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Effectiveness of variable-width buffer design for sediment reduction

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Introduction

Vegetative buffer strips are vegetated areas (usually strips) between fields and waterbodies that can mitigate the effects of agricultural activities by acting as a physical barrier to sediment and nutrients being carried to streams, and thereby have been widely used as a best management practice (BMP). Buffers can slow surface water flow and allow greater water infiltration, trapping the sediment entering from cultivated areas. In addition, research has documented the ability of buffers to removing pollutants from surface runoff and/or shallow groundwater (Lin et al., 2007; Ryder and Fares, 2008). For example, nitrogen can be removed by plant uptake or by microorganism denitrification within buffers (Lowrance and Hubbard, 2001).

Using appropriate buffer widths at prioritized locations is essential for maximizing the benefits and effectiveness of conservation buffers. A number of methods have been developed for buffer width design, among which using a uniform buffer width for the entire area is the most intuitive method and is still widely adopted. Different segments of field margins, however, often have different upland contributing area and thereby have different surface flow amounts and pollutant loads. As a result, the variable buffer width concept was proposed and several methods have been developed. One of the most widely-used methods is to vary buffer width for different field-margin segments so that the ratio of buffer area to its runoff contributing area stays the same for each segment (Bren, 1998). More recently, sediment trapping efficiency as a function of buffer area to field runoff area was generated and proposed using the buffer-filtration model (VFSMOD) after factoring in a number of variables including soil type, slope, and slope length (Dosskey et al., 2002). However, none of those methods designed buffer width based on the actual sediment load entering buffers, but either assumed a linear correlation between sediment load and runoff contributing area or used surface runoff as a surrogate. In this effort, we attempted to design variable buffer width based on the estimated sediment load from the upslope area for each field margin segment and compared its effectiveness in sediment reduction with other design methods (uniform width and constant buffer-area ratio). The Water Erosion Prediction Project (WEPP) model was used to estimate the sediment loading to the buffer and trapping by the buffer.

Materials and methods

Site description

Two farms were selected for this study, one from the Eastern Till Prairies (ETP) area and the other from Western Deep Loess and Drift (WDLD) area. The sites were chosen to try to represent typical soil and gradient in each region. The ETP farm is about 200 acres with a mean slope of 3.2% and the WDLD farm is about 90 acres with a mean slope of 7.1%. Kenyon loam and Sharpsburg silty clay loam is the predominant soil for the farm in ETP and WDLD, respectively.

Hillslope delineation

Digital Elevation Model (DEM) data (10 m) was used to obtain topographic information for the study farms. Flow direction was defined using the D8 algorithm in the TOPAZ application, which has been implemented in GeoWEPP (version 2.2008). GeoWEPP is a geospatial interface for the WEPP model. Each farm (watershed) was divided into a number of subareas (hillslopes) by TOPAZ based on flow directions. The derived watershed characteristics including the number of hillslopes, the number of channels, the total watershed area, and the mean slope steepness were used to build the watershed structure in the WEPP model for each farm.

Sediment load estimation

Sediment load for each hillslope was estimated using the WEPP model (v2006.5), which is a process-based, distributed parameter prediction model for soil erosion and sediment delivery from hillslopes and small watersheds (Flanagan and Nearing, 1995). Major hydrological processes were implemented in WEPP including erosion, infiltration, percolation, sediment transport and deposition, surface runoff, evapotranspiration, snow accumulation and melt, and irrigation. WEEP is useful for simulating the impact of land use and/or field management practices on soil loss and sediment transport on hillslopes and in small watersheds. The WEPP model not only can predict the long-term average erosion, but can also provide predictions for individual events. The performance of the WEPP model in predicting soil erosion and sediment yield has been validated for an Iowa watershed (Zhou et al., 2009).

A corn-soybean rotation system with chisel plow was simulated. Chisel-plow consisted of a fall chisel plow operation followed by field cultivation in the spring before planting.

