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Influence of Cabbage Growth on Ridge Erosion

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ABSTRACT

The influence of cabbage growth on ridge erosion was studied to simulate soil erosion on cropland with ridge and furrow cultivation by a physically based model. Simulated rainstorms were applied to container plots simulating crop rows with and without plants at 5 crop growth stages. Rainfall intensities, the row sideslope gradients, the canopy cover ratio, and soil losses from the slopes were measured. On the bare plots, soil losses were caused mainly by splash erosion due to the direct impact of raindrops on the soil surface. Soil loss increased in proportion to the square of the rainfall intensity and to the slope gradient. On the planted plots, soil erosion decreased as the crop developed. Our observations suggest that the direct impact of rain on soil not covered by the canopy contributed greatly to erosion, and that the canopy cover ratio was the only significant crop factor affecting soil erosion. The effect of cabbage cover on interrill erosion rate could be described as a linear function of the canopy cover ratio. The results suggest that variations in ridge erosion affected by cabbage growth over time can be estimated from the canopy cover ratio.

INTRODUCTION

Physically based erosion models, such as WEPP (Nearing et al., 1989) and EUROSEM (Morgan, 1994), can simulate temporal and spatial distribution of soil erosion across an agricultural field. The models can be applied to farmland with a wider range of conditions than empirical models can manage. Takagi et al. (1996) and Nakao et al. (1996) showed the applicability of the physical approach to bare sloping fields in Japan. Submodels describing the influence of crop and management on soil erosion need to be developed for more practical prediction of cropland erosion.

Ridge and furrow cultivation is common for the production of cabbage and other crops in Japan. When soil erosion is estimated by the physically based approach, ridge and furrow erosion processes are simulated separately. Ridge erosion is often treated as interrill erosion. The effect of crop cover on interrill erosion rate at each crop growth stage should be quantified in simulations of the ridge erosion process because crop growth causes variations in the interrill erosion rate over time (Meyer and Harmon, 1992).

It is well known that crop cover affects soil erosion. Wischmeier (1975) proposed a model to estimate the crop canopy factor, a subfactor of the crop and management factor (C) of the USLE. Khan et al. (1988) also developed the canopy factor model from laboratory experiments with a simple dummy of the canopy. These models showed that soil loss decreased in proportion to increasing canopy cover. Morgan (1985), however, observed that, although soil detachment decreased with increasing canopy cover for soybean, it increased with increasing canopy cover for corn. He suggested that the transformed raindrops from the canopy might have been a more efficient detaching agent than natural rainfall. Armstrong and Mitchell (1987, 1988) reported that drop size and spatial distribution of rainfall under a crop canopy depended on the canopy architecture. Although the effect of crop cover on interrill erosion has been studied for a long time, little information is available to quantify the effect for major crops.

The objective of this study was to assess the influence of crop growth on ridge erosion by measuring the effect of crop cover on interrill erosion rate. The study used cabbage, a major agricultural crop in Japan.

MATERIALS AND METHODS

Container plots simulating crop rows were prepared to study the effect of cabbage cover on interrill erosion rate (Fig. 1). Kuroboku soil taken from a cultivated field in the Tsumagoi district of Gunma Prefecture in Japan was used. This is a volcanic ash soil consisting of 78% sand, 15% silt, and 7% clay. After the soil was passed through a 5-mm sieve, it was dried to 20% water content. The soil was placed in the containers as uniformly as possible with oscillating sieves (Miura and Toki, 1982). Each container was 1000 mm long, 400 mm wide, and 525 mm deep. The average dry density of the soil was 0.56 g/cm^3 and the average hydraulic conductivity was 2.66×10^{-2} cm/s. The upper part of the each container was shaped with a knife into two parallel ridges, which were isosceles triangles in cross-section. Each ridge was 500 mm wide and 400 mm long. A soil collector, made of an angle bar, was installed in the bottom of the furrow to catch soil eroded from the center side slopes.

