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Experimental Study on Erosion Control Using Natural Soil Microorganisms

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Résumé : Le but de cette étude est d'évaluer quantitativement l’effet de limitation de l'érosion par la croûte biologique de sol constituée par des mycètes et des algues sur le sol. Des observations sur les lieux et des expériences laboratoire ont été effectuées. La croissance des micro-organismes a été évaluée par le niveau de résistance de la couche contre déplacement d’une barre fine ou de treillis. La croissance a été corrélée au taux d'érosion obtenus par des résultats des expériences de laboratoire. Avec une bonne combinaison de la température, de l'humidité et des éléments nutritifs, les micro-organismes de sol peuvent se développer très rapidement. Cette étude a démontré qu’ils peuvent provisoirement empêcher l’érosion en attendant que le reboisement puis être mis en œuvre.

Introduction

In Japan, the discharge of fine-grained sediment often impacts on the issues of flood control and water utilization as well as environment. Common examples include silting in dams and the extermination of organisms in coastal coral reefs. Attempts to prevent the sediment discharge using structural measurements tend to be costly and labor-intensive. Another approach is to use planting works at the source, but it often takes considerable time for the vegetation to be stabilized and effective enough. Thus, a true low-cost, instantaneously effective solution has never been found yet.

Previous studies such as Cameron (1966) have demonstrated the erosion control effect of the biological crust formed by soil fungi and algae. Although this is considered a promising solution, no quantitative evaluation of the efficacy of this technique has yet been carried out. This report presents the findings of the study in which field observations and hydraulic experiments were used to evaluate the extent of soil erosion achieved by biological crust formed by soil microorganisms, namely fungi and algae.

Methods and Results

The soil of interest is the reddish-yellow soil produced from intensively weathered sedimentary rock, hereinafter called “red soil”, taken from Okinawa prefecture in the south-western islands of Japan. It is a common source of fine particles damaging to coral reefs. Figure 1 shows the grain size distribution and the density of soil particles. Red soil has a high content of fine particles, with over 60% of the particles classified as silt or clay.

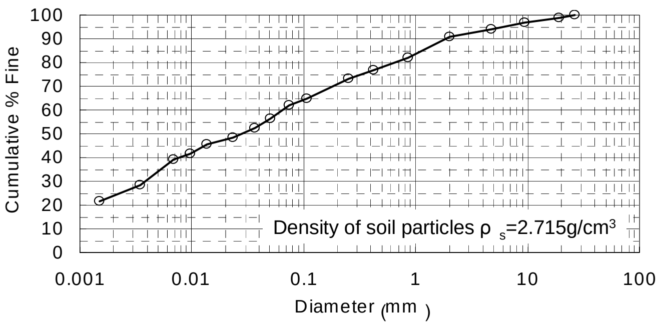

Fig. 1 Grain size distribution of the red soil

Bagasse, the fibrous residue of the sugarcane that remains after sugar extraction, was mixed into the soil to promote the microorganism growth. Figure 2 shows fungal growth in the soil, with the filaments helping to bind together the soil particles. The names of the fungi identified in the soil are *Trichoderma*, *Cladosporium*, *Alternaria* and *Penicillium*. Microscopic analysis suggests that these fungi grow steadily over time for a period of around two weeks in the conditioned laboratory, and that the supplementation of bagasse promotes microorganism growth in the soil.

Fig. 2 Fungal growth in soil

Field observations were performed in Okinawa at two sites: one where fungi and algae growth had produced a biological crust, and another with bare ground. Rainfall, runoff and suspended soil (SS) concentrations were measured over a period of five months, from June to October 2000. The sediment yield was obtained by multiplying the observed flow rate and SS concentration.

Figure 3 shows the results indicated the sediment yield of 1,038 g/m^2 from the bare ground site, compared to just 22 g/m^2 from that with fungi and algae, indicating that the biological soil crust reduces sediment yield to around 2%.

