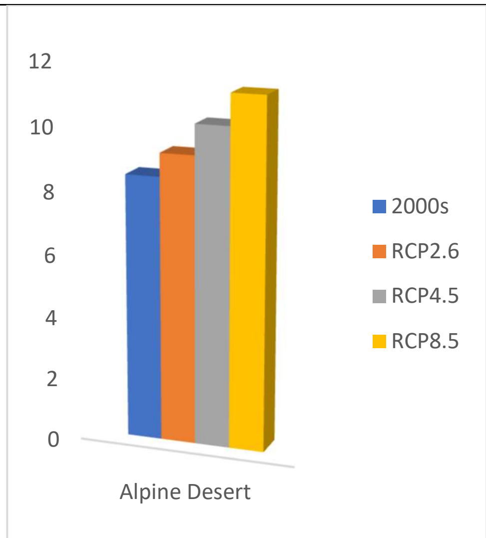


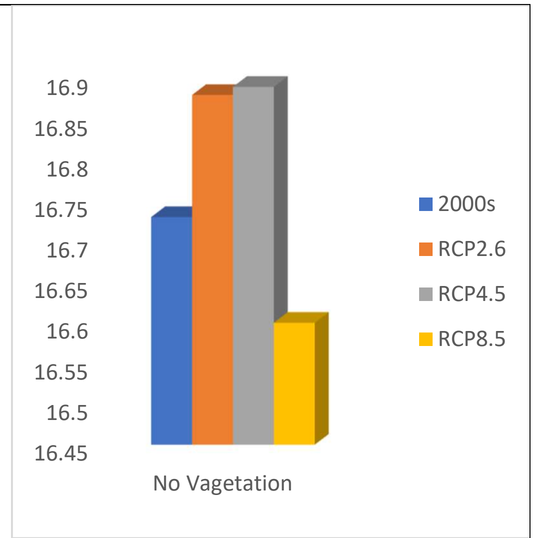
Other hand if we observe because temperature and humid climate some non-vegetative lands are facing vegetation which is increasing the soil organic carbon stock in this area. If you observe table number 5 then we can see, that some vegetation like Montane Steppe, Montane Shrub, Montane Forest, sab alpine meadow, and sab alpine shrub are increasing they are present. Because of those vegetation new Fresh plant residue is added to the soil, the reason behind increasing soil organic carbon which is reflected in table number 7. The area of the non-vegetative part is continuously shrunk as you see in table number 7 alpine desert and no vegetation regions are continuously losing their area because of climate change.

Table No 7, Increasing soil organic carbon because of climate change









CONCLUSION

The presence of adequate amounts of organic carbon in the soil is crucial for maintaining soil health. Currently, due to climate change, soil organic carbon stocks are changing drastically. If we are to protect future soil health and take the necessary steps to protect that health, we need to understand how soil organic carbon is changing dynamics. Changes in soil organic carbon vary from site to site based on climatic and soil nature and agricultural practices. Therefore, by combining all these parameters, different scientists have developed organic carbon models based on different assumptions regarding regions and land use practices. Those specific Soil organic carbon models help to understand the past present and future scenarios. Using those Model outputs we can Change our Agriculture practices and Make Plane to counter global warming.

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