Global Circulation of Carbon related to Climate Change and Environment

http://timetraveler.html.xdomain.jp

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Climate change, population increase, and food problem

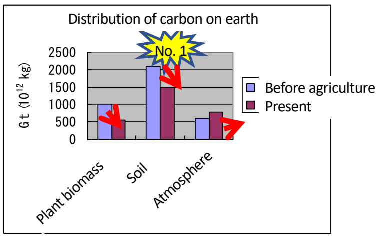
- World population will increase to 20 billion in 2050.
- The increase in food production to match the increased population can not be expected due to the global warming and climate change.
- Big typhoon → Flooding
- El Nino → Drought
- Salt accumulation in the crop land
  - ←Flooding in the coastal area
  - ←Salt accumulation due to drought

Large amount of gas is emitted from soil surface

Global Warming Potential

	Gasses	GWP
1	Carbon dioxide (CO_2)	1
2	Methane (CH_4)	21
3	Nitrous oxide (N_2O)	310
4	Trifluoromethane (CHF_3)	11,700
5	Difluoromethane (CH_2F_2)	650
6	Fluoromethane (CH_3F)	150

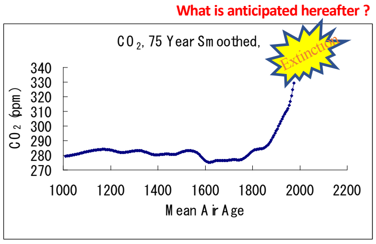
Distribution of C on Earth



Organic matter in plant and soil decreased remarkably due to human civilization.

土壌生化学 (1994)

What is anticipated hereafter ?



Change in atmospheric CO_2 concentration.
(From the Antarctic ice core data.)

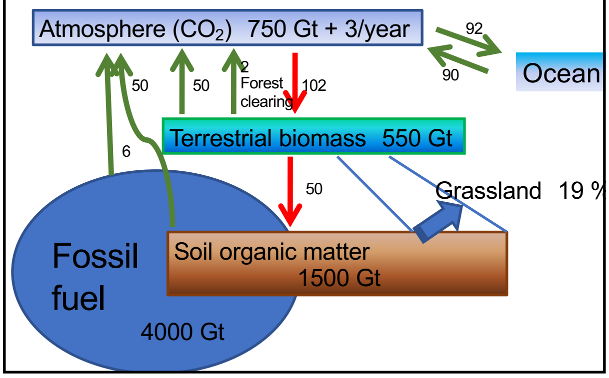
土壌学概論(2001) 表7.1で紹介

Stocks of carbon on the surface of earth

Stock pools		Stored amount (Gt=10^{12} kg)
Earth		
Plant biomass		550
Soil humus		1500
Atmosphere	1850 (CO_2 260 ppm)	560
	1890 (CO_2 290 ppm)	630
	2000 (CO_2 390 ppm)	820
Ocean		38000
Carbonate salts		20×10^6
Dissolved organic matter		600
Solid suspension and sediments		3000
Earth crust (fossil fuel)		4000
Total amount		44800

Hunt(1972), Paul and Clark(1989), Eswaran et al.(1993)
CO_2 concentration was calculated from ice-core data in Law Dome Antarctics.

Terrestrial carbon pool and its flux.



Occurrence of Nitrogen on Earth and its pool size.

Occurrence	10^6 t
Atmosphere	3.9×10^9
Terrestrial Plant	15×10^3
Animal	0.2×10^3
Soil organic matter	150×10^3
Ocean Biomass	0.5×10^3
Soluble and sediment	1200×10^3
Nitrate nitrogen in the above	570×10^3

植物栄養学第2版(文永堂)

Occurrence of Phosphorus on Earth and its pool size.

Occurrence	10^6 t
Terrestrial Biomass	2.6×10^3
Phosphorus rock	19×10^3
Soil	$96〜160 \times 10^3$
Fresh water	0.090×10^3
Ocean Biomass	$0.05〜0.12 \times 10^3$
Soluble inorganic P	80×10^3
Sediment	$840,000 \times 10^3$

Soil is the largest stock for C, N, P in the terra.

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Biomass production and Respiration/combustion on earth (10^9 t C/year)

	Biomass	CO_2 Production
Plant	500	34.5
Animal	0.5	4.1
Human	0.1	0.7
Microbes	1.0	112
Fire		6.9
Eruption		0.15
Factories		15
Total	502	173.5

Energy consumption by 1 person

- World (Average) 1.7 t /year (petrol equivalent)
- Japan 4.1 t /year
- USA 8.0 t /year
- Human life increases the atmospheric CO_2 concentration.
- Plant and Soil absorb and store the emitted carbon.

