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Performance of Grass Strips for Sediment Control in Okinawa

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Abstract

Reddish fine sediment runoff from upland fields has been one of the causes of coastal environmental pollution in Okinawa, Japan. Planting grass strips is a well-known measure to reduce runoff of non-point-source pollutants from agricultural fields. In this study, we investigated the performance of a centipede grass (*Eremochloa ophiuroides* (Munro) Hack.) strip for reducing sediment runoff from an upland field in Okinawa, focusing on strip length and sediment aggregate size as factors affecting performance. Field experiments were conducted in field plots with a 4.0-m by 31.5-m bare source area on a Kunigami-Maji soil using three strip lengths (0.5, 1.5 and 3.0 m) under natural conditions. The sediment removal efficiencies were 24% for the 0.5-m strip, 36 to 54% for the 1.5-m strip and 73% for the 3.0-m strip. The strips trapped well the sediment aggregates larger than 0.02 mm in diameter, regardless of strip length. The longer strip trapped more aggregates of the 0.002–0.02-mm size class, which were dominant in the eroded sediment runoff from the plots. The strips poorly trapped aggregates smaller than 0.002 mm. The sediment trapping resulted primarily from deposition of sediment due to slowdown of surface flow.

Discipline: Agricultural engineering
Additional key words: centipede grass, Kunigami-Maji soil, reddish fine sediment

Introduction

Reddish fine sediment runoff from lands to coastal areas has caused an environmental problem in Okinawa, Japan. Coastal pollution due to sediment runoff has damaged marine life and has had adverse impacts on fisheries and tourism. Some of the sediment originates from upland fields on Kunigami-Maji soil[8,18]. Several measures have been proposed to reduce the sediment runoff from upland fields.

Grass strips located at the downslope ends of agricultural fields are known to reduce runoff of non-point-source pollutants from the fields into streams[3]. The effects of the strips depend on many factors, including grass type, sediment particle-size distribution, slope and length of the strip, infiltration rate, and surface-flow conditions[5]. Information on quantitative relationships between these factors and strip performance will assist farmers in selecting the appropriate strip lengths for their fields. Field studies on agricultural plots in Okinawa have demonstrated the effectiveness of grass strips in reducing the eroded sediment runoff from upland fields in several specific cases[12,14,16]. However, these studies did not report in detail on the effectiveness of grass strips for controlling the fine sediment which pollutes the coastal area. Moreover, they did not provide sufficient information to determine the appropriate strip length to install. Strip length is important because the strip reduces available cropping space in an upland field.

The objective of this study was to investigate the performance of grass strips in reducing sediment runoff from an upland field in Okinawa, Japan, focusing on strip length and sediment aggregate size as factors affecting

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performance. In this study, field plot experiments were conducted using three lengths of grass strips. The sediment removal effects were examined with respect to strip length and aggregate size, and the primary sediment trapping mechanism of the strips was identified.

Materials and methods

Field experiments were conducted at the Arashiyama field site in Nago on the northern part of the Okinawa main island (26°38′N, 127°59.5′E) from June 2002 to February 2005. This study prepared three experimental plots on a clayey, fine-textured Haplic Red soil, a Kunigami-Maji soil. The properties of the soil are shown in Table 1. One plot had no grass strip and served as a control, whereas the others had grass strips at the lower ends (Fig. 1). Each plot had a bare source area which was 4.0 m wide and 31.5 m long, with a 2% slope along the long axis. Fifty-nine percent of the farmland in the Haneji-ohkawa district including the study site has been readjusted by farmland consolidation projects. The slope length of the fields in the farmland is from 29 to 34 m and the slope steepness is from 2 to 5%. Then, the slope length and steepness set in the experiment are regarded as one of the typical field conditions in the district. The plots were individually separated from their surroundings by plastic borders. Three experimental designs with varying grass strip lengths were used during three observation periods. A single 1.5-m-long strip was used in the first period from June 2002 to February 2003, a 1.5- and a 3.0-m-long strip in the second period from June 2003 to March 2004, and a 0.5- and a 1.5-m-long strip in the third period from April 2004 to February 2005. Centipede grass (*Eremochloa ophiuroides* (Munro) Hack.), a perennial turf grass, was grown in the grass strips. The grass was fully grown at the start of each experimental period, with an average height of 7.5 cm and with vegetation coverage of 100%. The bare source areas were tilled a few times during each period to avoid soil crusting. Herbicides were used to control weeds in the bare source areas.

