Sediment control practices in sloping highland fields in Korea

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Abstract
Soil erosion and muddy runoff from sloping highland agricultural fields located at the uppermost of major river systems in Korea have caused serious water quality problems in providing domestic water supply and maintaining the river ecosystem. The government designated the upper Soyang Watershed as a priority non-point source(NPS) pollution management region in the middle of 2007 and began to introduce various best management practices (BMPs) extensively to reduce soil erosion, muddy runoff and other NPS pollution discharges. Soil, crop, agricultural management practices and rainfall characteristics of the watershed were explained. Typical BMPs introduced were vegetated filter strip (VFS), vegetated levee, concrete drain channel, concrete diversion, gabion wall, masonry wall, drop structure, slope stabilization, sediment trap, perennial crop, and furrow dam. The functions of these BMPs were explained and recommendations were made for better implementation in the future. Most of the BMPs were not targeted for source control and the necessities for source control were emphasized. It was recommended that the Ministry of Environment (MOE) and the Ministry of Food, Agriculture, Forest and Fishery (MOFAFF) cooperate in controlling and managing agricultural NPS pollution, reducing the possibility of implementing wrong policies and programs, and helping improve water quality effectively and economically.

Key Words
Muddy runoff, sediment control, highland field, BMPs, soil erosion, water quality

Introduction

Land reclamation of steep mountain forests in the uppermost alpine watershed of the Han River in the 1980s to supply fresh vegetables has caused serious water quality problems due to muddy runoff. Muddy runoff from sloping highland fields during the monsoon season increased turbidity seriously as well as total nitrogen and total phosphorus concentrations in downstream water bodies. The impact of water quality degradation is very influential because the river is the one and only water source for Seoul metropolitan area of about 23 million residents in Korea. Also, the increased turbidity proved to cause serious impacts on the river ecosystem (Kim and Jung 2007).

The soil texture of the highland is mostly sand and/or sandy loam that is very vulnerable to water erosion, resulting in thick muddy runoff during heavy rainfall events. Muddy runoff is not directly drained to the sea but rather stored in a cascade of man-made dam reservoirs along the river and slowly discharged and creates the turbidity problem for a prolonged period. Especially in 2006 and 2007, the duration of muddy runoff in the North Han River lasted more than 240 days and caused serious disturbances in water supply and river ecosystem. The Korean government has not been very enthusiastic in controlling the muddy runoff until the turbid flow created serious public attention and awareness of soil erosion. Due to the event, the government declared the area (Soyang Watershed) as a priority NPS management region in 2007 and began to invest the government budget to reduce muddy runoff and soil erosion. It is the first government initiative in terms of NPS pollution control and management. Soyang Reservoir is the largest man-made lake in Korea and plays a key role in controlling flood and drought and providing domestic water supply in downstream Seoul metropolitan areas. The objective of the initiative was to keep the turbidity at the Soyang Dam site at 50 NTU or less.

Best management practices (BMPs) and technologies to control soil erosion and sediment discharges from highland alpine regions have not been investigated well, either theoretically or experimentally, in Korea. However, because of the prolonged muddy runoff event, the government began to build structural BMPs to reduce muddy runoff from 2008 and monitor the effects of the BMPs from the middle of 2009. The

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

objectives of this paper were to introduce and describe the effectiveness of the BMPs and to suggest recommendations for better implementation of the BMPs in the sloping highland agricultural fields.

Characteristics of Sloping Highland Fields in Soyang Dam Watershed

The area of Soyang Watershed is 269,435 ha, with 85.14% as mountain forest and 4.7% as upland fields (7,313) ha in 2006. Other land uses were urbanized 0.8%, paddy and other agricultural 2%, grassed 0.6%, lake and river 2.2%, and others 6.5%. During the 2006-07 muddy runoff event, total sediment yield from the watershed was estimated at 3,559,961 tons. Landslides in mountain areas, stream bank erosion, and upland erosion during the deluge caused by a heavy rainfall event were major sources of the sediment yield. Among the sediment, 865,062 ton or 24.3% was estimated to be eroded from upland fields. However, if a deluge is not the cause of numerous landslides and river bank erosion, most of the muddy runoff is generated and discharged from uplands, especially from sloping highland fields.

Upland located 600 m above the mean sea level (MSL) is classified and called highland field and upland between 400 and 600 m semi-highland field in Korea. About 53.7% or 3,925 ha of the upland lay 400 m above MSL. The slope of highland and semi-highland fields is not mild. Field slopes <7% comprises 26.3%, while slopes between 7-15% covers 40.9%, between 15-30% takes up 30.2%, and >30% is 2.8% of the area. Average annual rainfall in the watershed during the past 10 years (1997-2006) was 1,370 mm. Two-thirds of the rainfall generally occurred during the monsoon season of June, July and August.