We used a rainfall simulator similar to that developed by Meyer and Harmon (1979). Two kinds of nozzles, Veejet 80100 and 80150 (Spraying Systems Co., Tokyo, Japan), were used to simulate rainstorms of 5 intensities (20, 40, 60, 80, or 100 mm/h). The Veejet 80100 was used for a storm of

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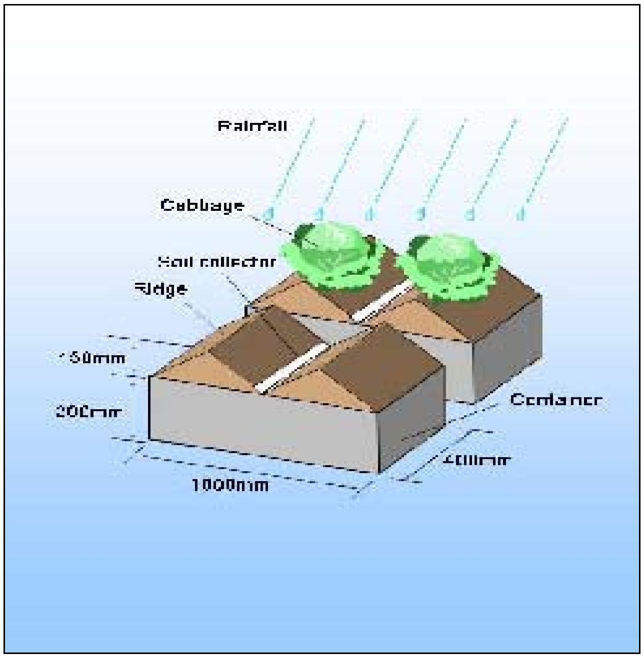

Figure 1. Schematic diagram of experimental plots.

20-mm/h intensity , and the Veejet 80150 was used for the other intensities. The pressure at the nozzles was 41 N/m^2, and the delay time for each pass across the plots was adjusted to give a rainstorm of the designed intensity.

The effect of cabbage cover on interrill erosion rate was studied with 3 replications of 2 plots. One plot had a cabbage plant at the center of each ridge; the other had no plants (Fig. 1). Two initial treatments were applied to standardize the plot conditions. For the soil moisture conditions, the bottom of the each plot was soaked in water for 24 h. For the surface conditions, a 20-min pre-wetting rainfall at 60-mm/h intensity was applied to the plots. A series of 5 rainstorms was applied to the plots after these treatments. The series was simulated at 100, 80, 60, 40, and 20 mm/h, each fall separated by about 10 min, for 20 or 30 min each. Rainfall was measured with 3 rain gauges placed beside the plots to determine the actual intensity. After each rainstorm, soil loss samples were collected and oven-dried for weight determination. Each ridge height, set initially at 150 mm, was also measured after each run.

The experiments were run at 5 crop growth stages. Cabbages were planted in the plots on 28 September 1997 and grown outdoors until 11 November 1997. The canopy cover ratio at each test was determined from photographs taken at a height of 3 m above the soil surface.

Additionally, 2 replications of 5 slope gradients (69.7%, 53.4%, 41.3%, 33.4%, and 19.9%) were used with bare container plots. The series of 5 rainstorms was applied to the plots, each of which started with a slope gradient of 69.7% after the standardizing treatments. The actual intensity and soil loss in each run were obtained. After the series of rainstorms for the first slope gradient, each ridge was adjusted to 53.4% slope gradient and the series of 5 rainstorms was applied again. The experiments were repeated for each slope.

RESULTS AND DISCUSSION

Erosion Process

In the bare plots, the direct impact of raindrops eroded soil and produced numerous pockmarks on the surface. Neither crusting nor rilling was detected. These observations indicated that splash erosion was the main cause of the soil erosion on the bare plots.