World energy consumption (2003)

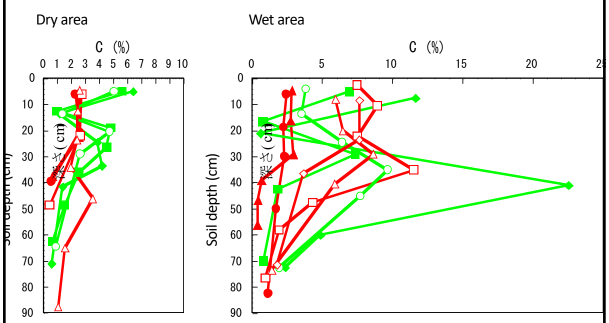
Source	Consumption (petroleum equivalent 10^8 tons)	
Petroleum	36.4	85.5
Natural gas	23.3	
Coal	25.8	
Atomic	6.0	12.0
Hydraulic	6.0	

CO_2 emission (Petroleum, Natural gas, Coal)

heat emission (Atomic)

Emission of CO_2 by human.

Factors	Increasing rate of CO_2
	Gt (10^9 t)/year
Combustion of fossil fuel	7
Land use change	2.2



Change in soil carbon distribution in uncultivated and cultivated volcanic ash soils in Obihiro.

uncultivated — cultivated

Greenhouse gas emission in Japan (2017).

(10^6 t in CO_2 equivalent.)

Gases		(10^6 t)	Items	(10^6 t)
CO_2				
	total	1191		
	Energy origin	1112	industry	413
			transportation	213
			service	206
			domestic	188
			energy transformation	92.3
	Non- energy	79.3	industrial process	46.2
			wastes combustion	29.8
			agricullture	3.3
CH_4				
	total	30.5	agriculture	23.5
			waste treatment	4.9
			fuel combustion	1.3
N_2O				
	total	20.5	agriculture	9.5
			fuel combustion, leak	6
			waste treatment	4
Hydrofluorocarbon		45.7		45.7
Perfluorocarbon		3.4		3.4

Data from the Ministry of Environment, Japan (2018). https://www.env.go.jp/press/106211.html

Emissions due to agriculture

Gasses			Countermeasures
CO_2	land use change	forest clearing	Stop or decrease forest clearing.
		grassland turning	Stop turning grassland to cropland.
		peatland burn and drain	Stop agricultural use of peatland.
			Do not drain the peatland.
	machine operation	fuel consumption	Decease the frequency of machine use.
	agricultural waste	burning	Do not burn the crop residue.
			Recycle the agricultural waste.
	soil	soil respiration	Minimise ploughing or non-ploughing.
		ploughing	Return organic matter and animal excreta to soil after composting.
			Grow green manure.
CH_4	agriculture	paddy field	Do not apply fresh organic matter.
		domestic animals	Intermittent drying of paddy field.
N_2O	agriculture	N fertilizer transformation	Decrease the use of inorganic fertilizer.
		denitrification	Do not make the anaerobic soil condition.
			Grow legume green manure for N source.

Stabilization and abundance of organic matter constituents in soil

Constituents	Abbreviation	Mean Residence Time	S (kg)	A_0 (kg)
Fresh organic matter (yearly imput)				1000
Decomposable Plant Material	DPM	1	10	10
Refractory Plant Material	RPM	3.9	470	120
Biomass	BIO	25.9	280	10.8
Physically stabilized organic matter	POM	94.8	11.3×10^3	119
Chemically stabilized organic matter	COM	2565	12.2×10^3	4.76
Whole Soil Organic Matter	SOM	91.7	24.3×10^3	265

Jenkinson and Rayner, Soil Scinece 123, 6, 1977

S (kg) : Expected accumulation of organic matter after 10000 years when 1000kg ha^{-1} of fresh organic matter is incorporated every year.

A_0 (kg) : Yearly gain of soil organic matter (kg ha^{-1}) ,

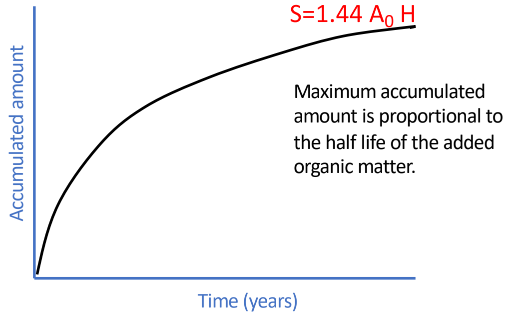
Calculated from S and mean age. A_0 = S/Average Age

Accumulation of organic matter in soil

$$S = (1/\log_e 2)\, A_0\, H$$
$$= 1.44\, A_0\, H$$

S: Accumulated amount of organic matter after infinite years
A_0: Annual input of organic matter
H: Half life of organic matter
1.44H: Mean residence time

Accumulated amount of organic matter in soil approaches the maximum limit with time.



