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Soil Erosion in Fields with Volcanic Ash Soil in Handa Kogen and Methods of Control

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Abstract
It is important for the agricultural administration of Kyushu, a region characterized by high temperature and precipitation, to promote the production of summer and autumn vegetables to achieve regional self-sufficiency. Therefore, fields for the production of summer-autumn cabbage and summer radish in cool areas such as Kuju, Handa and Aso have been developed on sloping lad reclaimed from native grassland. However, since cultivations is performed during the rainy season, soil is markedly eroded, resulting in the gradual degradation of the reclaimed fields. In this study, the onset mechanism of soil erosion in cabbage fields reclaimed from native grasslands was analyzed to develop methods of control. Based on the preventive effect of wild grass residues on soil erosion, the effect of the introduction of a second crop whose residues would be plowed-in was analyzed. It was observed that the use of rye as second crop, to plow stubbles 25 cm in length into soil, along with up-and-down high ridge culture of cabbage, resulted in a 40% reduction of soil loss and increase of yield compared with the conventional method.

Discipline: Soils, fertilizers and plant nutrition/Crop production
Additional key words: cabbage cultivation, contour ridge, native grassland, rainfall intensity, up-and-down ridge

Introduction

At Handa Kogen, a highland in Oita, Kyushu, cabbage is cultivated during the cool summer. In the 1980s growth injury associated with clubroot due to continuous cropping began to spread. As a result, cabbage was thereafter cultivated on sloping land reclaimed from native grassland. For the culture of Japanese radish, native grasslands were also used to increase the planted area. In such a sloping land, runoff of top soil and decrease of productivity are serious problems, since the use of agricultural machines and drainage of rain water take precedence over the soil conservation, and the major cultivation season for cabbage and Japanese radish takes place from June to September, when precipitation is abundant.

In this study attempts were made to analyze the process of soil erosion (water erosion) of cabbage fields consisting mainly of volcanic ash soil developed on sloping grasslands, along with the methods of control[1].

Characteristics of soil erosion in vegetable fields

In cabbage fields the construction of up-and-down ridges at a height of ca. 30 cm (Plate 1), is beneficial to the growth of cabbage and prevents the collapse of ridges. However, such up-and-down high ridges promote the loss of soil, since rain water on the land surface flows in the inter-row spaces.

In the fields of Japanese radish extending over wide areas, ridging is not applied. In the catchment area formed by the microtopography, a large number of areas with spotty erosion due to the runoff of the topsoil were observed (Plate 2). It was assumed that drainage of water flowing over the land surface in various directions may enable to prevent erosion.

In sloping land, erosion is accelerated by overland inflow from the upper slope into the fields. It is important for the prevention of erosion to control the water flowing into the fields and flowing out from other fields located in the lower slope.

Plate 1. Up-and-down high ridges in cabbage field

Plate 2. Soil erosion in Japanese radish field

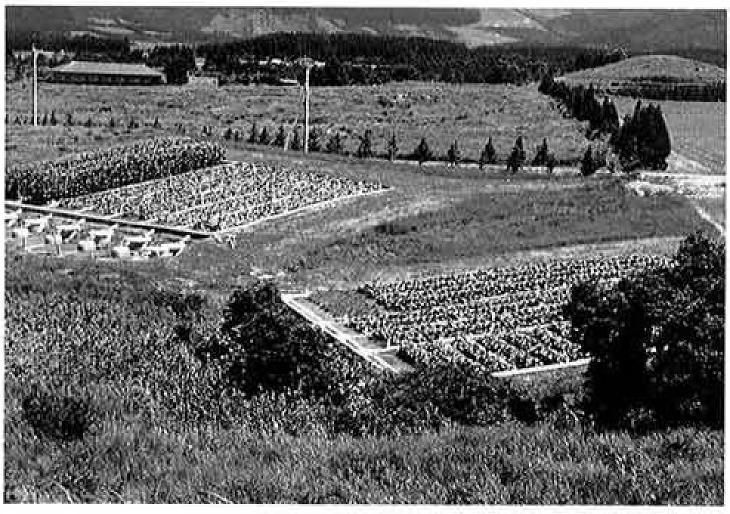

Plate 3. Experimental field developed from native grassland

Table 1. Changes in the amount of wild grass residues (stubbles and roots) and their C–N ratio after reclamation of the native grassland

(oven-dried basis)

	1982	1983	1984	1985	1986
Quantity (g/m^2)	1,565	714	485	301	182
C/N	115	85	65	52	-

Reclamation of the native grassland in May, 1982.

