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Sensitivity of Global Soil Carbon to different Climate Change Scenarios

Alireza Shakiba, Ph. D.
Assistant Professor, Faculty of Earth Science, Shahid Beheshti University
Aliakbar Matkan, Ph. D.
Assistant Professor, Faculty of Earth Science, Shahid Beheshti University

Abstract

One of the most pressing questions in the current debate about global climate change is what will happen to organic carbon sequestered in organic matter in soils if global warming occurs. This paper aims to study the potential effect of changes in temperature and precipitation on organic carbon sequestered in global soils. Interpolated data from a General Circulation Model (GCM), predicting temperatures and precipitation as well as world vegetation data set were used in a soil organic carbon decomposition model to study the likely effects of climatic change on organic carbon in soils over the next 100 years under three different scenarios. Results show that levels of organic matter in global soils will decrease as a result of an increase in global temperatures and precipitation. Results also show that different climatic zones of the Earth appear to be affected differently by global warming. Results from the research, as with climatic change modeling itself, represent only one of many possible outcomes. Results from only one GCM were studied in this study. The project results depend largely on a number of justifiable but major assumptions in the theoretical models and sets of data that were used in the study. Moreover, many environmental processes in the atmosphere, oceans and on land are not well understood. As a result, most if not all physical attempts to model the coupled effects of an atmosphere-soil system will contain significant errors. Although the results show (as with previous works) that the level of organic matter in global soils will decrease as a result of an increase in global temperatures and precipitation, such an outcome is by no means certain.

Keywords: Climate change, GCM, Global warming, Modeling, Soil organic matter, Temperature.

تغییر پذیری مواد آلی موجود در خاک نسبت به سناریوهای متفاوت تغییر اقلیم در مقیاس جهانی

علیرضا شکیبا
دکترای جغرافیای طبیعی، استادیار دانشکده علوم زمین، دانشگاه شهیدبهشتی
علی اکبر متکان
دکترای سنجش از دور، استادیار دانشکده علوم زمین، دانشگاه شهیدبهشتی

چکیده

یکی از سئولات کلیدی و مهم در مبحث تغییرات اقلیمی در مقیاس جهانی، تغییرات در میزان مواد آلی موجود در خاک در صورت ادامه گرمایش جهانی است. این مقاله تلاش دارد تا تأثیر چنین تغییرات احتمالی را بر ذخایر کربن موجود در خاکهای جهان بررسی نماید. تحقیق حاضر بر مبنای یکی از دادههای مدل‌های اقلیم جهانی (GCM) انجام پذیرفته است. داده‌های درون یابی شده حاصل از مدل GCM،داده‌های بارندگی و دمای خاک مدل شده به همراه داده‌های رقومی خاک و پوشش گیاهی در مقیاس جهانی در یکی از متداول ترین مدل‌های تعیین و پیش بینی رفتار و تغییرات کربن (RothC- 26.3) وارد شده تا بدان وسیله شرایط مطالعهٔ تأثیر احتمالی تغییرات اقلیمی را بر روی کربن آلی خاک (SOM) در طی صد سال آینده و تحت شرایط ۳ سناریوی متفاوت تغییر اقلیم فراهم سازد. این سه سناریو عبارتند از: سناریوی کنترل، سناریوی افزایش گازهای گلخانه‌ای (GHG)،و سناریوی تأثیر مشترک گازهای گلخانه‌ای و هواویزها($GHG + SO_4$). نتایج این تحقیق نشان می‌دهد که مناطق مختلف جهان نسبت به تغییرات اقلیمی واکنش‌های متفاوتی را نشان داده و هر یک متناسب باسناریوی تبیین شده، از دامنه تغییرات متفاوتی برخوردار می‌باشند. بر اساس این نتایج، سطح مواد آلی موجود در خاک‌های جهان در نتیجه تغییر در میزان دما و بارندگی در هر سه سناریو، روندی کاهشی خواهد داشت. البته میزان تغییرات کربن در اکوسیستم‌های مختلف تابعی از میزان شدت تغییرات اقلیمی رخ داده در آن اکوسیستم بر اساس سناریوهای متفاوت می‌باشد، به‌طوریکه میزان این تغییرات تحت تاثیر سناریوی (GHG) نسبت به دو سناریوی دیگر بیشتر می‌باشد. اگر چه نتایج این تحقیق کاهش سطح مواد آلی موجود در خاک‌های جهان را با توجه به تغییرات دما و باران بیان می‌نماید، کماکان مجهولات متعددی درخصوص چنین تحقیقاتی به لحاظ مدل و داده‌های حاصل از آن مطرح می‌باشد.