Table 1. Properties of the soil at the study site

Particle size distribution* (%)	
Sand	30.0
Silt	29.0
Clay	41.0
Soil texture*	LiC
Dry density (Mg m^{-3})	1.26
Specific gravity	2.74
pH (H_2O)	4.6
EC (μS cm^{-1})	22

*: ISSS method.

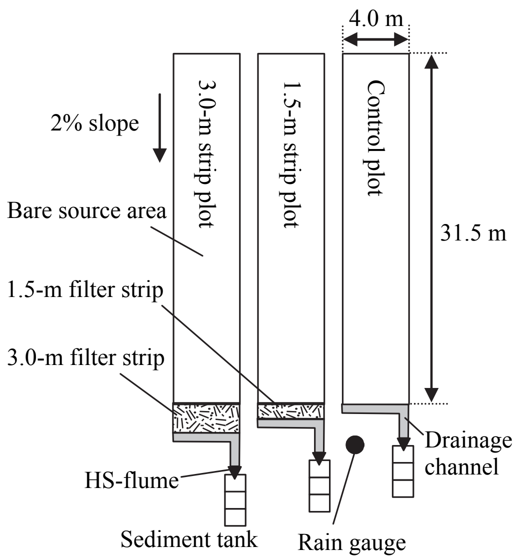


Fig. 1. Schematic diagram of the field plot for the experimental design from June 2003 to March 2004

Field measurements of rainfall, surface flow rate and sediment yield were conducted throughout the observation periods. Rainfall was measured by a rain gauge located at the experimental site. The surface flow rate from each plot was measured with an HS-Flume[1]. Sediment yield for each plot was measured twice a month with the sediment tank used by Shiono et al.[14] at the downstream end of each flume. To obtain the aggregate size distribution of the sediments, we collected sediment samples from the sediment tanks and analyzed them in the laboratory using the pipette method.

Results and discussion

1. Observations and results

The daily rainfall and cumulative sediment yields during the three observation periods are shown in Fig. 2. No data were obtained for sediment yields from 15 August to 9 September 2003. The total rainfall values recorded during the first, second and third periods were 1,743, 1,454 and 2,032 mm, respectively. The total sediment yields of the control plot during the first, second and third periods were 116, 117 and 230 kg, respectively. The total sediment yields for the grass strip plots in each period were clearly less than those from the control, indicating that the grass strips reduced sediment runoff.

The value of EI_{30}, an erosivity index defined by Wischmeier and Smith[17], was obtained for each rainfall event. The sum of the EI_{30} values for the rainfall events that generated more than 100 mm of total rain corre-