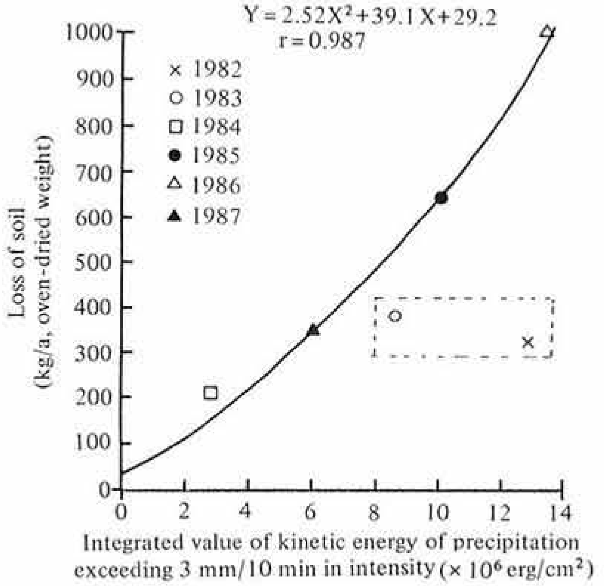

Fig. 1. Relationship between integrated value of rainfall kinetic energy and soil runoff in the rainy season after reclamation of the native grassland

At the initial stage of development of grasslands, prevention of erosion by covering the topsoil with large quantities of wild grass residues (stubbles and roots) is effective. Based on the annual changes of the amount of soil lost by rainfall (over 3 mm/10 min) it was demonstrated that such preventive effect disappears after 3 years, because wild grass residues are decomposed in soil with morphological changes (Table 1, Fig. 1).

Soil erosion in cabbage fields

The mechanism of soil erosion in the fields developed from grasslands was studied from 1982 to 1987 under conventional cultivation consisting of single cropping of cabbage with up-and-down high ridges (20 m in slope length, 7.2° in gradient, and 60 m^2 in area).

The mean precipitation during the 6-year period was 2,445 ± 338 mm annually, 60.5 ± 6.2% of which occurring in the period from June to September. Furthermore, 28.4 ± 6.5% of the annual precipitation was concentrated within a few weeks of the rainy season (Table 2). The number of days when rainfall exceeded 3 mm/10 min in intensity were 11.5 ± 4.3 days in June and July in the rainy season, compared with 7.7 ± 3.2 days in August and September.

Loss of soil occurred for rainfall with an intensity of 2.7–3.0 mm/10 min (precipitation of ca. 30 mm or more). The amount of soil lost during the cultivation of cabbage (June–September) was 565 ± 252 kg/a (oven-dried weight) as an average of 6 years, which was equivalent to 14 mm in soil depth and 82.5 ± 8.9% occurred in the rainy season (mid-June to end of July) (Table 3).

It was concluded that the rainfall intensity exerts a considerable effect on the increase of the overland flow ratio of rain water. The ratio of overland flow to the amount of precipitation from June to September was 27% in 1984 when the integrated value of minimum kinetic energy of rainfall[2] exceeded 3 mm/

Table 2. Characteristics of rainfall in the rainy season

Item / Year	1982	1983	1984	1985	1986	1987
Total precipitation (mm)	940.5	422.0	452.5	805.0	927.5	675.5
Rainfall with intensity of more than 3 mm/10 min						
Precipitation (mm)	409.0	253.5	95.5	334.0	400.0	197.0
Integrated time of rainfall (10 min)	80	36	22	75	67	45
Mean of rainfall intensity (mm/10 min)	5.1	7.0	4.3	4.5	6.0	4.4
Integrated value of kinetic energy* ($\times 10^6$ erg/cm^2)	12.9	8.6	2.8	10.1	13.1	5.9

*$e = 21400\ i^{1.22}$ (e: kinetic energy erg/cm^2, 10 min., i: rainfall intensity mm/10 min)[2].

Table 3. Amount of soil lost during cultivation of cabbage (June – September)

(kg/a, oven-dried weight)

Item / Year		1982	1983	1984	1985	1986	1987	Mean
June – September	(A)	439	491	292	774	1,018	375	565
Rainy season	(B)	323	380	214	643	996	337	482
(B) / (A)	(%)	74	77	73	83	98	90	83
Rainy season with precipitation exceeding 3 mm/10 min in intensity								
Per integrated amount of rainfall 100 mm		79	150	224	193	250	171	–
Per integrated value of kinetic energy (1.0×10^6 erg/cm^2)		25	44	76	64	76	57	–

10 min in the rainy season, and 34% in 1985 when the precipitation was moderate (partly including estimated values). It was then assumed that these ratios would increase in 1982 and 1986 due to the high level of precipitation.