In the planted plots, the cabbage canopies intercepted the raindrops. There were no appreciable pockmarks caused by water drops from the leaf margins. This is probably because the drops from the margins, falling only 0–10 cm, had insufficient kinetic energy to detatch the soil. No appreciable overland flow occurred. This implies that raindrops through the canopy, drops from the leaf margins, and overland flow on the ridges contributed little to the ridge erosion in the planted plots.

The physical binding of soil by plant roots may affect the erodibility of a soil (Stocking, 1994). We found that the roots bound the soil beneath the canopy but not elsewhere.

Pockmarks were present on the parts of the soil surface that the canopy did not cover. This suggests that the total volume of soil loss from the whole of each plot was nearly equivalent to that from the uncovered part of the plot. Thus, the size of the uncovered part of the planted plot influenced the quantity of soil loss. It is safe to say that the canopy cover ratio was the only significant crop factor affecting soil erosion (others being canopy height, architecture, and roots).

Effect of Rainfall Intensity

The soil erosion increased with rainfall intensity. We used erosion data from the bare plots with an initial ridge height of 150 mm to describe the effect of rainfall intensity on soil erosion. Regression analyses determined the parameters of an interrill erosion equation used by Meyer (1981):

$$\boldsymbol{D_i = a\, I^p} \qquad (1)$$

where $\boldsymbol{D_i}$ is the interrill erosion rate (kg m^{-2} s^{-1}), $\boldsymbol{I}$ is rainfall intensity (m s^{-1}), and $\boldsymbol{a}$ and $\boldsymbol{p}$ are coefficient and exponent, respectively. The coefficients of determination (r^2) for the regression equations varied from 0.86 to 0.96. The values of $\boldsymbol{p}$ varied from 1.80 to 2.15. Figure 2 shows examples of the relationship between rainfall intensity and interrill erosion rate. Regression analyses were used to find the r^2 values for a constant exponent form:

$$\boldsymbol{D_i = a\, I^2} \qquad (2)$$

The r^2 values ranged from 0.86 to 0.93. This indicates that equation (2) could express the effect of rainfall intensity on interrill erosion rate for the studied soil. This result was similar to that reported by Meyer (1981), who found that equation (2) worked quite well for soils with low clay contents.

Effect of Slope Gradient

The effect of sideslope gradient of the crop row on interrill erosion rate was studied with data from the bare plots with different slopes. Fitting the data to equation (2) gave r^2 values from 0.94 to 1.00. As shown in Figure 3, there is a linear relationship between coefficient $\boldsymbol{a}$ and slope

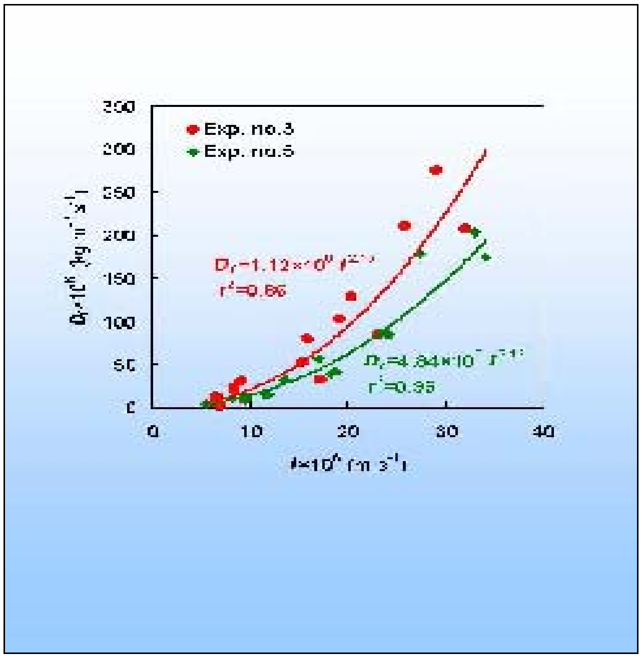

Figure 2. Examples of effect of rainfall intensity *I* on soil loss rate D_i.