Agricultural practices in the Korean highland fields are quite intensive. Cereal crops are not preferred, but vegetable crops such as potato, radish and Chinese cabbage are mostly cultivated. The soil surface is either disturbed by conventional tillage and seed bed preparation, leaving no surface cover until the crop canopy develops, or soil is mulched with thin plastic sheets at the time of seed bed preparation. The rainfall season begins before the crops develop full canopy, and serious soil erosion and sediment discharge occur from the fields. Runoff from mulched fields with plastic sheet increases because of limited infiltration and rills and gullies easily develop in downward furrows, resulting in high soil erosion and muddy runoff. In a survey, it was found that both chemical and organic fertilizers were applied to the alpine fields at many times greater than recommended doses. Considering the characteristics of soil, crop, rainfall and management practices in highland fields, relevant and aggressive BMPs should be applied to reduce soil erosion, runoff, and NPS pollution load from the fields.

BMPs and Recommendations

Water quality problems caused by muddy runoff from sloping alpine fields have become evident from late 1990s. Central and local governments have begun to apply BMPs to alleviate the negative impact of muddy runoff from fields (Table 1). It is noted that the budget increased sharply from 2008 after the area was designated as a priority NPS pollution management region in the mid-2007.

Table 1. Annual investment and BMPs to reduce muddy runoff from the priority NPS pollution management region.

Budget and BMPs	2001-5	2006	2007	2008	2009	Total
Budget (×10^3 US$)†	6,212	3,166	3,260	7,005	13,993	33,635
VFS (m^2)	14,391	0	0	0	5,500	19,891
Vegetated levee (m)	8,305	0	0	0	15,775	24,080
Concrete drain channel (m)	15,986	5,431	1,463	16,027	63,510	102,417
Concrete diversion (m)	22,186	12,068	16,472	24,231	53,007	127,964
Gabion wall (ea)	234	376	167	1,906	5,040	7,723
Masonry wall (m^2)	10,879	1,874	2,802	18,998	23,724	58,277
Drop structure (ea)	59	26	86	253	106	530
Slope stabilization (m^2)	98,313	47,294	24,190	61,804	124,700	356,301
Sediment trap (ea)	12	3	1	7	4	27
Perennial crop (m^2)	0	0	0	120,000	0	120,000

†Exchange rate is 1,300 Korean Won, to 1 US dollar.

A vegetated levee is a concept similar to the terrace in the USA, but the scale is much smaller than the terrace. The survey showed it was not effective in reducing muddy runoff and it was recommended not to pursue this BMP anymore. Vegetated filter strips (VFS) in the alpine region is very different from ones found in the USA. The width of VFS is at most 1 m, but mostly <0.5 m, because the field sizes were smaller, ranging mostly from 0.5 to 3 ha. It cannot remove nutrients, but contributes to filtering sediment and preventing rills and gullies at the edge of fields. It was recommended that the VFS width be kept at least 1 m wide by persuading farmers with lucrative incentives, because farmers would not give up their land without any reimbursement.

Concrete drains and diversion channels have been the most popular BMPs in the sloping highland fields. Concrete diversion channels were found to be very effective in preventing soil erosion from fields, because it safely diverted runoff from neighbouring forests to drainage channels. Concrete drain channels however were only effective if placed where the slope of channel was steep enough to erode the bottom and the side of ditch. In many cases, concrete channels were constructed where the slope was mild and no channel erosion was expected. It was recommended that concrete drain channels need not be placed where the slope is low, but should be constructed only where channel erosion is expected. It was observed that large amounts of soil were moved into concrete channels during farming operations, such as tilling and seed bed preparation, because there was often no buffer or vegetated filter strip between the concrete channel and the field. If this was the case, the soil and other debris in the concrete channels needed to be removed in a timely manner before the rain comes. Also, some parts of the base of concrete channels were eroded during runoff events and timely maintenance and reinforcement works were necessary before it collapsed.

Gabion (or rock sack) and masonry walls are placed along stream banks and the mountain toe field boundaries. These were very effective in stabilizing stream banks and steep mountain toe slopes. Also, it helped farmers to not encroach on the mountain toe to enlarge their fields. Drop structures were a part of concrete channels, and were used to adjust the slope of the channel. These were considered as BMPs in Korea. Slope stabilization was an effective means of controlling soil erosion and landslides. Vegetation was the most popular method for slope stabilization. It was recommended that the vegetation treatment be well maintained by applying fertilizers regularly, because the soil was mostly sand and vegetation cannot be established well without the nutrient supply. Sediment traps are small concrete structures that have one or two chambers, 4 to 6 m^3 each, that are placed along concrete channels or at the end of a channel where it drains to a stream. It was found that the chambers, however, could not trap fine sediment particles because of the chambers were too small to trap sediments during the turbulent flow of runoff events. The recommendation was to not construct the small sediment traps. Perennial crop cultivation instead of vegetable crop farming was determined to be a very effective BMP for reducing soil erosion and runoff. It was strongly recommended that perennial crop (e.g. apple, grape, ginseng and wild edible greens) cultivation be supported and expanded.