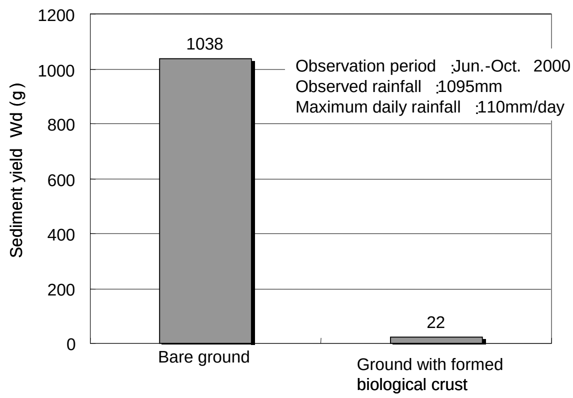

Fig. 3 Sediment yield per unit area

A rectangular experimental channel at an inclination was used to determine erosion rates by measuring the discharged sediment for various different flow rates. The experimental channel of width of 30 cm and length of 1 m was set in the flume and filled with the soil collected from the site. Water was flowed in the channel at five different flow rates for a period of 10 minutes each. The sediment yield was measured at the lower end of the channel.

Figure 4 shows the results of the experiments. The horizontal axis represents the average flow velocity and the vertical axis represents the cumulative sediment yield. Two cases are shown: untreated soil and soil mixed with bagasse. It can be seen that, for any given water flow velocity; soil containing bagasse is less likely to be washed away than untreated soil. Up to a certain point, the amount of improvement is proportional to the quantity of bagasse in the soil.

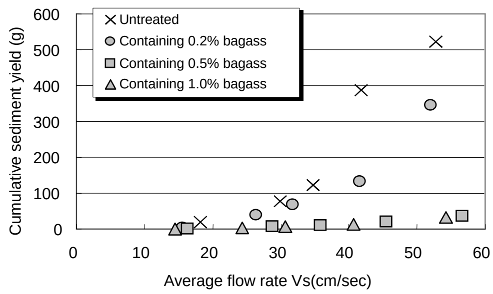

Fig. 4 Average water flow velocity versus sediment yield

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The tensile resistance experiment involves laying a lattice (or stainless steel rods of diameter ø2.5 mm) over the ground surface. The lattice is then removed by lifting away gently from the ground after the growth of soil microorganisms. The level of the resistance during the removal process is measured. As shown in Fig.2, the microorganisms bind the soil particles together and may increase the level of resistance to the removal of the lattice. Figure 5 shows the way to measure the tensile resistance.

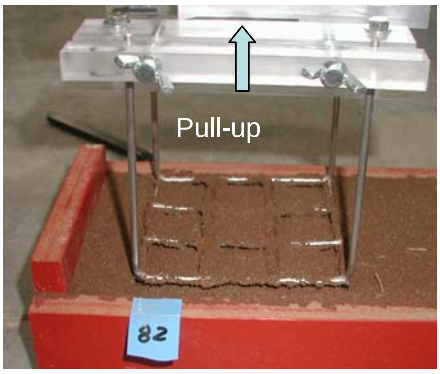

Fig. 5 Tensile resistance experiment

Figure 6 shows the temporal increase in the tensile resistance. It can be seen that the resistance increases in proportion to the growing period. Resistance was 0.034 N/cm after 14 days, rising to around 0.04 N/cm after 28 days. Microscopic observation shows microorganism growth in proportion to the growing period, suggesting that growth of soil microorganisms is linked to the increase in tensile resistance.