کلیدواژه‌ها: مواد آلی خاک، گرمایش جهانی، تغییرات اقلیم، مدل‌های GCM، مدل کربن RothC-26.3.

Introduction

Soils play an important role in the carbon cycle of the Earth. Soils hold one of the largest near-surface pools in the global carbon cycle, containing between 1,400 to 1,600 Peta gram C in organic forms, with a large proportion of this total amount lying near the surface (Schlesinger *et al.*, 2000). The soil carbon pool is large and dynamic; increases or decreases in the amount of carbon in soils could have significant effects on the concentration of CO_2 in the atmosphere. An extensive literature shows that human activities - especially cultivation - reduce the pool of carbon in soils and that most of this carbon is transferred to the atmosphere. Under the various scenarios of climate change, there is a less knowledge about the potential for soils to serve as a sink for CO_2.

Climate affects carbon storage in terrestrial ecosystems because temperature, moisture, and radiation influence both ecosystem carbon gain (photosynthesis) and loss (respiration). The amount of organic matter in soils and its rate of decomposition vary under different climatic conditions. Soils in a cold climate keep more soil organic matter (SOM) than that of warm climate. For example, at about 25 °C, with good soil aeration, there is a balance between production and breakdown and above this temperature organic carbon does not accumulate (Ajtay *et al.*, 1979). Rates of carbon dioxide efflux increase as a function of soil temperature and there is a good reason to believe that rates of soil respiration will increase with global warming (Kirschbaum, 1995; Schimel *et al.*, 2000; Schlesinger *et al.*, 2000).

The effects of climate on the nature, status and distribution of organic matter in soils has been studied by many scientists over the past century. Typically, these studies were made at different locations around the world and the results were drawn together to build a global picture of what was happening. This study attempts to build upon that earlier scientific work.

There is evidence to show that the average temperature of the Earth's surface has risen during the 20th century (for example, Hansen *et al.*, 1999; O'Hare, 2000; Drake, 2000). Satellite observations (Hecht, 1998; Drake, 2000) and microwave emissions from the atmosphere suggest that the average temperature of the earth's surface is rising slowly.

The pool of carbon in soils is about twice the amount in the atmosphere and is large enough for changes in this pool significantly to affect the composition of the atmosphere. Precipitation and temperature are the two main climatic factors that control the amount of soil organic matter. Melillo *et al.*, (1996) argued that land carbon stocks will change in future in response to changes in any or all of the following factors; area of agricultural land, age structure of forests, climate, chemistry of the atmosphere and precipitation. Post *et al.* (1982) argued that changes in global climate can be expected to alter total storage of carbon in soils. They suggested that small changes in either temperature or precipitation, for example in sub-polar regions, could have profound effects on the amount of carbon stored in the carbon rich soils found in these regions.

An increasing temperature globally does not have the same effect on soil organic matter in different parts of the world. According to predictions made using General Circulation Models (GCM), the temperature increase at high latitudes will be greater than at low and mid-latitudes. It is expected that soils in high latitudes will lose carbon in response to global warming. This has been confirmed by Kirschbaum (1995) who showed that a 1 degree increase in temperature could ultimately lead to a loss of over 10% of soil organic carbon in regions of the world with an annual mean temperature of 5 °C but would lead to a loss of only 3% of soil organic carbon for a soil at 30 °C.

