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논 문

Effect of On-field Sediment Traps on Sediment Control from a Sloping Upland Culture

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요 약

강원도의 고랭지 감자밭에 3개의 침사구를 2002년도에 설치하고 유출수와 함께 배출되는 유사의 제거효과를 평가하였다. 연구유역의 토성은 사질토로 침투능이 매우 커서 강우량과 강우강도가 컸을 때만 5회의 유출현상이 발생하였다. 침사구의 유사제거 효과는 3개의 침사구에서 모두 98% 이상으로 측정되었다. 유사제거 효과가 매우 큰 원인중의 하나는 토성이 사질토로 유출수의 유속이 침사구에서 감소하면서 다량의 유사가 침전하였기 때문으로 분석되었다. 농경지에 설치한 작은 침사구가 기능을 연속적으로 발휘하기 위해서는 침사구가 유사로 채워질 때마다 퇴적된 유사를 인위적으로 제거해 주어야 한다는 단점이 있었다. 강원도 고랭지에서 발생하는 탁수를 방지하기 위해서는 경지면적당 최대 허용 유실량을 제정하여 토사유출은 법적으로 규제할 수 있는 제도를 도입하고, 농민들이 농경지 주변에 배수로와 침사구를 설치할 수 있도록 전문가의 기술지원과 환경개선 부담금을 정부가 부담해야 할 필요가 있다. 또한 최적영농관리방법을 농민들에게 홍보하여 유출량과 유사의 발생을 최소화할 수 있는 정책이 필요하다.

Abstract

Three small-scale sediment traps were built on sloping potato fields at the alpine belt in Korea to examine the sediment and non-point source pollutant reducing capabilities of the traps. Throughout the research period from January 2002 to December 2002, there were only five times of runoff and sediments produced from the fields. This is because very highly permeable sandy soil is the dominant soil type in the fields. The sediment traps functioned very well and the sediment removal efficiency of the traps exceeded 98%. The high sediment removal rate could be achieved partly by the sandy soil with small amounts of clay particles. One of the disadvantages of the traps was that the sediment traps had to be emptied after each runoff and sediment event so it can be prepared for the next rainfall event. Priority to control muddy runoff laden with sediment and NPS pollutants was necessary to establish judiciary systems for farmers to build drainage channel system, and for local government to set the maximum tolerable soil loss limit from the field. Also, it was necessary that agricultural Best Management Practices and other conservative measures to reduce muddy runoff could be effectively carried out if the judiciary systems are established.

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Ⅰ. Introduction

The mountain region higher than 600 m above the mean sea level (MSL) is called as the alpine belt, and the region between 400 m and 600 m above the MSL called as the semi-alpine belt in Korea. These belts are generally colder than those below 400 m in altitude, and most fields on these belts have been cultivated for fresh vegetables such as Chinese cabbage, radish, potato, and others. These fresh vegetables supplied to large cities play very important role in food supply system in Korea. These products are brought to market during the summer and fall seasons, the major income sources for most farmers in this region.

The slope of upland along the alpine range is generally steep, the soil is mostly weathered granite of which apparent density is between 1.05–1.15 g/cm^3 and adhesion is very weak, and the topsoil is completely disturbed annually by conventional tillage and bed preparation before seeding or transplanting. The duration and intensity of the rainfall event during the summer rainy season are generally short and high enough to cause very high peak runoff and water erosion. Especially, rainfall during typhoon season between the late August to September is very intensive, causing large flood damage. Topographical geological, agricultural management, and rainfall conditions happen to be harmonized to accelerate upland soil erosion and dump huge amount of muddy runoff laden with sediment and Non-point Source (NPS) pollutants into the upper reaches of the Han river every year. The Seoul metropolitan with about 22 million population is located in the downstream areas of the Han river watershed. The Han river naturally supplies waters to the metropolitan, provides recreation grounds, and supports natural ecosystems. However, the water quality of the Han river has been rapidly degraded and the Korean government has been trying to preserve and improve the water quality of the river. It is now widely accepted that NPS pollution is one of the key factors causing water quality degradation. Although many efforts have been made to reduce the water quality degradation, and to preserve / improve the water quality in the Han river watershed, none of them was achieved as expected.