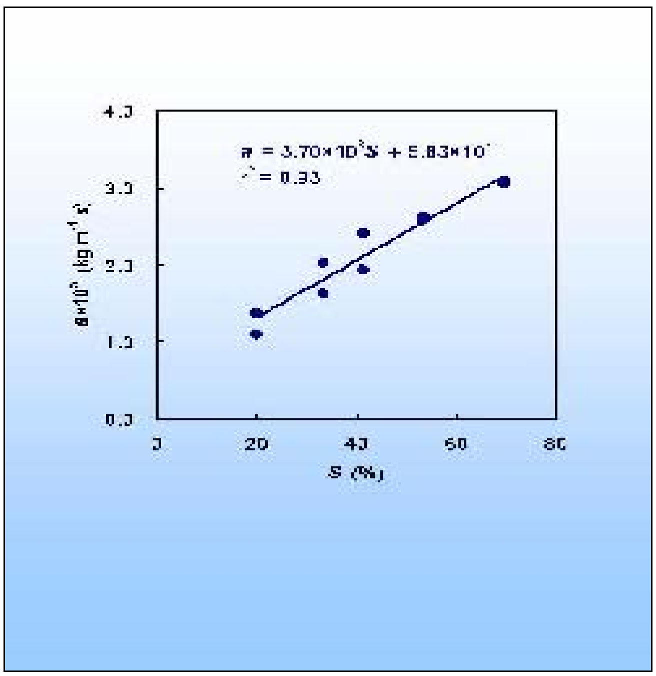

Figure 3. Effect of slope gradient *S* on coefficient *a* for interrill erosion equation $D_i = aI^2$

gradient. A linear regression equation describing this relationship gave an r^2 value of 0.93. The slope gradient evidently caused this variation in ***a*** because the surface and soil water conditions of the experimental plots were standardized. Thus, with reference to Foster et al. (1977) and Liebenow et al. (1990), an interrill erosion equation with a slope factor separated from coefficient ***a*** of equation (2) can be expressed as follows:

$$D_i = b\, I^2 S_f \qquad (3)$$

$$S_f = c\, S + d \qquad (4)$$

where S_f is a slope factor describing the effect of slope gradient on soil erosion, ***S*** is the slope gradient (%), and ***b***, ***c***, and ***d*** are coefficients.

A change in soil surface condition during a rainstorm, such as crusting and rilling, may affect the quantitative relationship between slope gradient and interrill erosion rate. Kinnell and Cummings (1993) reported that soils showing a linear response to variations in slope gradients tended to produce surface crusts under rainfall. The soil used in this study showed a linear relationship, but no crust formed on the surface.

Effect of Cabbage Cover

We studied the effect of cabbage cover on erosion by comparing the data from the planted plots with the data from the bare plots. A factor, ***C*,** describing the effect of crop cover on interrill erosion is defined by the following equation:

$$C = b_c / b_b \qquad (5)$$

where b_c is coefficient ***b*** of equation (3) for the planted plot, and b_b is that for the bare plot. The b_c and b_b values were calculated from equations (3) and (4), and the ***C*** values were determined from equation (5). The coefficients of equation (4) were c = 0.0145 and d = 0.228 when S_f = 1.0 at 53.4% slope gradient. The relationship between the value of ***C*** and the canopy cover ratio ***cov***, fraction of the soil surface covered by the canopy, is plotted in Figure 4. The figure shows that the value of ***C*** decreases linearly with increasing ***cov***. The best-fit equation describing the relationship, where

*C = 1.0 at **cov** = 0.00, is Change line*

$$C = -0.89\,cov + 1.0,\ (r^2 = 0.80) \qquad (6)$$

This result indicates that the relationship can be approximately expressed by the linear equation (6).

Multiplying ***b*** of equation (3) for a bare ridge by ***C*** gives an actual interrill erosion rate affected by cabbage cover at a particular crop growth stage. Using the canopy cover ratio ***cov***, we can predict the temporal variation in ridge erosion influenced by cabbage growth. As an example, Figure 5 indicates the temporal variation in ***C*** during the cropping period in the Tsumagoi district.