Jenkinson *et al.*, (1991), using a soil organic matter model, studied the effects of increasing global average temperature on soil organic matter. They showed that if the world's temperature rose by 0.03 °C yr^{-1} (the increase considered as most likely by the Intergovernmental Panel on Climate Change (IPCC), Houghton *et al.*, 1990), the additional release of CO_2

from the soil organic matter over the next 50 years would be 61 x 10^{15} g C. They also showed how much CO_2 would be released from the world stock of soil organic carbon if world temperatures rose uniformly by 0.2 °C (41 x 10^{15} g C), or 0.5 °C (100 x 10^{15} g C) per decade according to the IPCC report on global warming.

Using the carbon model, studies already carried out have shown that there is a strong correlation between soil carbon pools and climatic parameters. Analyses carried out by Post *et al.*, (1982), Schimel *et al.*, (1990), Jenkinson *et al.*, (1991), Thornley *et al.*, (1991) and Kirschbaum (1993; 1995) have confirmed the relationship between temperature and soil organic carbon.

Most of the models that study soil carbon or explore the parametric effects on this matter, use three different input data, and pay less attention to the effect of the climate parameter on the soil organic carbon variations. Studying the effect of the climate parameters will be the main aim of this paper.

Method and Data

The following describe the theories, methods, models and data sets that were used in this study. The study uses data collected in two different ways:

1) A study of the likely future of temperature and other climatic parameters such as precipitation using data generated by a GCM. This approach allowed the author to study how temperature and precipitation are likely to vary under different assumptions about global climatic conditions.
2) A study of the effects of global climate change on sequestered carbon in soils using the soil carbon model RothC-26.3. The relationships between temperature, climatic factors and soil carbon show to what extent global climate change will affect the amount of soil organic carbon.

Model

The carbon model that was used to study the likely effects of climate change on the amount of organic carbon sequestered in soils is the current Rothamsted model for the turnover of organic carbon in soil. It was obtained from the Institute of Arable and Crop Research at the Rothamsted site (U.K.). This model is called the Rothamsted Carbon Model (RothC-26.3). The first version of this model was created by Jenkinson and Rayner (1977) but was subsequently developed further by Coleman and Jenkinson (1995).

Data

A variety of different types of data were investigated in order to obtain consistent, reliable and appropriate sets of global data for this study. The data used in this study were all obtained from NASA-GISS as follows:

1) Data generated by a General Circulation Model (GCM) were used to provide estimates of climatic variables in order to run the soil organic carbon models.
2) A world soil data set was used in soil carbon model. This was derived from digital soil maps of the world, prepared by the United Nations Food and Agricultural Organization with a global resolution of 1X1 based on Zobler (1986).

A global land cover data was used in the soil carbon model with a global resolution of 1X1.

Land cover data is derived from the world vegetation data set (Matthews, 1983) and Holdridge's life zone classification (Post *et al.*, 1982; and Jenkinson *et al.*, 1991).

The value of Inert Organic Matter (IOM) was estimated from total soil organic carbon (SOC) according to Falloon *et al.*, (1998b) by using the following equation:

$$IOM = 0.049 \times SOC^{1.139} \qquad (1)$$

The GCM data were only available at a coarser resolution of 4 x 5 degrees. Rather than degrade the soil and vegetation data set it was decided to interpolate the GCM data to a 1 x 1 degree resolution. This is because a 4 x 5 degree resolution is too coarse for any detailed soil analysis. Obviously, interpolation is not as accurate as data on a 1 x 1 degree grid, however, GCM data is not widely available at such a these fine resolution. Downscaling is a significant problem facing many disciplines dealing with sub-grid scale problems and as yet no single method has come (Wilby and Wigley, 1997). The interpolation was made using Inverse Distance Weighting Technique. This technique estimates the grade of unknown points using surrounding points.

Results

Many studies have shown that sequestered organic carbon in soils is likely to decrease in volume with an increase in average temperatures at the Earth's surface as a result of global warming. (Post *et al.*, 1982; Jenkinson *et al.*, 1991; Shaver *et al.*, 1992, Kirschbaum, 1995; and Schimel *et al.*, 2000). The results highlight the potential changes in sequestered organic carbon in soils under different assumptions about global climatic change over the next 100 years (2000-2099). The three different GCM scenarios used are control simulation with constant 1950 atmospheric composition (Control); observed greenhouse gases to 1990, 0.5% CO_2 increase after 1990 (GHG) each year; and greenhouse gases condition same previous scenario with tropospheric sulphate aerosol changes (GHG + SO_4).