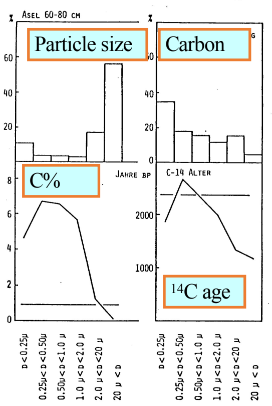
Carbon sequestration in soil

For the purpose of carbon sequestration, it is important to return the organic matter in stabilized form, for example, after composting, or after charring.

Black soil in Soellingen upland field

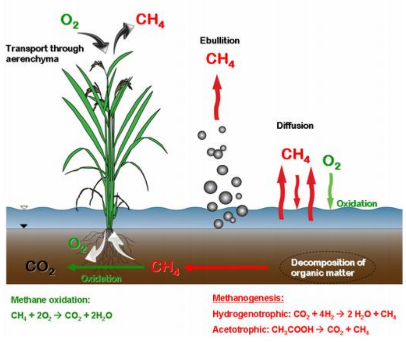
Soil organic matter stabilization on different size of soil particles

Organic matter bound to clay lasts long in soil



Scharpenseel, H.-W., Tsutsuki, K., Becker-Heidmann, P. and Freytag, J., Zeitschrift fur Pflanzenernaehrung und Bodenkunde, 149: 582-597 (1986)

Formation of methane from paddy soils



Characteristics of paddy soils

- Characteristics of paddy soils are due to the flooding.
- Supply of oxygen is limited by the surface water, and the oxygen in the ploughed layer soil disappears. Iron oxide and manganese dioxide are consumed by the microbes and the soil becomes anaerobic.

Problems related to paddy soils (1)

- Problems due to soil reduction after flooding

  Formation of volatile fatty acids

  Acetic acid, Propionic acid, Butyric acid

  Formation of hydrogen sulfide

  due to sulfuric acid reducing bacteria

  SO_4^{2-} → H_2S

Problems related to paddy soils (2)

Formation of methane

- Around 10 % of the global methane formation is from paddy field.
- Formation of methane from paddy soils is controllable by field management, organic matter management, and irrigation water management.

Formation of nitrous oxide

- During the denitrification process, N_2O is formed.

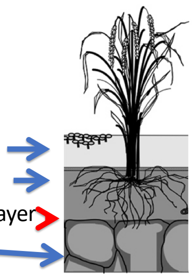
How to solve the problems

- Problems of volatile fatty acid, methane, and nitrous oxide formation can be solved by the following measures.
- Avoiding to bring the soil condition strictly anaerobic by conducting intermittent drying.
- Avoiding to incorporate fresh rice straw or fresh green manure.
- Wait some time after organic matter application before seeding rice.
- Refrain from excess nitrogen fertilizers.
- Apply ammonium form fertilizer deep in the reduced soil layer.

Composition of paddy soil

Paddy field has many excellent merits.

- Surface water
- Ploughed layer
- Ploughed pan layer
- Sub layer



Merits of paddy soil

① Problems due to continuous cropping are rare.

- Reason

1) Pathogenic fungi and nematodes die under anaerobic condition.

2) Growth inhibiting substances are washed by the irrigation water.

→ Rice cropping is continued for more than thousands of years in some places, e.g. rice terrace in Banaue, Philippines.

② Soil fertility does not decrease.

- Reason

1) Supply of nutrients from the irrigation water.
2) Decomposition of organic matter is repressed due to the anaerobic condition.
3) Various kinds of nitrogen fixing organisms are living in the surface water, and in the root zone soil.

③ Natural nutrients are supplied abundantly.

- Reason

1) Nitrogen is supplied from soil organic matter, and the formed ammonium is held by clay minerals and will not be washed away easily.
2) Iron phosphate becomes soluble after the reduced condition is formed.
3) Potassium and silicates are abundant in the irrigation water.
4） Soil pH becomes neutral after flooding the soil.

④ Due to the high ability to adjust the temperature, rice crop becomes tolerant to meteorological hazard.

- Reason

Due to the high specific heat of water, soil temperature is kept high and the cold injury of rice is mitigated in the cold area.

⑤ Removes nitrogen and phosphorus from the irrigation water.

- Reason

1) Excess nitrogen is denitrified.
2) Excess phosphorus is adsorbed on soil constituents.

⑥ Soil erosion hardly occurs.

- Reason

1) The paddy field is flat.
2) Soil erosion is controlled by the ridges and flooding water.

⑦ Weeds grow little.

- Major weeds in the paddy field are Eriochloa species and Carex species.
- Few weeds grow in flooded water.

⑧ Genetic potential of rice.

Rice plant tolerant to climate change.
New varieties from IRRI.

- Flood tolerant rice
- Drought tolerant rice
- Salt tolerant rice
- High temperature/ Low temperature tolerant rice
- Problem soil tolerant rice（Zinc deficiency・Potassium deficiency・Iron excess・Aluminum excess）