Buffer width design

Constant buffer-area ratio: in this method 10% of each subarea was planted with perennial grasses at the bottom of the hillslope, i.e. the buffer width for each subarea was equal to 10% of the average hillslope length of that subarea when representing each subarea by a rectangular hillslope in WEPP.

Constant buffer-sediment ratio: in this method the total buffer area was still the same as in the constant buffer-area ratio method, i.e., 10% of total study area. However, the buffer area of each subarea was in proportional to the total sediment load from that subarea during a 10-year return period storm. In other words, the ratio of buffer area to sediment load was the same for each subarea. The sediment load of the 10-year return period storm was estimated using the return period analysis implemented in the WEPP model. A 10-year event has a 10% probability being equaled or exceeded in any one year over a long period of time.

Uniform buffer width: in this method the buffer width was determined by dividing the total buffer area (i.e., 10% of total study area) by the total length of field margins where buffers were built.

Results and discussion

Tables 1 and 2 list the estimated sediment yield and surface runoff during the 10-year return period storm for each subarea of the two study farms. As expected, the WDLD farm had greater estimated sediment yield and runoff flow for the 10-year event than the ETP farm because of its higher slope gradient. The overall sediment yield was 3.9 and 22.4 ton/acre for the ETP and WDLD farm, respectively (Figure 1). The WEPP-estimated sediment load of subareas varied between 1.1 and 8.4 ton/acre for the ETP farm, and between 4.5 and 32.4 ton/acre for the WDLD farm, suggesting that sediment yield per unit area had a large variation among subareas. Some areas of the farm had a more serious soil erosion problem than the other areas and thereby more buffer area would be needed in those areas. On the other hand, some areas had relatively small sediment yield due to the gentle gradient and therefore narrow buffers may function well for those areas. For example, the estimated sediment yield was 4.7 and 1.3 ton per acre for the subareas H11 and H14, respectively, therefore more buffer areas may be needed built for H11 despite both subareas having a similar size of runoff contributing area (about 13.4 acres). As a result, the runoff contribution area itself may not be a good indicator of sediment load entering the buffers.

In contrast to sediment yield, the estimated surface runoff per unit area showed little variation among subareas of each farm (Tables 1 and 2). This suggested that the runoff contributing area could be used as a surrogate for the surface runoff when determining buffer widths for the study farms.

Compared to the 100% row-crop scenario, the estimated sediment yield for the 10-year return period storm decreased by different degrees when implementing various buffer designs (Tables 3 and 4). For subareas with high erosion potential the constant buffer-sediment ratio method reduced sediment yield to a greater extent because it has wider buffer widths than the other methods. The estimated sediment yield of subarea H8 in the WDLD farm, for example, was 1064.3, 314.9, 375.0, and 491.8 tons for the 100% row-crop treatment, 10% buffer area with constant buffer-sediment ratio, 10% buffer area with constant buffer-area, and 10% buffer area with uniform buffer width, respectively (Table 4). It should be noted that the sediment yield in areas with low erosion potential may be higher for the constant buffer-sediment ratio method than the other two buffer design methods since the widths of the buffer may be smaller in these areas. When summing up the sediment yield from all the subareas, the sediment reduction in areas with relatively high erosion potential were much more than the sediment increases in areas with relatively low erosion potential. As a result, the buffers with a constant buffer-sediment ratio had an overall better performance in sediment reduction than the buffers using the other two design methods. Also the constant buffer-area ratio method performed better than the uniform width method. The overall sediment yield was 1.7, 1.9, and 2.3 ton/acre for the ETP farm and 8.6, 9.3 and 10.5 ton/acre for the WDLD farm, when using the constant buffer-sediment ratio, constant buffer-area ratio, and uniform width method, respectively (Figure 1).

Table 1. Estimated sediment yield and surface runoff for each subarea in the ETP farm during the 10-year return period storm.