Predicted Effects of Climate Change on SOM

This study recalculated the annual input of organic carbon to soil by using the RothC-26.3 model with different values of Inert Organic Matter (IOM) from the total soil organic carbon (SOC) regardless of soil type, land use or climate using the equation (1). By applying values for Inert Organic Matter for soil organic carbon of various life zones, the aggregated return of carbon for all zones predicted by the model was found to be about 65.8 x 10^9 t C yr^{-1}, which is a little greater than the Net Primary Production (NPP) (Table 1).

The results of calculating the percentages of resent annual carbon input to soil and total soil carbon show that more than 60% of total of soil carbon have been distributed between five zones; tundra, cool temperate steppes, tropical woodland and savanna, boreal forest wet and cultivated lands and that less than 40% is distributed between other 12 zones (Figure 1). Except for woodland and savanna that make up one of the main sources for soil carbon, the other four zones chiefly lie at high latitudes where the low average temperatures most of year limit the biological, chemical and physical processes of the soil.

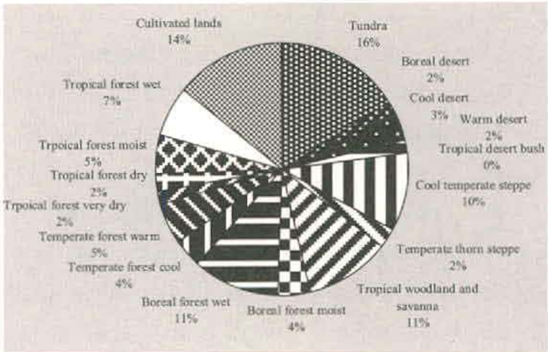

Figure 1- Percentage of present total soil carbon for each biome.

In contrast, the percentage of annual carbon input to soil showed that, in the areas where the temperature and precipitation are suitable for decay processes, more annual soil carbon is needed to maintain the carbon content of that zone. For example, from total annual carbon input to the world's soil, more than 65% belongs to tropical forest wet, moist, tropical woodland and savanna, and cultivated zones, and less than 35% of this belongs to the other 13 zones (Figure 2). This analysis also showed that in cold areas of the world or even in warm and hot areas, such as warm deserts and very dry or dry tropical deserts, a minimum annual carbon input is needed to maintain the total organic carbon content in the soil. This is because of the absence of a high enough temperature (cold areas) or enough moisture in soil (warm deserts).

Variation in Total Soil Organic Carbon (SOM) under GCM Data Set

The carbon model was run under A control similation

Table 1- Total soil carbon and calculated annual input of carbon for the world's soils according to Jenkinson *et al.*, 1991 and this study.

Zone	Total C [£] (x 10^9 t)	Carbon input * (x 10^9 t yr^{-1})	Carbon input ** (x 10^9 t yr^{-1})
Tundra	191.8	0.8	0.9
Boreal desert	20.4	0.09	0.1
Cool desert	41.6	0.6	0.9
Warm desert	19.6	0.7	0.6
Tropical desert bush	2.4	0.11	0.1
Cool temperate steppe	119.7	2.0	2.7
Temperate thorn steppe	29.6	1.7	1.8
Tropical woodland and savanna	129.6	10.8	11.5
Boreal forest moist	48.7	0.7	0.8
Boreal forest wet	133.2	3.7	4.7
Temperate forest cool	43.2	2.0	3.1
Temperate forest warm	61.1	6.5	7.1
Tropical forest very dry	22	1.5	1.7
Tropical forest dry	23.8	1.0	1.1
Tropical forest moist	60.4	10.8	13.2
Tropical forest wet	78.3	13.8	15.3
Cultivated lands	167.5	9.0	10.2
Wetlands	202.4	-----	-----
Total	1395.3	65.8	75.8
Total without wetlands	1192.9		