The relationship between the overland flow ratio and the loss of soil by rainfall, indicated that when the overland flow ratio (X) increased, the loss of soil (Y) rapidly increased ($\log Y = 0.116X + 0.145$, $r = 0.736$) in June and July (Fig. 2), unlike in August and September. It was then concluded that in addition to the above-mentioned difference in rainfall conditions, other factors played a role, i.e. the fact that since soil after plowing and ridging became swollen and soft it ranoff readily in June and July, and the ratio of the land surface covered by cabbage was low (ca. 20% even by the end of July) (Table 4). The factors that accelerated erosion in the cabbage fields in addition to rainfall are as follows: 1) up-and-down high ridging that readily induces overland flow, 2) the fact that soil after plowing and ridging is exposed to strong rainfall in the rainy season when it is swollen and soft and likely to runoff easily, since the cropping season characteristic of highland products is limited, and 3) for the same reason it is not possible to adopt another cropping type of cabbage, which covers the land surface in a high ratio in June and July when strong erosion prevails.

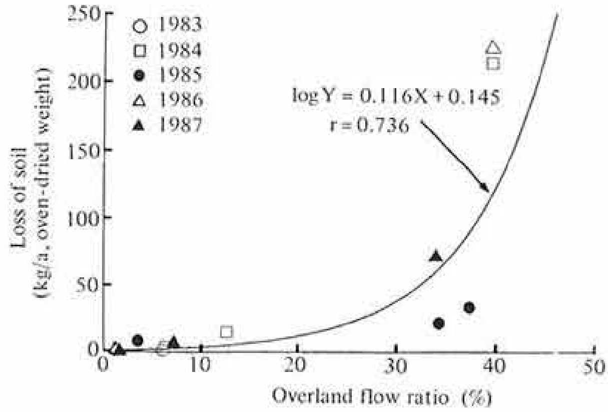

Fig. 2. Relationship between overland flow ratio and loss of soil by rainfall (June and July)

Control of soil erosion in relation to cabbage yield

In the field reclaimed from the grassland with a 20 m slope length, and gradient of 6.2 – 7.2° (3.6 a in area) and 4.2 – 5.6° (4.8 a in area), respectively, the effects of several preventive measures (60 or 120 m^2 plots) on conventional cabbage cultivation (standard plot) in single cropping and up-and-down high ridging as well as the yield of cabbage were compared (Plate 3, Fig. 3).

By contour high ridging (5.5 m in ridge length, height of ca. 30 cm), the index of soil runoff to

Table 4. Ratio of land surface covered by cabbage

(%)

Year/Time	Planting time End of June	Vegetative period		Harvest time End of Sep.
		Initial-stage End of July	Middle-stage Initial of Aug.	
1982	0	12	42	57
1983	0	21	55	63

Up-and-down high ridges.
Planting density: 485 cabbage head/a.

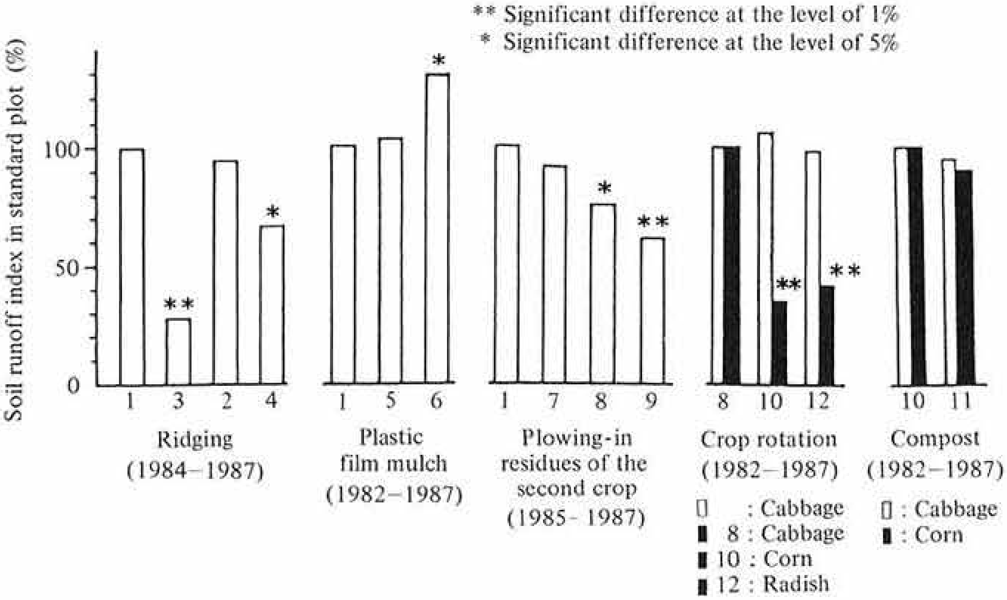

Fig. 3. Effects of several measures of control of soil erosion in cabbage fields
Plot 1: Standard (single cropping and up-and-down high ridging), Plot 2: No ridging, Plot 3: Contour high ridging, Plot 4: Grass belt, below the up-and-down high ridges, Plot 5: Plastic film mulch culture, Plot 6: Partial plastic film mulch culture, Plot 7: After cultivation of Italian ryegrass as second crop, Plot 8: After cultivation of rye as second crop, Plot 9: After cultivation of rye as second crop and cutting at a height of 25 cm, Plot 10: Crop rotation (cabbage, corn), Plot 11: Crop rotation (cabbage, corn) and compost, Plot 12: Crop rotation (cabbage, Japanese radish).