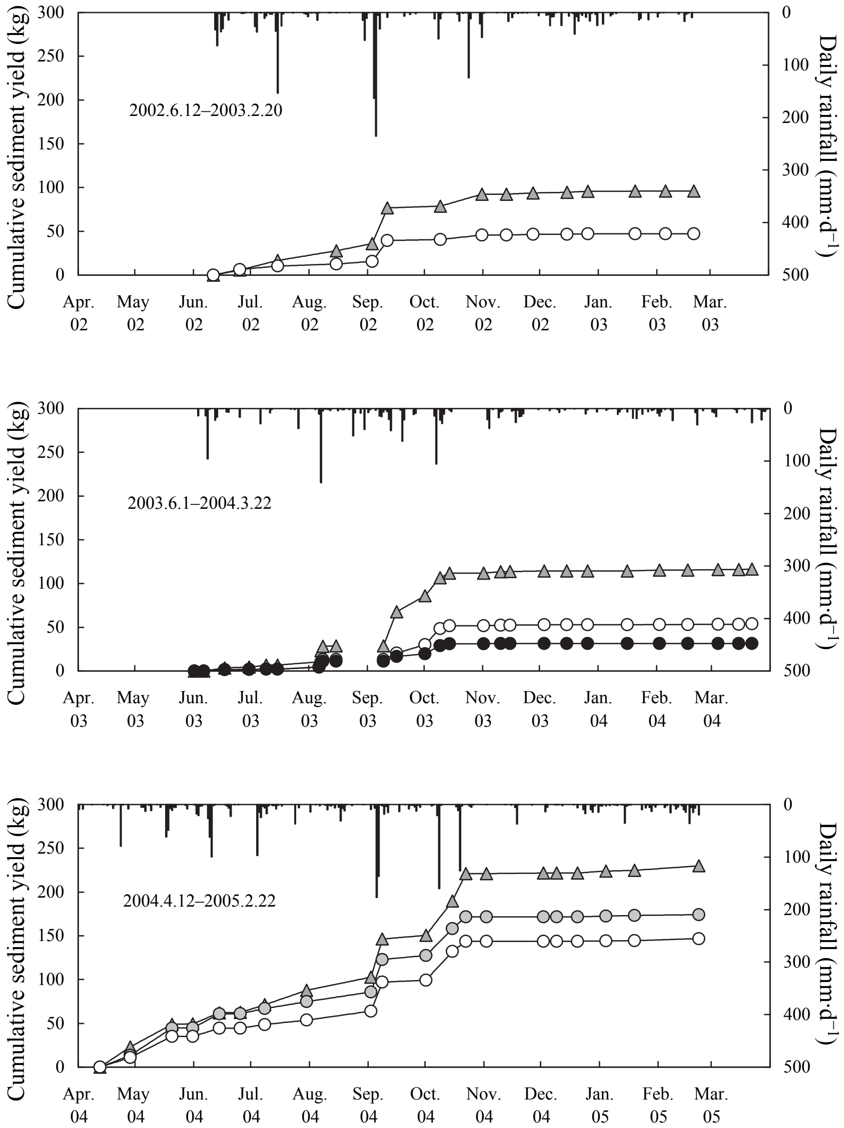


Fig. 2. Daily rainfall and cumulative sediment yield for each observation period

—— : Rainfall, —▲— : Control plot, —◎— : 0.5-m-strip plot,
—○— : 1.5-m-strip plot, —●— : 3.0-m-strip plot.

Table 2. Aggregate size distribution in the total sediment collected from the control plot

Observation period	Proportion of total (%)				
	0–0.002 mm	0.002–0.02 mm	0.02–0.2 mm	0.2–2 mm	2 mm+
2002.6.12 – 2002.12.15	2.2	42.2	50.0	3.5	2.3
2003.6. 2 – 2003.12. 3	13.2	76.7	6.7	2.7	0.7
2004.4.12 – 2005. 2.22	8.8	62.7	20.1	6.0	2.4

sponded to 48 to 71% of the total value of EI_{30} during each observation period. This finding showed that these heavy rainstorm events generated most of the sediment yields of the plots and indicates the importance of sediment control during heavy rainstorm events.

Aggregate size distribution in the sediment collected from the control plot in each period is shown in Table 2. The sum of the percentages for the sediment size classes smaller than 0.2 mm accounted for more than 90% in all three periods. Furthermore, the sediments in the

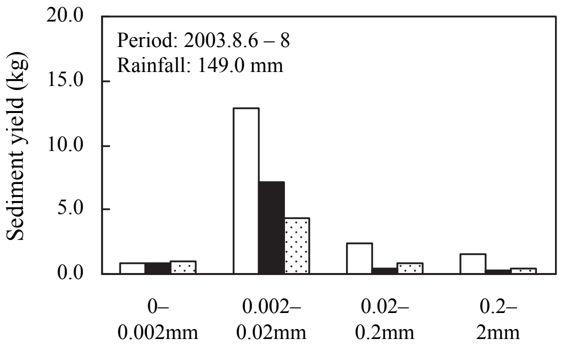
0.002–0.02-mm size class had large proportions of 42.2, 76.7 and 62.7%. Previous studies[10,11] reported that sediment particle diameters were mostly smaller than 0.074 or 0.1 mm in stream flow runoff from watersheds comprising agricultural fields with Kunigami-Maji soils. Particles of this size can be generally regarded as the primary cause of coastal pollution from upland fields. In this study, aggregates in the 0.002–0.02-mm size class were especially dominant and should be the primary target of sediment control.