Monitoring and modeling of NPS pollutant discharges from paddy fields and agricultural watersheds have been actively studied recently (Oh et al., 2002; Kim et al., 2002; Kim and Chung, 2002; Seo et al., 2002; Choi et al., 1999; Choi et al., 2001; Choi and Yang, 2002; Im et al., 2002; Kim et al., 2003; Kwun et al., 2003). However, only a few limited studies on soil erosion and sediment control from the alpine fields have been conducted by a few researchers (Choi et al., 2000; Choi et al., 2000; Choi et al., 1998; Choi et al., 1997; Choi et al., 1995). However, these studies were conducted mainly to describe the characteristics of NPS pollutant discharges from small runoff plots with respect to tillage mark and crop residue, cover crop under potato or corn cultivation. Direct structural methods, such as sediment trap or sediment basin, to remove sediment from runoff generated from sloping alpine fields have not been tried yet.

The areas of uplands in the alpine belt were generally small and were divided by small levee or ridge depending on the slope. For the small patches of fields terraced along the slope and surrounded by levees, soil erosion could be negligible and did not create any severe water quality problems. However, with the advancement of farm mechanization, small patches of fields of about 0.5 ha or less have been gradually reclaimed into a larger field of about 1 ha or larger, resulting in bigger on-field flow concentration and more gully development. Besides, diversions and drain ditches to divert runoff from mountain forests and upper fields are not well developed, again resulting in large flow concentration at the lower parts of a field or an agricultural watershed. The concentrated flow is the most important factor in forming a gully and sediment production from a field.

It is much needed to measure the amount of sediment, suspended solids, and other NPS pollutants originated from the alpine uplands systematically, and to develop effective erosion control methods to reduce sediment and other NPS pollutants from runoff. It has been known that the most effective erosion control practice is the one that the farmers actually employ in their crop field. Thus, the efficiency of the sediment traps installed on the crop field was investigated in this study.

The objective of this research was to investigate the applicability of on-field sediment traps to reduce sediment discharge from sloping uplands at the alpine and semi-alpine belts in Korea. This research results may be applied to develop the best management practices (BMPs) in the region where sloping upland cultures are practiced.

Ⅱ. Methods

A sloping upland located in the alpine belt of about 800 m in altitude was chosen to install three sediment traps. The upland of about 15,000 m^2 in size is located around a mountain top and has three aspects. The three sediment traps were placed at the lowest part of each aspect, respectively. The dominant soil types of the upland are sand and sandy loam, and the slopes for these three aspects were between 5% to 13%. Potato and radish were rotated every year for many years, and potato was cultivated during this research period. Potato was planted on April 20, 2002 and harvested on September 20, 2002. Conventional plowing and bed (ridge and furrow) preparation was made for potato planting. Plowing was directed strait along the long side of the field,

Table 1. Size of sediment trap, watershed areas, tillage, dominant soil type, and land use for three locations

Sediment trap	Size (m^3)	Watershed (m^2)	Tillage	Soil	Crop
1	4.0	1,878.0	Contour	Sand	Potato
2	1.5	736.4	Up-and-down	Sand	Potato
3	0.5	209.9	Up-and-down	Sandy loam	Potato

making tillage marks contour, up-and-down and mixed depending upon the location because the upland has three aspects. Table 1 shows the size of the sediment trap, watershed areas contributing runoff laden with sediment to each sediment trap, tillage mark, dominant soil type, and crop planted at three locations. The bottom of the sediments trap was covered with a geo-textile to prevent native soil from being mixed with eroded/transported sediment. Runoff from each sediment trap was measured using a partial flume flowmeter and a data logger (Figures 1 and 2). Recorded runoff data was manually read after each rainfall event, and deposited sediment in the traps was manually removed with a shovel and its weight was measured. The sediment traps had to be emptied after each runoff because they became full with the sediment loadings from the muddy runoff. Sediment water content was measured, and its dry weight was computed from it. Runoff samples were also collected and analyzed with respect to Total phosphorus (T-P), Total nitrogen (T-N), Suspended Solid (SS), and Biological Oxygen Demand (BOD).

Daily rainfall data had been measured from April 2002 to November 2002 at an automated weather station, about 6 km away from the site. The total rainfall during the experiment period was 1,371 mm, and 69.5% rainfall events were occurred between July 2002 and August 2002. Daily rainfall events of 10 mm or greater were summarized in Table 2. Among 30 rainfall events of 10 mm or greater, only five rainfall events produced runoff and sediment. Runoff was only produced when the rainfall intensity is high enough to exceed the infiltration capacity of the sandy soils. For example, 135 mm/day rainfall on July 14 did not produce runoff because the rainfall intensity was mostly less than 10 mm/hour. However, rainfall events on August 23 was only 58.0 mm but was a downpour in about 2 hours and produced runoff and sediment.


