Soil Humus Distribution as Affected by Climatic and Pedological Conditions

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Abstract

In order to elucidate the principles determining plant residue decomposition and humus accumulation in soil, we attempted to make a simple model of soil organic matter accumulation. In this model, soil organic matter accumulation was related to the decomposition rate and annual plant production, both of which were treated as functions of annual temperature. Results of calculations showed tendencies in soil organic matter distribution along a temperature gradient, though the effects of soil factors were considered to be highly significant.

1. Introduction

Soil organic matter plays an important role in fertility and changes in it accompanying climatic disturbance, may have some effects on food production. Nevertheless, it has not yet been assured whether or not there is any 'general law' in soil organic matter distribution.

The objectives of this report are to present a simple model of soil organic matter accumulation, to consider its geographical distribution, and to consider the climatic and pedological factors affecting humus distribution.

We assumed the following three suppositions:
1) The degradation process can be approximated by a first order kinetic model. This was postulated by H. Jenny (1949) for the first time, and thereafter accepted by other researchers.
2) Chemical components of plants and chemical reactions in soils are in principle common all over the earth.
3) Based on these two suppositions, it should be possible to correlate the degradation rate with the amount of accumulation or the geographical distribution of humus.

2. A model

When a certain amount (P) of plant residue is added into soil once a year and its decomposition occurs following the first order kinetics,

\[ \frac{dP}{dt} = -kP \]  (1)

the total amount of humus remaining in soil (C) after n years will be
where \( k \) is a kinetic constant. When \( n \) is sufficiently large, Eq. (2) is rewritten as follows:

\[
C = P \exp(-k) /[1 - \exp(-k)]
\]  

(3)

Annually added plant carbon will be a part of the net primary production (NPP). The part will be proportional to NPP, which is calculated using the Chikugo model proposed by Uchijima and Seino (1985):

\[
\text{NPP} = 0.29[\exp(-0.216\text{RDI}^2)]\text{Rn}
\]  

(4)

where RDI is the radiative dryness index (RDI = Rn/(lr)), where Rn is net radiation, \( l \) is latent heat of evaporation, and \( r \) is precipitation. In this model, NPP is a function of net radiation and precipitation. However, net radiation data are seldom included in soil profile descriptions. Therefore, it would be more convenient to use temperature rather than net radiation. Seino and Uchijima (1992) proposed the following empirical relationship between net radiation and annual mean temperature.

\[
\text{Rn} = 10.18 + 3.13 \text{Ta} \quad \text{when} \quad \text{Ta} \geq 0
\]  

(5)

Thus, when annual mean temperature (Ta) is above 0 degrees C and RDI is 1, we can calculate the amount of plant residue (P) from

\[
P = 0.23(10.18 + 3.13 \text{Ta})h
\]  

(6)

where \( h \) is a proportional constant.

As for the effect of temperature on the kinetics, the Q_{10} rule is familiar to us. The Q_{10} rule would be replaced by Arrhenius' equation,

\[
k = k' \exp(-\text{Ea}/\text{RT})
\]  

(7)

where \( \text{Ea} \) is activation energy, \( R \) gas constant, \( k' \) a constant and \( T \) absolute temperature.
3. Results and Discussion

Assuming that $k'$ is $\exp(20)$ and $T_a$ is 15 °C, $E_a$ could be calculated for $k$ ranging from 0.02 to 0.4. By combining $E_a$ with $k'$, we should be able to calculate the amounts of accumulated carbon in the soil. The results are shown in Fig. 1.

Comparing the curves calculated with some combinations of $E_a$ and $k'$, we can find that a decrease in soil organic matter due to higher temperature would surpass the increase of plant production in lower latitudinal districts.

In this figure, the observed data of accumulated carbon of more than 20 volcanic ash soils in Japan were plotted. The data were divided into two groups. One group indicates volcanic ash soils including active (dithionate soluble) $\text{Al}_2\text{O}_3$ of more than 3%, the other soils include active $\text{Al}_2\text{O}_3$ less than 3%. The figure shows that soils with active aluminum have higher amounts of carbon.

These results show that plant production and climatic conditions are factors determining the amount of soil organic matter, and also that we need to take into account soil factors, such as active aluminum contents, soil type, fertilizers, and so on. Some of these soil factors, such as clay and active aluminum would be suppressive to the decomposition of plant material. Other factors, such as fertilizers, would accelerate decomposition. Though soil physical conditions such as moisture contents or aeration could be important for decomposition and the accumulation of soil organic matter, the effects were not considered in our model.

4. Conclusion

In this study, we developed a simple model to calculate soil organic matter accumulation by combining a first order kinetic model of decomposition and a plant production model (the Chikugo model). Our simple model indicated that kinetic constant $k$ affects the amount of carbon accumulation in soil.

References


Figure 1. Relationships between humus accumulated (C, t/ha) and annual mean temperature (Ta, °C).

△: volcanic ash soils with active Al>3%
▲: volcanic ash soils with active Al<3%