[£] = calculated by Post *et al.*, 1982

* = calculated by this study

** = calculated by Jenkinson *et al.*, 1991

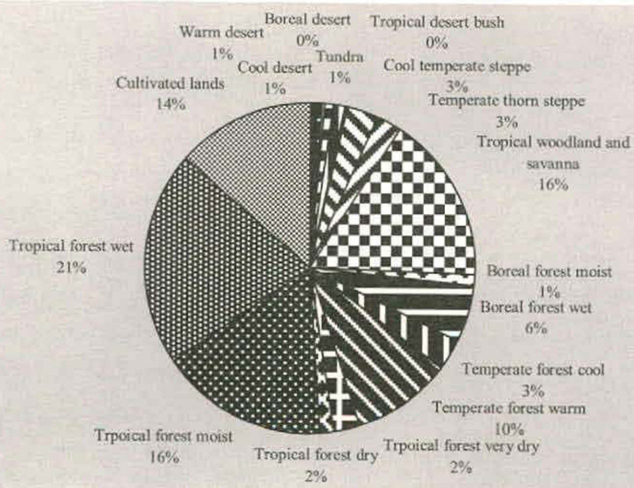

Figure 2- Percentage of present annual carbon inputs to soil for each biome.

simulation to estimate the soil carbon and CO_2 values for different regions of the world.

Under the control simulation, the total amount of soil carbon that will be lost from the world's soils compared with the present soil organic carbon stock would be about 156.2 x 10^9 tons and 205.5 x 10^9 tons until 2050 and 2099, respectively.

Table 2 presents that the variation in total soil organic carbon under GHG to 2050 and 2099 for world's soils for each zone separately. It shows how much of the total organic carbon will be lost from soil over the next 100 years in comparison with the control simulation (year 2000). If we assume that total soil organic carbon (SOM) in 2000 under the control simulation is about 1173.7 x 10^9 tons (excluding wetlands), it will be decreased to 960 x 10^9 tons and 840 x 10^9 tons by 2050 and 2099 under GHG simulation. If the results of the control and GHG scenarios are compared, then the latter would decrease by 58 x 10^9 tons and 128 x 10^9 tons in total SOM over the next 50 and 100 years, respectively, in the world's soils.

The effects of GHG + SO_4 on future climatic change, in comparison with control simulation, are given in Table 3. The amount of organic carbon held in world soils, from the control value of 1173.7 x 10^9 tons, will decrease to 987.1 x 10^9 tons by 2050 and to 890.8 x 10^9 tons by 2099. In other words, about 186.6 x 10^9 tons and 282.9 x 10^9 tons of carbon will be lost from world soils by 2050 and 2099, respectively.

Results from all climate scenarios have shown that the amount of soil organic carbon in all biomes decreases with changes in the climate. In other words, the amount of soil organic carbon lost from the world's soils can be related to variations in soil temperature and precipitation over time. Different areas of the world responded differently to this variation. Generally, carbon loss from soil occurred at the highest rate in zones where soil temperature and precipitation provided the most suitable conditions for decay processes in the soil. Geographically, high and mid-latitudes were found to be more sensitive to global climate change than low latitudes. Some areas with relatively high predicted soil temperature and a predicted increase in precipitation would expect to lose nearly 50% of total soil organic carbon by 2099 under the GHG scenario. An increase in precipitation in tropical and warm deserts produced 50% and 70% of soil carbon loss by the end of next century.

CO_2 released to the atmosphere

The extra carbon evolved over 50 and 100 years from soil organic carbon under GHG + SO_4 scenario are 30.3 x 10^9 t and 77.5 x 10^9 t, and for GHG are 60.5 x 10^9 t and 120.5 x 10^9 t, respectively. These calculations also showed that the CO_2 released into the atmosphere was not the same across the world so that each zone responded differently, mainly depending on its climate conditions (Figure 3). Generally speaking, the rate of extra CO_2 released into the atmosphere was high in those zones where the effects of global warming were greatest. This is because, the increase in temperature and precipitation provide suitable conditions for soil organic matter decomposition. For example, the rate of extra CO_2 released to the atmosphere by 2099 under the GHG scenario is the highest in tundra, boreal forests and cultivated lands. This is despite the fact that most of the time the soil in tundra and boreal forests appears cold and frozen, and these high values of extra CO_2 seem to be unusual. However, when we look at the soil temperature variation in these areas, it is apparent that a few months with above-zero temperatures could make such a difference. Nevertheless, more research needs to be done in this area to reach a correct answer. The high rate of this extra CO_2 in cultivated land might be due to irrigation operations, because they are distributed in different climate zones rather than any particular area. Temperate thorn steppe has a lowest release of extra CO_2 to the atmosphere. This is despite the area having a high enough temperature to activate the decomposition processes in the soil, however the lower humidity causes less decomposition in this area.