During the BMP survey, it was found that furrow dams made of small permeable sandbags and/or sheaves of straw worked well in reducing soil erosion and muddy runoff by preventing rills and gullies along furrows. Farmers put small sandbags along furrows to slow down runoff velocity and reduce soil erosion. The furrow dams were very effective in preventing rills and gullies at the downstream end of furrows. Some farmers created the idea of cultivated barley or wheat as a barrier instead of sandbags or straw sheaves. This was also recommended as a BMP to be supported aggressively.

Most of the above BMPs are not aimed at reducing soil erosion and muddy runoff at the source. The source control, such as no-till, reduced tillage, or crop residue cover, were already acknowledged as best practices to reduce runoff and erosion. One of the best source control practices was no-till, where the surface was not disturbed by plowing and left covered with crop residues. The residue cover protects the soil surface from raindrop impact, reducing soil erosion, and because the soil pores are not clogged by eroded soil particles, water infiltration was maintained and surface runoff is minimized. Rills and gullies were the main cause of soil erosion in the highland fields, and since residue cover slowed runoff velocity, the rills and gullies did not develop as readily.

In Korea, there are two important reasons for BMPs to not target the source control. The first and the most important reason is that the authority of the control and management of water quality is in the hand of the MOE. And thus, Ministry of Food, Agriculture, Forest and Fishery (MOFAFF) does not pay much attention to policies and programs related to the prevention of soil erosion and water quality. MOE does not know about the agricultural best management practices and does not want to be involved in the agricultural BMPs, because that is the domain of MOFAFF. MOE doesn't want to interfere in MOFAFF's affairs. It is acknowledged that the contribution of point source pollution to the total water pollution is sharply decreased as the legal and systematic control of point source pollution is practiced. While the contribution of NPS pollution is expected to reach about 70% in 2015, and NPS pollution control and management have become key issues for improving water quality, however, because of the authority, good policies and programs to control soil erosion, muddy runoff and other agricultural NPS pollution are not well developed and implemented. The second reason is the lack of support for agricultural BMP research and incentive systems. Incentive systems for farmers to voluntarily use BMPs is a critical factor for the successful adoption of BMPs. Fundamental theories and techniques of BMPs are already developed in many other countries. Studies and field application experiments to adjust these practices to local agricultural environments are needed. However, BMP application experiments have not been well supported by either MOE and MOFAFF.

It is recommended that MOE and MOFAFF cooperate in controlling and managing agricultural NPS pollution. They have to form a joint task force or committee along with professionals and local governments to share information, develop programs and policies, support research programs, educate rural farmers, establish and support local governance system, and campaign various governmental and civil movements for water quality improvement. Cooperation between MOE and MOFAFF would contribute greatly improving water quality effectively and economically.

During the survey of BMPs in the sloping highland fields, it was noticed that officers and engineers of local governments as well as local engineers in construction and consulting firms did not have proper engineering knowledge and information on the theories and applications of BMPs. They didn't want to try to persuade farmers to join and adopt BMPs in their farming because it is costly and required labour, but there is no incentive system to compensate for farmer to adopt BMPs. The government investment will continue until 2014 or until the goal is achieved. And it is expected that source control to reduce soil erosion and muddy runoff will be introduced more aggressively than before by either MOE and/or MOFAFF because structural BMPs have its limit in reducing muddy runoff.

Conclusions

Agricultural NPS pollution is often called runoff pollution, because of its strong dependency on rainfall and runoff events. NPS pollution is largely affected by management practices, crops, soil characteristics, slope and slope length as well as rainfall amount and intensity. Understanding pollutant fate and transport is critical in developing the right policies and managing the correct practices to reduce soil erosion and muddy runoff. This study separated out the BMPs that were truly effective in controlling runoff and erosion from those that did not work. Knowledge of the potential, limitations and factors that affect the efficiency of individual practices is the first necessary piece of NPS pollution management. Being able to combine the knowledge, including that of any interactions between practices, with site-specific conditions, is the second necessary piece to develop overall system of in-field and off-site policies and practices (Baker *et al.* 2008). Due to these facts, it was recommended to develop programs that educate local government and consulting firm engineers on the BMP theories and application technologies.

Acknowledgements

This research is supported by Han River Environment Research Center, Ministry of Environment, Korea. Also, a part of the paper was supported by the Agricultural and Life Sciences Research Institute, Kangwon National University. We acknowledge the generous support.

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