Figure 1. Sediment trap 1


Figure 2. Sediment trap 2

Ⅲ. Results and Discussion

The dimension of the sediment traps was not determined by pertinent engineering design procedures. Rather, its dimension was determined by the rule of thumb based on the landowner's years of observations and the guidelines of ODNR

Table 2. Daily rainfall of 10 mm or greater during the experiment (unit: mm)

Date	Rainfall	Date	Rainfall	Date	Rainfall	Date	Rainfall	Date	Rainfall
04-16-2002	34.5	06-10-2002	46.0	07-14-2002	135.0	08-06-2002	129.5	09-01-2002	20.5
04-29-2002	34.5	06-12-2002	24.5	07-17-2002	31.0	08-07-2002	154.0	09-14-2002	12.5
04-30-2002	49.0	06-20-2002	15.5	07-19-2002	22.0	08-08-2002	20.0	09-29-2002	10.5
05-03-2002	10.0	07-05-2002	47.0	07-22-2002	27.0	08-23-2002	58.0	10-05-2002	20.0
05-07-2002	24.5	07-06-2002	16.5	07-23-2002	51.5	08-27-2002	13.0	10-06-2002	10.0
05-06-2002	13.5	07-07-2002	16.0	08-05-2002	61.5	08-31-2002	111.5	10-26-2002	20.5

(1996). The sediment traps were designed to hold at least the amounts of sediment generated from the two severe storm events.

Tables 3 and 4 show measured rainfall, runoff, sediment loading, runoff coefficient, and unit sediment removal rate at three sediment traps. No runoff and sediment data are available for the sediment traps 1 and 3 for the storm events occurred on August 6, 2002 and August 7, 2002. With 283.5 mm of rainfall events occurred on these two consecutive days, the gully was formed and its concentrated flow overpasses the sediment trap 1. The dimension of the sediment trap 1 was extended further to be prepared for the next coming big rainfall events. The flowmeter was used to measure the runoff at the sediment traps, but it did not work properly for some reasons during these rainfall events occurred on August 6 and August 7. Timely maintenance and correction of the traps could not be made because the experimental site was far away from the University and the problems were not expected at the beginning of the measurement. Thus, the runoff and sediment data for the sediment traps 1 and 3 were not measured for those two days.

It was shown that runoff and sediment discharge from the field did not have direct relationship with rainfall amount, but were influenced by both rainfall amount and intensity. Runoff and sediment were observed only when rainfall amount and intensity exceeded the infiltration rate of the soil. Also, it was observed that runoff and sediment discharge increased where the topsoil was saturated and subsurface flow emerged to soil surface at the middle and low parts of sediment trap 2 watershed. Figure 3

Table 3. Runoff and sediment measured from the sediment traps for each runoff event

Date		04-30-20	08-06-02	08-07-02	08-23-02	08-31-02
Rainfall (mm)		49.0	129.5	154.0	58.0	111.5
Runoff (m^3)	Sediment trap 1	0	Not measured	Not measured	65	
	Sediment trap 2	0	25	73	63	
	Sediment trap 3	1.8	Not measured	Not measured	14	
Sediment (kg)	Sediment trap 1	0	Not measured	Not measured	840	
	Sediment trap 2	0	1,250		930	
	Sediment trap 3	40	62		50	

Table 4. Runoff coefficient and unit sediment removal rate for each runoff event

Date		04-30-20	08-06-02	08-07-02	08-23-02	08-31-02
Rainfall (mm)		49.0	129.5	154.0	58.0	111.5
Runoff coefficient	Sediment trap 1	0	-	-	0.20	
	Sediment trap 2	0	0.26	0.64	0.50	
	Sediment trap 3	0.7	-	-	0.39	
Sediment (kg/ha)	Sediment trap 1	0	-	-	840	
	Sediment trap 2	0	16,974		930	
	Sediment trap 3	1,906	842		50	

Figure 3. Sediment deposit in Sediment trap 2 after August 6–7 rainfall event

shows the sediment deposit in sediment trap 2 after August 6–7 rainfall event.

Sediment removal rate of the traps was estimated with measured runoff and sediment data (Table 5). Total sediment was computed by adding sediment deposited in the traps and sediment discharged from the traps as suspended solids with runoff. The sediment discharged was computed by multiplying the concentration of suspended solids and runoff volume.

It was demonstrated that these small sediment traps built in the lower part of a field could remove more than 98% of total sediment occurred in the potato field if properly managed after each rainfall and runoff. However, the sediment traps had to be emptied once they were filled with sediment for the next rainfall event. It means that farmers have to spend more labor and money to keep the traps to function properly.