The amount of extra CO_2 released into all desert

Table 2- Total soil carbon variation under GHG simulation for world's soils.

Zone	C 2000 ($x 10^9$ t)	C 2050 ($x 10^9$ t)	C 2099 ($x 10^9$ t)	2050-2000 ($x 10^9$ t)	2099-2000 ($x 10^9$ t)
Tundra	191	163.9	146.9	27.1	44.1
Boreal desert	20.3	17.2	15	3.1	5.3
Cool desert	41.2	32.5	26.5	8.7	14.7
Warm desert	18.4	7	5	11.4	13.4
Tropical desert bush	2.26	1.4	1.15	0.86	1.11
Cool temperate steppe	117.6	85.4	65.2	32.2	52.4
Temperate thorn steppe	29.4	25.4	23	4	6.4
Tropical woodland and savanna	125.3	98.4	85.7	26.9	39.6
Boreal forest moist	48.1	37.4	31.9	10.7	16.2
Boreal forest wet	133.16	124.6	115.3	8.56	17.86
Temperate forest cool	43.18	40.3	3.1	2.88	6.08
Temperate forest warm	60.1	50.3	46.1	9.8	14
Tropical forest very dry	20.8	12.3	10.8	8.5	10
Tropical forest dry	23.1	15.3	12.4	7.8	10.7
Tropical forest moist	59.9	54.6	47.6	5.3	12.3
Tropical forest wet	76.9	64.6	61.7	12.3	15.2
Cultivated lands	163	128.9	108.8	34.1	54.2
Total	1173.7	959.5	840.15	214.2	333.55

Table 3- Total soil carbon variation under GHG + SO_4 simulation for world's soils.

Zone	C 2000 ($x 10^9$ t)	C 2050 ($x 10^9$ t)	C 2099 ($x 10^9$ t)	2050-2000 ($x 10^9$ t)	2099-2000 ($x 10^9$ t)
Tundra	191	167.5	152.1	23.5	38.9
Boreal desert	20.3	17.7	16.1	2.6	4.2
Cool desert	41.2	33.5	28.6	7.7	12.6
Warm desert	18.4	7.3	5.3	11.1	13.1
Tropical desert bush	2.26	1.5	1.2	0.76	1.06
Cool temperate steppe	117.6	87.3	72	30.3	45.6
Temperate thorn steppe	29.4	26.1	23.9	3.3	5.5
Tropical woodland and savanna	125.3	99.4	87.8	25.9	37.5
Boreal forest moist	48.1	38.6	33.6	9.5	14.5
Boreal forest wet	133.16	128.8	121.5	4.36	11.66
Temperate forest cool	43.18	41.5	39.4	1.68	3.78
Temperate forest warm	60.1	52.3	48.7	7.8	11.4
Tropical forest very dry	20.8	12.8	11.3	8	9.5
Tropical forest dry	23.1	16.2	14.3	6.9	8.8
Tropical forest moist	59.9	57.4	54.7	2.5	5.2
Tropical forest wet	76.9	66.3	63.1	10.6	13.8
Cultivated lands	163	132.9	117.2	30.1	45.8
Total	1173.7	987.1	890.8	186.6	282.9

areas except cool desert was shown to be low. This is because the absence of enough moisture in the soil of these regions limits the soil organic carbon decomposition. The exception for cool desert areas can be explained due to different pattern of precipitation compared with other desert areas. The extra CO_2 released into tropical and temperate forests particularly in wet zones is also less. This is due to the fact that in these areas the soil is always wet and warm enough for decomposition to proceed at its maximum permitted rate.