2. Sediment removal efficiency

Assuming that the sediments were generated equally in the bare source areas of all three plots, we can define the sediment removal efficiency E (%) of each strip as follows:

Table 3. Sediment removal efficiencies for the grass strips

Observation period	Sediment-removal efficiency (%)		
	0.5 m	1.5 m	3.0 m
2002.6.12 – 2003.2.20		47	
2003.6. 2 – 2004.3.22		54	73
2004.4.12 – 2005.2.22	24	36	



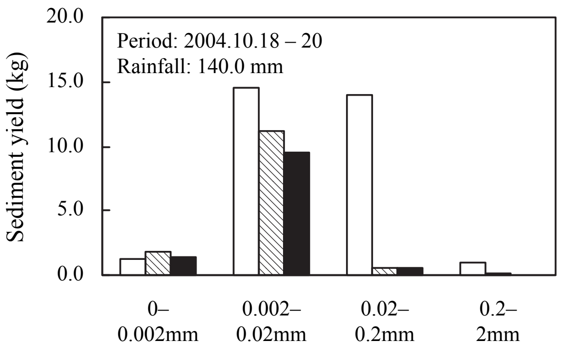


Fig. 3. Sediment yield for each aggregate size class during two rainstorm events
□ : Control plot, ▧ : 0.5-m-strip plot,
■ :1.5-m-strip plot, ⚄ : 3.0-m-strip plot.

$$E = \{ (SY_{ctl} - SY_{gs}) / SY_{ctl} \} \times 100 \quad (1)$$

where SY_{ctl} is the sediment yield from the control plot (kg) and SY_{gs} is the sediment yield from the grass strip plot (kg). The E values of each strip for the three observation periods are summarized in Table 3. The E values were 24% for the 0.5-m strip, 36 to 54% for the 1.5-m strip and 73% for the 3.0-m strip. The values for the longer strips exceeded those for the shorter strips in the second and third experimental periods, which suggests that the length of the grass strip is an important factor affecting the efficiency of sediment removal.

The sediment yields for each aggregate size class for each plot during two heavy rainstorm events are shown in Fig. 3. The E values ranged from 67 to 96% for the aggregate classes larger than 0.02 mm in diameter. The strips trapped the sediment well regardless of the length of the strip for this aggregate size class. In contrast, the sediment yields for the 0.002–0.02-mm size class varied according to the length of the strip. The E values for this size class were 45% for the 1.5-m strip and 68% for the 3.0-m strip for the rainfall event from 6 to 8 August 2003, and were 23% for the 0.5-m strip and 35% for the 1.5-m strip for the event from 18 to 20 October 2004. The longer strips trapped more sediment of this size class. For the aggregate class smaller than 0.002 mm, the sediment yields were approximately the same, regardless of strip length, and the strips poorly trapped the aggregates. Thus, sediment size distribution also appears to be a considerable factor affecting the efficiency of sediment removal. Meyer et al.[7] also reported the importance of the sediment size distribution as a factor affecting the removal efficiency of narrow grass hedges.

3. Sediment removal mechanism

Mechanisms that assist the removal of sediment by a grass strip are deposition of sediment as a result of decreased flow velocity, and movement of fine sediments into the soil matrix with infiltrating water. Filtration by the grass alone is ineffective, because the spaces between blades of grass are large relative to the size of the sediments. In this study, deposition of sediment aggregates as a result of decreased flow velocity was evidently the primary mechanism for the removal of sediment by the grass strips. This can be explained from the following observations concerning surface flow, ground surface profile and hydrological relationships.