CONCLUSIONS

We used simulated rainfall on small plots to study the influence of cabbage growth on ridge erosion. The effects of rainfall intensity, sideslope gradient of ridge, and cabbage cover on interrill erosion rate could be described as empirical equations.

The relationship between the effect of cabbage cover on interrill erosion rate and the canopy cover ratio can be used to estimate temporal changes in ridge erosion in relation to cabbage growth. The relationship could be incorporated as a submodel of a physically based model simulating soil erosion in cabbage fields. The relationship is probably applicable to crops with a similar growth habit as cabbage, such as lettuce and cauliflower.

The relations presented in this study should be effective at estimating the erosion rate from planted ridges of Kuroboku soil, a typical soil in Japan, in the field. Further work is required to test the relations in the field.

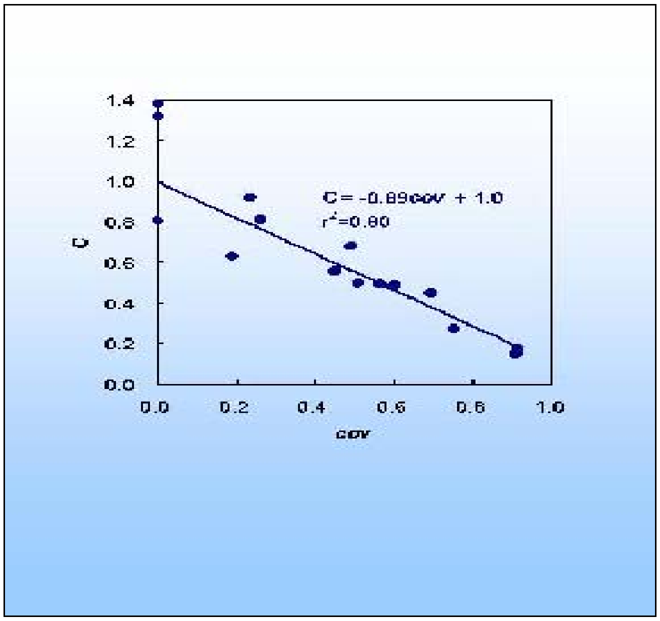

Figure 4. Relationship between effect of crop cover on interrill erosion *C* and canopy cover ratio *cov*.

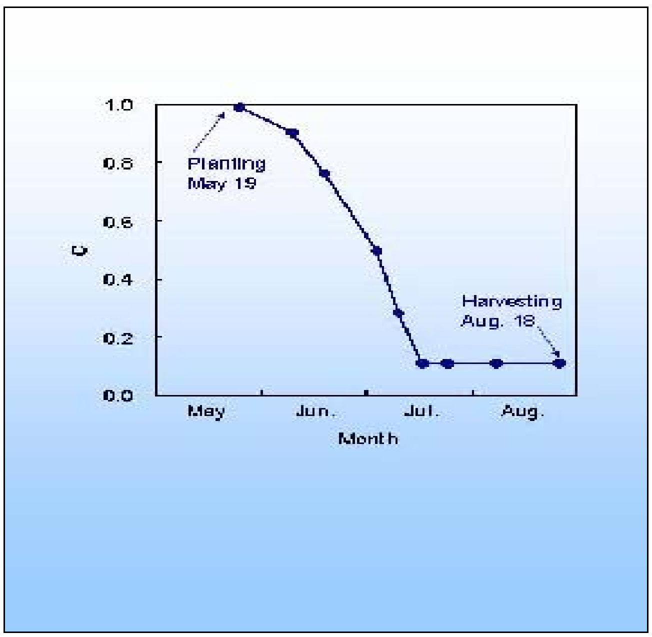

Figure 5. Temporal variation in *C* describing the effect of cabbage cover on interrill erosion in Tumagoi, 1998.

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