The amount of CO_2 released into the atmosphere under GCM scenarios will make a significant contribution to further warming. As mentioned before, there is a strong relationship between the trend of global warming and the amount of CO_2 in the atmosphere: more CO_2 in the atmosphere causes more warming to take place. This relationship was seen in this study both when analyzing the soil temperature and precipitation data and when the RothC-26.3 model was used to predict the soil organic carbon variation under different GCM scenarios. There was more loss of soil carbon from the world's soils or more extra CO_2 from soil to the atmosphere when the model uses the climate data under GHG rather than control or GHG + SO_4 simulations.

Discussion

In some regions of the world, the combined influence of temperature and precipitation under GHG led to more organic carbon being lost from the soil. For example, in cool deserts the organic carbon lost from the soil was more than organic carbon lost from warm or boreal desert soils over the same period of time. This is because most cool deserts lie in the margin of the continents, where are expected to be wetter according to GCM predictions than the centers of the continents (Manabe and Wetherald, 1987).

Results from predicting the effects of climate change on organic carbon in global soils illustrates that, apart from the tundra area, the decay processes in cool temperate steppes and cultivated lands seem to be much more active than in other biomes. Since, in these regions of the world, the temperature changes would be at about its global mean, a minimal change in temperature and precipitation pattern could lead to considerable changes in storage of soil carbon. In agricultural regions, in addition to effect of climatic parameters, the biological activity and inappropriate land use and soil mismanagement, in which man is often a predominating factor, lead to more loss of soil organic carbon, so that in many agricultural soils the soil organic carbon contents are below their potential levels (Batjes, 1999).

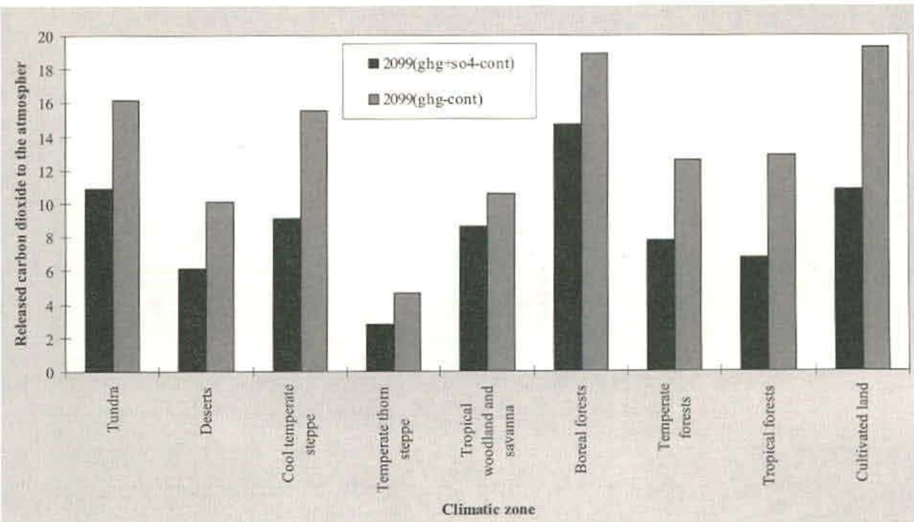

Figure 3- Extra CO_2 released to the atmosphere for each zone by 2099.

Calculated input values of organic carbon to soil carried out by this study showed some agreements and also some differences with the work of other researchers. For example, the calculated litter input or (NPP) in tropical forests was 15.5 t ha yr^{-1}, which is almost twice the values given by Ajtay *et al.*, (1979). However, my estimate for tropical woodland and savanna, 4.5 t ha yr^{-1}, is almost twice as large as Ajtay's corresponding estimate for tropical savanna. The estimates for boreal and temperate forests agree with those of Ajtay. The global estimate of NPP is around 60 x 10^9 t C yr^{-1} (Ajtay *et al.*, 1979; Amthor *et al.* 1998). While this study estimated the annual inputs of carbon to soil to be slightly grater than published NPP, around 66 x 10^9 t C yr^{-1}. This is because we used the RothC-26.3 model in reverse, rather than using the published data and therefore some errors appear if the model overestimates this data in some biomes. As a whole, the distribution of annual inputs of carbon to soil, both published and calculated by this study, shows that tropical forests wet and moist and tropical woodland and savanna account for almost 50% of this carbon input. This shows how important these regions are for sequestering carbon particularly in case of a shift to grasslands or agricultural lands.