Table 6 shows the result of water quality analysis from the sediment traps. Except Sediment trap 3, August 6–7 runoff quality was worse than August 31 runoff quality. The difference between the two water qualities was larger in Sediment trap 2. It was not clear what caused the difference between the runoff qualities.

One of the reasons to conduct this research except the objective described previously was to find local characteristics that might cause severe muddy runoff and to suggest methods that could reduce the muddy runoff. The relationship between local agricultural management methods,

Table 5. Sediment removal rate from sediment traps 1 and 2

Sediment trap	Date	Sediment deposited (kg)	Sediment discharged (kg)	Total sediment (kg)	Sediment removal rate (%)
1	08-31-02	840.0	5.0	845.0	99.4
2	08-07-02	1,250.0	15.0	1,265.0	98.8
2	08-31-02	930.0	5.0	935.0	99.5

Table 6. Result of runoff quality analysis from the sediment traps

Sediment trap	Date	T-P (mg/ℓ)	T-N (mg/ℓ)	SS (mg/ℓ)	BOD (mg/ℓ)
1	02-08-07	1,584	5,755	138.8	8.1
	02-08-31	1,146	1,654	79.8	1.7
2	02-08-07	2,412	7,310	155.1	22.0
	02-08-31	1,146	1,654	79.8	1.7
3	02-08-07	1,252	1,110	69.2	5.6
	02-08-31	0,179	2,272	60.4	6.7

soil texture, crop characteristics related to soil erosion, land size and micro-topography, land reclamation, addition of fresh topsoil to existing field, irrigation and drainage channel system, and other factors that might affect soil erosion processes were closely reviewed. And it was found that many factors comprehensively interact together and these interactions are responsible for muddy runoff. Crops popular to the alpine belt were potato, radish, Chinese cabbage, and others. The seeding and transplanting processes of these crops with tillage disturb the soil structures every year. The sand and sandy loam soil were very susceptible to soil erosion. The slope and slope length are getting steeper and longer resulting in greater flow concentration leading to gully formation. Farmers tended to add new fresh topsoil every 3 to 5 years to complement soil eroded and transported from the field. The soil added to field to the depth of 10 to 15 cm in general was again weathered granite that contains practically no nutrient and is very susceptible to erosion and farmers applied sizable amount of chemical and organic fertilizers to supply nutrients for crops. These nutrients also lost with soil erosion. The elevation of many fields is getting higher because of the new soil addition. Practically no irrigation and drainage channel system was established in these fields and precipitation is the only source of water supplies. Some farmers use irrigation pumps to irrigate fields if fields are located along a stream. However, there was no way to drain runoff safely in case of severe rainfall events. The runoff concentrates and forms a gully easily with the severe and intensive rainfall events, resulting in severe muddy runoff and sediment discharge.

It was believed that among the many factors that caused muddy runoff, priority should be given to build drainage channel system. Constructing drainage channel system would be very difficult because farmers want to use their land to the last inch for agricultural products. Lawful enforcement, incentives for environmental improvement, environmental education, and public information could help persuade farmers to build drainage channel system voluntarily if they understand the importance of topsoil as a good source of nutrients to the crops. Once the drainage channel system is installed, labor and material for channel maintenance should be supported by means of environmental quality incentives for farmers. The slope of drainage channel should be graded so that the channel can act as a sediment trap. Also, priority should be given to set the maximum allowable annual soil loss from a sloping field. If a certain agricultural management practice can not satisfy the maximum allowable soil loss from the field, the fields need to be advised or enforced to change its land use from crop production to permanent pasture or forest. Once the drainage channel system and the maximum allowable soil loss guideline are established, it was thought that the agricultural BMPs could be effectively implemented.

Ⅳ. Conclusion

Three small sediment traps were built on a sloping potato field in the alpine belt in Korea. Highly permeable sandy soil produced five runoff and sediment throughout this research from January 2002 to December 2002. The sediment traps functioned very well and the sediment removal efficiency of the traps exceeded 98%. The high sediment removal rate could be achieved partly by the sandy soil that contains small amount of clay particles. Disadvantage of the traps was that the sediment traps had to be emptied after each runoff and sediment event for the next rainfall event because the traps were small.

Priority to control muddy runoff including sediment and NPS pollutant was necessary to build drainage channel system and to set the maximum allowable soil loss from a field after investigating many factors. It also was necessary that agricultural BMPs and other conservative measures to reduce muddy runoff could be effectively carried out if the two systems are established.

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