土壌硬化剤を用いた改良土壌の侵食抑制効果

Soil erosion reduction effect on soil improvements by adding hardening agent

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1. Introduction

In recent years, the erosion of red soil in Okinawa has become a serious problem which effects not only agriculture, but also ecosystems, fisheries and tourism. The excessive loss of red soil has a negative impact on the water environment in the Okinawa and seriously damages the watershed ecosystem represented by the coral reef. Besides, soil erosion means the loss of farmland surface soil, which is a great loss to farmers. In order to reduce soil erosion effectively and sustainably, it is considered to adding soil conditioners. Soil hardening agent, "Farm-Coat", is developed using polymer emulsion by Denka Company Limited which could harden the soil surface to reduce soil erosion. It includes humic acids which could promote the growth of crops and retention. However, the specific amount of erosion reduction is not quantified.

Based on the above background, the objective of this study is set to quantitatively evaluate soil erosion reduction effect on soil improvements by adding soil hardening agent, Farm-Coat. Specifically, laboratory erosion experiments and numerical erosion simulation using Water Erosion Prediction Project (WEPP) would be conducted to evaluate the erosion reduction effects of improved soils with addition of Farm-Coat. Also measuring the physical properties of soil during the improvement, such as aggregates and water permeability. The relationship between them with erosion reduction effect will be discussed.

2. Materials and methods

WEPP is a physically-based model developed by USDA which can present erosion process. By inputting climate data, soil data, topography data, and management data, not only the soil erosion occurred on the farmland, but also the sediment transport process in the watershed can be expressed. In the process of soil erosion, rill erosion (soil detachment and transport in the rill) and interrill erosion (mainly occurs on the slope between rills) are the main factors. WEPP uses rill erodibility, interrill erodibility, and critical shear stress to estimate the erosion loss. In this study, these parameters are obtained by experiments.

Amount of interrill and rill erosion is estimated by following equations.

$$D_i = K_{ib} \cdot I \cdot \sigma \cdot S \qquad (1)$$

$$D_f = K_{rb}\left(\tau_f - \tau_{cb}\right) \qquad (2)$$

where, D_i : interrill erosion loss [kg·m^{-2}·s^{-1}], K_{ib} : interrill erodibility [kg·m^{-4}·s], I : rainfall intensity [m·s^{-1}], σ: runoff rate [m·s^{-1}], S: interrill slope adjustment, D_f : rill erosion loss [kg·m^{-2}·s^{-1}], K_{rb} : rill erodibility[s·m^{-1}], τ_f : overland flow shear stress [Pa], τ_{cb} : critical shear stress [Pa].

As laboratory experiments, erosion tests conditions are showed in **Table 1**. Amount of application and dilution ratio of soil conditioner are showed in **Table 2**. Changing the presence and amount of various soil conditioner as the conditions to estimate the amount of erosion.

Table 1 Erosion tests conditions

	Interrill erosion test	Rill erosion test
Soil box	50 cm × 37 cm × 16 cm	50 cm × 5 cm × 15 cm
Slope	7.5°, 15°	5°～25°
Rainfall / Runoff intensity	18.3～71.1 mm/h	0.23～2.13 L/min

Table 2 Conditions for adding soil hardening agent

Conditioner	Soil	Amount	Dilution rate	Code
Farm-coat	Kunigami-Maji	500 g· m^{-2} *	4	F500
	Kunigami-Maji	100 g· m^{-2}	20	F100
	Kunigami-Maji	50 g· m^{-2}	40	F50

*500 g·m^{-2} was a standard usage reported by Denka Company Limited

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3. Results and discussion

Interrill erodibility, rill erodibility, and critical shear stress of test soil with soil conditioner were summarized in **Table 3**. Comparing with the control, interrill erodibility of all conditions were decreased. Even had a larger agent addition, interrill erodibility of F100 showed a less reduction than F50. Comparing runoff ratio of F100 and control, the values were almost same. Furthermore, significant cracks were not developed in the interill erosion test of F100. Above these results, Farm-Coat 100 g·m^{-2} was not fully functioned in interrill erosion test. In the case of rill erodibility, value of F500 and F100 showed more than 99% reduction, and F50 also fell 65%. Critical sheer stress was not measured directly in the case of F500 and F100 due to limitation of runoff rate on rill erosion test. Compared with the control, critical sheer stress under all conditions of adding Farm-Coat had been improved.

Table 3 Erodibility of test soil with soil conditioners

Test soil	Interrill erodibility K_{ib} (kg·m^{-4}·s)	Reduction (%)	Rill erodibility K_{rb} (s·m^{-1})	Reduction (%)	Critical shear stress τ_{cb} (Pa)
Control	1.22×10^{6} *	—	9.77×10^{-3} *	—	1.02 *
F500	0.01×10^{6}	99	0.0007×10^{-3}	99	—
F100	0.80×10^{6}	34	0.017×10^{-3}	99	—
F50	0.48×10^{6}	61	3.42×10^{-3}	65	1.83

* Values were used from Kojima et al. (2018)

To estimate the annual soil loss, WEPP model was used by inputting climate data, topography data, management data, and soil data including acquired soil erodibility parameters. In the case of critical shear stress that not measured directly, this study used the largest value in rill tests as input values. This study used 100-years virtual climate data of Naha, Okinawa which generated by CLIGEN. Slope length 100m, gradient in the downflow direction 3% were inputted as topography condition. For management data, we used bare soil. Simulation results are presented in **Table 4**. F500 and F100 showed more than 97% reduction in annual soil loss. Especially, the reduction ratio of rill erosion loss was almost 100% in F500 and F100. This indicates that rill erosion has been greatly prevented. Soil loss of F50 also had a 40% decrease.

Table 4 Annual soil loss estimated by WEPP

Test soil	Soil loss (kg·m^{-2}·yr^{-1})	Reduction (%)	Interrill erosion (kg·m^{-2}·yr^{-1})	Rill erosion (kg·m^{-2}·yr^{-1})
Control	48.82	—	2.099	46.721
F500	0.023	99	0.022	0.001
F100	1.387	97	1.38	0.007
F50	29.115	40	0.827	28.288

Table 5 Economic benefit of soil hardening agent for sugarcane field

Amount	Soil loss (t·ha^{-1}·yr^{-1})	Soil loss reduction (t·ha^{-1}·yr^{-1})	Economic benefit (1000 yen·ha^{-1}·yr^{-1})
500 g· m^{-2}	0.04	40.5	10,088
100 g· m^{-2}	2.39	38.2	9,504
50 g· m^{-2}	11.77	28.8	7,168

However, the high cost of soil hardening agent is a serious problem. According to Okinawa prefecture (2008), economic benefits of prevent red soil was 249,000 yen·t^{-1}·yr^{-1}. To suggest an effective cost performance option, this study compared soil hardening agent with economic benefit under management of sugarcane in **Table 5**. All of usage of Farm-Coat showed a high economic benefit. This suggests that Farm-coat may show great cost performance in practical application.

4 Conclusion

Soil improvements by adding hardening agent was effective for reduction of soil erosion. Farm-Coat reduced rill erosion significantly. It also showed possibility of high cost performance. For practical applications, it is necessary to compare the values obtained by WEPP simulation with field test results. Also, effect persistence of improvement by soil hardening agent should be tested.

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Reference

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