Figure 4 shows the surface flow conditions in the control and 3.0-m-strip plots during a rainstorm event. Smooth, shallow surface flow was observed over the whole area of the control plot. In contrast, backwater due to the hydraulic resistance of the grass strip was observed

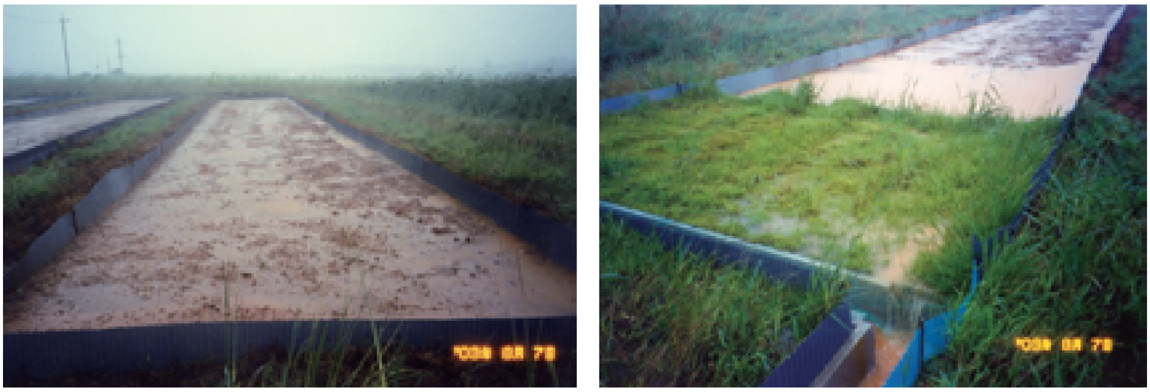


Fig. 4. Flow condition in the field plots during the rainstorm event from August 6 to 8 in 2003
Left: Control plot, Right: 3.0-m-strip plot.

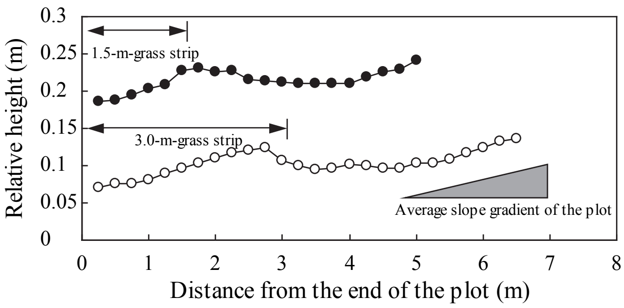


Fig. 5. Averaged ground surface profile along the long axis around 1.5-m- and 3.0-m-grass strip at the end of the second observation period
-●- : 1.5-m-strip plot, -○- : 3.0-m-strip plot.

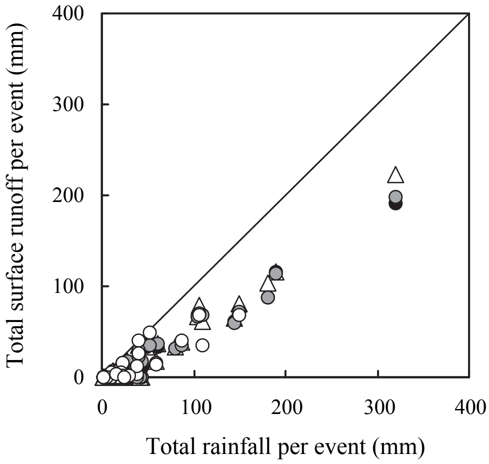


Fig. 6. Relationship between total rainfall and total surface runoff in each rainfall event
△ : Control plot, ● : 0.5-m-strip plot,
○ : 1.5-m-strip plot, ○ : 3.0-m-strip plot.

upstream from the strip in the 3-m-strip plot. The formation of a backwater showed that the surface flow of water had slowed, resulting in deposition of the sediment aggregates both in the backwater region and in the grass strip[2]. This was supported by the observed ground surface profiles along the long axis near the strips after the second observation period, as shown in Fig. 5. These profiles show that the surface levels at the upstream ends of the strips were relatively high, indicating that sediment has been deposited in the area in and upstream from the strip during the experimental period. Similar surface profiles were reported in previous studies[4,13,15] as the depositional patterns of sediment due to a slowing of water flow caused by a grass strip. Therefore, deposition of sediment aggregates as a result of decreased flow velocity was a primary mechanism in the removal of sediment by the grass strip.