Using the same soil carbon model as this study, Jenkinson *et al.*, (1991), predicted the amount of released CO_2 to the atmosphere to be 41, 61 and 100 x 10^9 t by 2050, using uniform air temperature increases, given in the IPCC report, of 0.2, 0.3 and 0.5 °C per decade, respectively (Houghton, 1990). By applying temperature and precipitation data under different climate scenarios, we predicted that the overall rate of the extra carbon that evolved over 50 years (2000-2050) from soil organic carbon under the GHG + SO_4 scenario is 30.3 x 10^9 t and for GHG is 60.5 x 10^9 t, respectively. Given that, using the GISS data, temperature will increase globally by about 1.5 °C under GHG by 2050, our estimates are low. Our estimates are also low under the GHG + SO_4 scenario compared with the minimum amount reported by Jenkinson *et al.*, (1991).

The analysis of temperature change suggested an increase in organic matter decomposition under all climate scenarios. Many studies would support these findings (e. g. Jenkinson *et al.* 1991; Kirschbaum, 1995; Boone *et al.* 1998; and Katterer *et al.* 1998), although some studies argue the effect of temperature leads to an increase in NPP (e.g. Klein Goldewijk *et al.*, 1994; Cao and Woodward, 1998). Liski *et al.* (1998) pointed the fact that the decomposition of old organic matter is less sensitive to increased temperature than is the decomposition of young litter.

The analysis we have presented here is useful in exploring the expected direction and relative magnitude of changes in soil organic carbon storage for a future world with a higher CO_2 and a warmer climate. In this work we have only considered how climate change can influence the decomposition process in soil. But the amount of organic carbon in soil at a particular time is determined both by the rate of decomposition and the annual input of plant debris. Climate also can influence the rate of incoming plant material to soil through the photosynthesis and respiration processes. Therefore, to explore how climate change can influence the amount of soil organic carbon, there is a need to study the effect of these processes in soil carbon with the decomposition process at the same time. To do this, more reliable data and suitable models need to be developed.

Conclusion

The main aim of this study was to study the likely effects of climatic change on the global organic matter stock in soils and the potential effects of any additional carbon dioxide released from soil into the atmosphere over the next 100 years. This study combined data from different global climate scenarios with a model of organic matter decomposition in soils in order to predict likely changes in sequestered carbon in soils. And ,finally, by applying the above approach to the world's environmental systems, this study predicted the potential effects of global climate change on organic carbon in soils.

The conclusions of this study can be summarized as follows:

1) The value of using the GCM data in studying the effects of climate change on environmental phenomena such as soil organic carbon. This study showed that there will be a relationship between climate and soil organic carbon through the process of decomposition. Global soil organic carbon decreased under three climate change scenarios over the next 50 and 100 years. This decrease ranged from 156 G tons for control simulation to 214 G tons by year 2050 for greenhouse gases scenario and from 205 to 333 G tons by year 2099 for same climatic scenarios, respectively. This study also showed a decrease trend of soil organic carbon in all biomes. However, the decrease of this pool was different in various regions of the world mostly depending on their climatic conditions and the global warming rate. There was greater loss of organic carbon from soils at high latitudes than that at mid or low latitudes.
2) A relationship between climate change and increase in atmospheric CO_2 was also distinguished. The amount of atmospheric CO_2 was increased globally and regionally according to climate change scenarios. As with soil organic carbon variations, this study revealed a greater release carbon from soil to the atmosphere under GHG than the other two scenarios. This extra increase ranged from 77.5 G tons for the GHG + SO_4 scenario to 120.5 G tons for the greenhouse gases scenario over the next 100 years. However, this additional CO_2 released from soil into the atmosphere is not greater than CO_2 additions from the burning of fossil fuels over the same period of time (540 G tons).

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