Subarea	Area (acre)	Sediment yield (ton/acre)	Surface runoff (inch)
H1	6.7	5.0	2.5
H2	1.6	5.8	2.4
H3	3.8	6.3	2.3
H4	3.8	5.8	2.2
H5	3.6	3.5	2.4
H6	14.0	4.3	2.4
H7	9.5	1.3	2.4
H8	18.2	8.4	2.4
H9	8.2	6.6	2.2
H10	7.0	7.4	2.4
H11	13.4	4.7	2.4
H12	0.6	2.8	2.3
H13	1.8	4.8	2.4
H14	13.5	1.3	2.4
H15	1.4	2.7	2.4
H16	1.8	1.2	2.4
H17	14.3	1.1	2.4
H18	39.6	2.7	2.4
H19	10.3	3.5	2.4
H20	4.7	2.9	2.4
H21	3.5	2.6	2.1

Table 2. Estimated sediment yield and surface runoff for each subarea in the WDLD farm during the 10-year return period storm.

Subarea	Area (acre)	Sediment yield (ton/acre)	Surface runoff (inch)
H1	6.4	4.5	3.5
H2	3.5	5.6	3.4
H3	9.0	10.2	3.5
H4	6.2	11.4	3.5
H5	3.9	5.4	3.4
H6	2.8	6.8	3.4
H7	20.2	32.4	3.4
H8	35.4	29.8	3.5

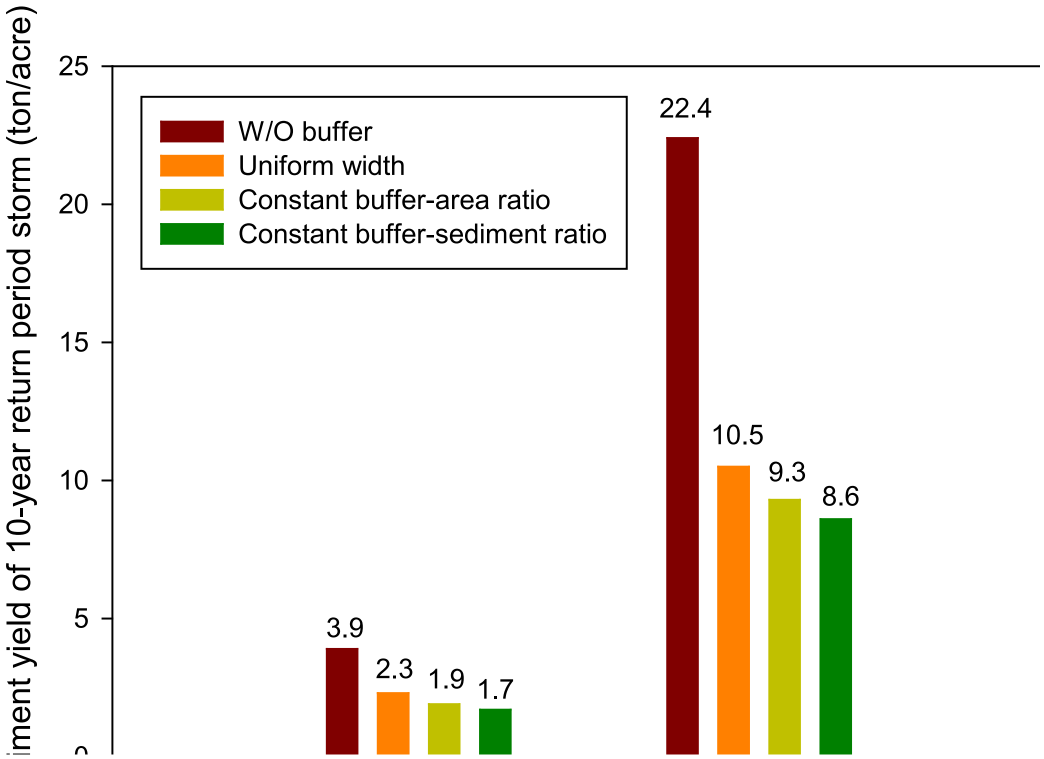

Figure 1. Sediment yield per acre during the 10-year return period storm under various buffer designs for the two study farms.

Table 3. Estimated sediment yield for each subarea in the ETP farm during the 10-year return period storm under various buffer designs.