The relationship between total rainfall and total surface runoff from each plot in each rainfall event is shown in Fig. 6. There was little difference between the measured total surface runoff from the control plot for each rainfall event and that from each strip plot. This showed that infiltration in the area of each grass strip contributed little to reducing the total surface runoff for each strip plot. There were two possible reasons for this. First, the grass strips accounted for a small percentage of the areas of the plots. Second, the deposition of fine sediment decreased the infiltration rate in the area of the strip. Nakamura et al.[9] reported that a layer formed by the deposition of fine sediment on the ground surface disturbed infiltration in a field with the same soil as our study plots. It is reasonable to say that trapping of fine sediments by infiltration in the area of the strips was ineffective. Therefore, sediment removal attributed to the strips primarily resulted from sediment deposition in the area in and upstream from the strip.

The efficiency of sediment removal in terms of strip length and sediment size is explained by this mechanism. When the surface water flow slowed in the area in and upstream from the strip, the bedload aggregates were deposited immediately and the suspended aggregates started to settle down to the ground surface. The finer suspended aggregates required more time to settle because of their slower settling velocity. Therefore, the longer strip trapped more sediment, and less of the finer sediment was trapped than the coarser sediment.

This study showed that aggregates of the 0.002–0.02-mm size class were dominant in the eroded sediment discharged from the field plots and that aggregates of this size range can be expected to pollute coastal areas. The longer grass strips used in our study trapped more aggregates of this size class, which suggests that longer grass strips will improve sediment control under conditions such as those of our study.

4. Application of grass strips

This study indicated that the use of longer grass strips would improve sediment control. However, the installation of very long strips in upland fields would be unrealistic from the farmers' perspective because the presence of the strips reduces the available cropping area. Some compromise may be necessary between the environmental and social benefits provided by sediment reduction versus the costs and diminished cropping area for the farmer when the optimal length of such strips is considered. Additionally, soil aggregation may be another way to improve sediment removal and to allow the use of shorter grass strips in the fields. Enlarging the size of the eroded aggregates will improve the performance of the grass strip.

Based on the sediment removal mechanism of the grass strips, grass with high flow resistance is a good choice for constructing an effective strip. Other criteria to consider, in addition to sediment removal effectiveness, include grass maintenance and ease of strip construction. The centipede grass used in this study fulfills the criterion of effective sediment removal. The density of the grass was relatively high, slowing surface runoff, and the blades were sufficiently stiff to remain erect under storm flow conditions. Additionally, the grass was moderately short and did not disturb agricultural field practices. Little mowing was required to maintain the grass and seeding of the grass strips required little effort. However, because of its slow growth rate, a few months passed before it was effective. Centipede grass was also considered suitable for covering the soil surface between pineapple rows in the field for erosion control on Ishigaki Island, Okinawa[6].

This study obtained the sediment removal efficiencies of the grass strip in a certain geographical condition. The efficiency may vary according to the geographical condition of the field site. Further research will be required to find out the quantitative relationship between the efficiency and the geographical condition. Then, the information will contribute to the appropriate design of the grass strip.

Conclusion

This study investigated the performance of strips of centipede grass, a perennial turf grass, in reducing sediment runoff from an upland field on a Kunigami-Maji soil. The study used field plot experiments to consider the effectiveness of grass strips of different lengths and the impact of sediment aggregate size. The aggregates of the 0.002–0.02-mm size class were dominant in the sediment runoff from the study plots and were regarded as an important target for sediment control. The sediment removal efficiencies were 24% for the 0.5-m strip, 36 to 54% for the 1.5-m strip and 73% for the 3.0-m strip. The efficiencies for the longer strips exceeded those for the shorter strips. The strips trapped well the sediment aggregates larger than 0.02 mm in diameter, regardless of the strip length. The longer strips trapped more aggregates of 0.002–0.02 mm size. All strips poorly trapped aggregates smaller than 0.002 mm. The sediment trapping resulted primarily from deposition of sediment due to slowing of surface water flow, rather than by movement into the soil matrix with infiltrated water. Although lengthening of grass strips would be a way to improve sediment control, installation of very long strips within the fields would be unrealistic. At present, it appears that choosing a grass strip length that reflects a compromise between the benefits and costs is the most practical approach to sediment control in the study area.

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