Table 5. Amount of plowed-in residues from the second crop (rye and Italian ryegrass) and their C-N ratio

(oven-dried basis)

Crop	Year	Amount of residues		C/N	
		Stubbles (g/m^2)	Roots	Stubbles	Roots
Italian ryegrass[a)]	1983	86	168	27	33
	1984	153	185	32	33
	1985	161	254	35	32
	1986	102	150	-	-
	1987	251	425	-	-
Rye[b)]	1983	350	300	77	49
	1984	360	267	64	43
	1985	472	243	53	33
	1986	339	238	-	-
	1987	336	378	-	-
Rye[c)]	1985	563	-	-	-
	1986	383	-	-	-
	1987	491	-	-	-

a): Cutting: ca. 5 cm from the ground, b): Cutting: ca. 15 cm, c): Cutting: ca. 25 cm.

soil loss in the standard plot decreased to a value of 22 (1982–1987, with a significant difference at the level of 1%). In 1988 the measures were applied to fields with a ridge length of 24 m to match the length of actual contour ridging, and it was observed that preventive effects could be achieved even for longer ridges. However, the overland flow water ran along the direction of the microtopography, and in the catchment area, partial collapse of ridges and stagnant water were observed. Thus the yield of cabbage in these areas was reduced by 10–20%.

When cabbage was grown without ridging, in a year with lower precipitation (in 1984, the value of the index of soil runoff to soil loss in the standard plot was 54), erosion was effectively prevented. However in a year with high precipitation (in 1986, the index was 106), the effect was not observed.

Italian ryegrass and rye were cultivated as second crops after cabbage, and the effect of plowing-in stubbles on the cultivation of cabbage with up-and-down high ridges was studied (Table 5). Erosion was prevented by the large amount of residues of rye stubbles (in 1985–1987, the index was 76, with a significant difference at the level of 5%). By cutting at a height of 25 cm from the ground to obtain a larger amount of residues from stubbles, the effect was more pronounced (in 1985–1987, the index was 61, with a significant difference at the level of 1%). Furthermore, the yield of cabbage was 6% higher than that in the standard plot in both cases.

The supply of grass belts over 10% of the slope length (2 m), below the up-and-down high ridges, resulted in the reduction of soil loss (in 1984–1987, the index was 67, with a significant difference at the level of 5%). In 1988 when an area of 3.6 a was selected to match actual conditions, a beneficial effect was obtained. It was noted that a terrace had developed by sedimentation of the runoff soil in the inter-row spaces above the grass belt, as well as in the grass belt. Due to the sedimentation of the runoff soil, the region below the slope became humid, resulting in a reduction of the yield of cabbage (kg/a) (in 1988, 417 ± 45 above the slope, 394 ± 40 in the middle of the slope, and 309 ± 28 below the slope).

When a plastic film mulch was applied to cover the up-and-down high ridges, the soil in the inter-row space was lost (the index was 103 in 1982–1987). These observations suggest that the effect on the field below the slope must be taken into consideration in sloping land when a plastic film mulch is used, as the amount of rain water flowing over the land increases. The use of a plastic film mulch enabled to maintain a high content of inorganic nitrogen in soil, resulting in the increase of the yield of cabbage by 13% compared with the standard plot. However, in the case of strong wind and abundant precipitation in a light Andosol, the plastic film mulch was easily peeled off, requesting frequent repairs.

Conclusion

The main issue in the prevention of erosion in the cabbage fields located in Handa Kogen with abundant precipitation, is how to strike a balance between the need for retaining stagnant water or reducing the water flow rate, while implementing rapid drainage of water for the growth of cabbage.

Against this background, it is recommended to use rye as second crop in order to plow-in stubbles cut at a certain height above the ground, and to employ up-and-down high ridges.

Control of erosion by contour high ridging, up-and-down high ridging and development of grass belts, aims at preventing the water from flowing over the land and reducing the current velocity. However, the increase in the humidity level of soil may adversely affect the growth and yield of cabbage. Therefore to maximize the use of contour high ridges and grass belts in the up-and-down high ridges, the preventive effect on erosion may decrease. It was concluded that drainage of overland flow water compatible with the microtopography of the respective fields is important in order to increase the yield and improve the quality of cabbage.

Based on the above results, the following rotational system consisting of wild grass field → vegetable field ⇆ pasture, or pasture ⇆ vegetable field, in making use of the preventive effect of soil erosion by plowing-in the crop residues, is proposed.

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