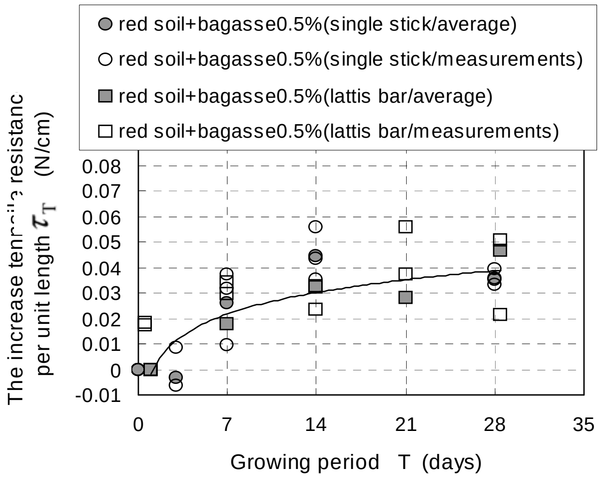

Fig. 6 The increase in the tensile resistance and the fungal growth to the tensile resistance

Discussion

The results from the above experiments were used to conduct a quantitative analysis of the erosion control effects of the microorganisms in soil.

Figure 7 shows the correlation between the normalized erosion rate (R) and the increase in the lattice tensile resistance $\Delta\tau_T$ where the erosion rate at 0 days (with zero growth in soil microorganisms) is defined as a unity. It can be seen that the normalized erosion rate declines in direct proportion to the increase in $\Delta\tau_T$. Removal resistance due to the growth of microorganisms (as shown in Fig. 6) was added to the erosion equation derived from untreated soil with no microorganisms to produce the following general expression for the erosion rate (E):

$$E = 4\times10^{-7}(U_* - 2.5)\cdot\left(\frac{0.01}{\beta\cdot C_{0s}}\right)^4 \qquad (1)$$

$$\beta = R^{-1/4} \qquad (2)$$

$$R = -21\times\Delta\tau_T + 1 \qquad (3)$$

$$\Delta\tau_T = 0.013Ln(T) + 0.0013 \qquad (4)$$

where; β = correction factor of C_{0s} for biological crust
U_* = friction velocity (cm/s)

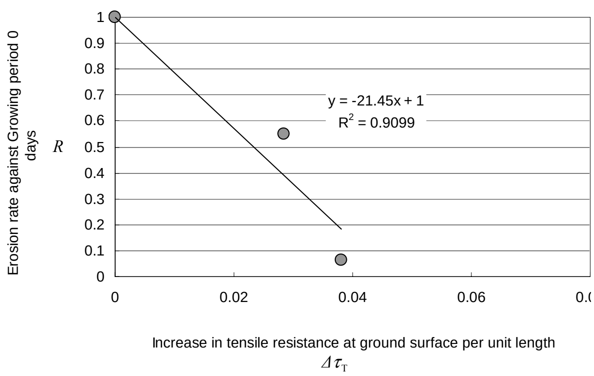

Fig. 7 Relationship between tensile resistance and erosion rate

C_{0s} = cohesion of the surface layer for untreated soil (N/cm^2)
T = fungal growing period (days)

Conclusions

This study used a combination of field observation and experiments to evaluate the erosion control properties of the biological soil crust formed by soil microorganisms.

The conclusions were shown as follows.

a) Nutrient material such as bagasse promotes the growth of soil microorganisms.
b) The tensile resistance of the soil microorganism increases according to the curing period.
c) Sediment yield per unit area is lower in areas with a well-formed biological soil crust relative to areas of bare ground.
d) The erosion rate is inversely proportional to the lattice removal resistance.

An expression for erosion rate was derived on the basis of a quantitative analysis of soil microorganism growth.

Soil microorganisms grow very quickly under the right combination of temperature, humidity and nutrient conditions. Promoting the growth of soil microorganisms represents an effective temporary solution during the period when planting works have not yet taken hold, particularly in farm fields and other locations where structural measurements are unfeasible. Given that microorganism growth is vulnerable to variations in external environmental factors such as temperature and humidity, however, further practical testing and development in the field is considered necessary.

Literature cited

[1] Cameron, RE and GB Blank. (1966); Desert algae: soil crusts and diaphanous substrata as algal habitats. Jet Propulsion Laboratory Technical Report 32-971