	Sediment yield (ton)			
Subarea - ETP farm	W/O buffers	Constant buffer-sediment ratio	Constant buffer-area ratio	Uniform width
H1	33.7	13.5	8.1	17.5
H2	9.5	4.2	5.4	2.9
H3	23.8	8.3	12.1	11.0
H4	21.9	7.6	11.7	10.6
H5	12.6	5.1	6.1	5.4
H6	60.1	19.6	22.4	32.2
H7	12.3	12.3	11.4	10.4
H8	153.2	54.7	74.8	78.4
H9	54.0	18.8	28.6	26.2
H10	51.6	20.2	30.	30.7
H11	62.8	22.7	26.7	94.9
H12	1.7	1.5	1.5	0.6
H13	8.5	5.3	3.7	3.4
H14	17.5	13.5	8.1	13.5
H15	3.7	3.1	2.7	1.6
H16	2.2	2.0	1.8	1.4
H17	15.7	15.7	12.9	14.3
H18	107.0	39.6	31.7	47.6
H19	36.0	25.7	24.7	12.3
H20	13.5	11.2	10.3	4.2
H21	9.1	7.7	5.9	4.2

Table 4. Estimated sediment yield for each subarea in the WDLD farm during the 10-year return period storm under various buffer designs.

	Sediment yield (ton)			
Subarea - WDLD farm	W/O buffers	Constant buffer-sediment ratio	Constant buffer-area ratio	Uniform width
H1	28.8	21.8	10.9	12.8
H2	19.7	18.3	15.4	8.8
H3	91.7	69.2	58.4	56.6
H4	71.0	47.3	36.1	41.7
H5	20.8	18.5	13.9	10.0
H6	19.2	17.5	14.9	11.0
H7	654.2	242.3	284.7	280.6
H8	1054.3	314.9	375.0	491.8

Conclusions

A variable-width buffer design in proportion to the estimated sediment load entering buffers at each field margin could further improve the effectiveness of buffers when compared to the commonly-used uniform-width buffers and the constant buffer-area method. The use of the WEPP model allowed for a quick estimation of sediment yield of delineated subareas for return period storms and assessment of buffers on sediment reduction. For the future work, the constant buffer-sediment ratio method will be further evaluated for more watersheds using WEPP and other models.

Acknowledgements:

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References

Bren, L.J. 1998. The geometry of a constant buffer-loading design method for humid watershed. Forest Ecology and Management 110: 112-125.

Dosskey, M.G., M.J. Helmers, D.E. Eisenhauer, T.G. Franti, and K.D. Hoagland. 2002. Assessment of concentrated flow through riparian buffers. Journal of Soil and Water Conservation 57: 336-343.

Flanagan, D.C., Nearing, M.A., 1995. USDA Water Erosion Prediction Project. In Flanagan D.C., Nearing, M.A. (eds.) Hillslope profile and watershed model documentation. NSERL Report 10. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN, USA.

Lin, C. H., R. N. Lerch, H. E. Garrett, D. Jordan, and M. F. George. 2007. Ability of forage grasses exposed to atrazine and iosxaflutole to reduce nutrient levels in soils and shallow groundwater. Communications in Soil Science and Plant Analysis 38: 1119-1136.

Lowrance, R., and R. K. Hubbard. 2001. Denitrification from a swine lagoon overland flow treatment system at a pasture-riparian zone interface. Journal of Environmental Quality 30: 617-624.

Ryder, M. H., and A. Fares. 2008. Evaluating cover crops (sudex, sunn hemp, oats) for use as vegetative filters to control sediment and nutrient loading from agricultural runoff in a Hawaiian watershed. Journal of the American Water Resources Association 44: 640-653.

Zhou, X., Helmers, M.J., Al-Kaisi, M. Hanna, H.M., 2009. Cost-effectiveness and cost-benefit analysis of conservation management practices for sediment reduction in an Iowa agricultural watershed. J. Soil Water Cons. 64: 314-323.