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Watering or buffering? Runoff and sediment pollution control from furrow irrigated fields in arid environments

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ABSTRACT

Surface irrigated agriculture in arid and semi-arid regions contributes to downstream environmental degradation. Changes in irrigation system operational scenarios (ISOS) can represent an economic alternative to reduce surface runoff impacts. At the same time the use of vegetative filter strips (VFS) can have a positive impact on the ecological health of rural landscapes by reducing erosion, improving water quality, increasing biodiversity, and expanding wildlife habitat. The goal of this paper is, using a combination of field data and mechanistic modeling results, to evaluate and compare the spatial effectiveness of improvements in ISOS and introduction of VFS to reduce surface runoff pollution in the semi-arid/arid furrow irrigation agroecosystem that exceeds current regulatory turbidity limits (25 NTU). Five main factor interactions were studied: four soil textures, two field slopes, three ISOS, six filter vegetation types, and ten filter lengths. Slope and runoff volume were identified as the two main drivers of sediment export from furrows. Shifting from current ISOS to less water consumptive irrigation practices reduce runoff in addition to sediment delivery to comply with environmental regulations. The implementation of 3–9 m vegetative buffers on experimental parcels were found to mitigate sediment delivery (greater than 90% sediment reduction) on tail drainage ditches but had limited effect in the reduction of runoff flow that can transport other dissolved pollutants. These findings were insensitive to filter vegetation type. Thus, introduction of improved ISOS is desirable while VFS may be targeted to specific hot spots within the irrigation district. This study shows that the adoption of dense vegetation buffers in vulnerable semi-arid irrigated regions can be effective to mitigate agricultural impacts and provide environmental protection. However, it should not be adopted as an alternative to proper on-site irrigation practices, rather as a complementary off-site pollution control practice.

1. Introduction

Irrigated agriculture in arid and semi-arid regions offers the advantage that in these settings crops tend to achieve exceptionally high photosynthetic efficiency (Sojka et al., 2007). At the same time, irrigation in semi-arid environments represents one of the most serious challenges to sustainable agriculture. Semi-arid, irrigated agriculture is conducted largely on shallow soils vulnerable to irrigation-induced erosion (Sojka et al., 2007), contributing to water quality degradation for downstream users. The issue is exacerbated by large concentrated flows applied under surface irrigation management, and in particular under furrow irrigation (also referred to as rill irrigation), where water application efficiency rarely achieves more than 60% and tailwater runoff results in major water and sediment losses (Koluvek et al., 1993). Currently, 45% of the United States' 22 million hectares irrigated croplands are under surface irrigation, of which about half is furrow irrigated (USDA, 2009). Thus, to meet water quality standards and to protect natural ecosystems there is a pressing need to substantially improve water quality in furrow irrigation return flows (Szogi et al., 2007).

Among best management practices (BMP), vegetative filter strips (VFS) represent an efficient and economical way to reduce agricultural nonpoint source pollution, reduce runoff and remove suspended solids, nutrients and pesticides from runoff (e.g., Barfield et al., 1978; Muscutt et al., 1993; Qiu and Dosskey,

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2012). Dense vegetation in VFS acts as a filter by increasing surface roughness and augmenting infiltration that decreases flow volumes and velocity. This reduces the transport capacity of flow and encourages sediment deposition in the VFS (Barfield et al., 1978; Foster, 1982; Rose et al., 2002). These processes have a direct impact on sediment-bound nutrient transport and an indirect impact on soluble compounds by increasing infiltration (Kuo and Muñoz-Carpena, 2009). Lovell and Sullivan (2006) point out that VFS can have a positive impact on the ecological health of rural landscapes by reducing erosion, improving water quality, increasing biodiversity, and expanding wildlife habitat. However, VFS efficiency depends on several external and internal factors such as: incoming runoff volume, discharge, soil properties, filter sizes, and vegetation characteristics (e.g., Barfield et al., 1978; Muñoz-Carpena et al., 1993a; Vought et al., 1995). Several researchers have used this knowledge to model and analyze the characteristics and efficiency of VFS in humid and sub-humid agricultural watersheds. For example, Dosskey et al. (2008), presents a design aid for determining width of VFS under Hortonian runoff based on a process-based Vegetative Filter Strip Model (VFSMOD, Muñoz-Carpena and Parsons, 2011). Moreover, to help optimize the placement of VFS within watersheds, Dosskey et al. (2011) developed a spatial index based on VFSMOD that related runoff source area to different locations. White and Arnold (2009) also developed a revised algorithm for VFS efficiency for the watershed model SWAT based on results from VFSMOD simulations for a wide range of conditions. Research on modeling surface irrigation in arid/semi-arid regions has primarily focused on simulating the furrow system (e.g., Nearing et al., 1989; Bautista et al., 2009). To our knowledge, no research has addressed the pollution control through vegetative buffers at the end of furrow irrigated fields or the coupling of furrow irrigation and VFS systems using a mechanistic approach.

This study explores the operation improvement of the furrow irrigation system and the novel implementation of VFSs in arid environments as a BMP to control sediment transport in the Yakima River Basin, central Washington State. Granger Drain (Fig. 1) is a tributary to the lower Yakima River that has historically contributed high sediment loads that exceed suspended sediment water quality standards (Joy and Patterson, 1997). While VFSs are typically used to mitigate storm runoff in humid regions, this semi-arid region receives a mean annual precipitation of 150 mm (~5 in.) and sediment transport is largely governed by off-field movement of irrigation water (Fuhrer et al., 2004). One third of the parcels in Granger Drain use furrow irrigation, as this is a simple and cost-effective irrigation method. Water turbidity (NTU), used as a surrogate of total suspended sediments, at the Granger drain outlet exceeds the recommended values (25 NTU turbidity, Fig. 2) approximately 60% of the time based on criteria to protect aquatic life (Sigler et al., 1984). Elevated turbidity levels are synchronized with the irrigation season (April–October, Fig. 2) (Tooley, 1995), creating a need to evaluate BMPs to mitigate water quality impairments imparted by irrigation practices, such as changes in irrigation system operational scenarios (ISOS) and the implementation of VFS.

The goal of this paper is to utilize a combination of field data from a semi-arid/arid furrow irrigation region and deterministic mechanistic modeling under a wide range of field conditions to evaluate the water quality improvement of vegetative buffers, and compare these with several irrigation system operational

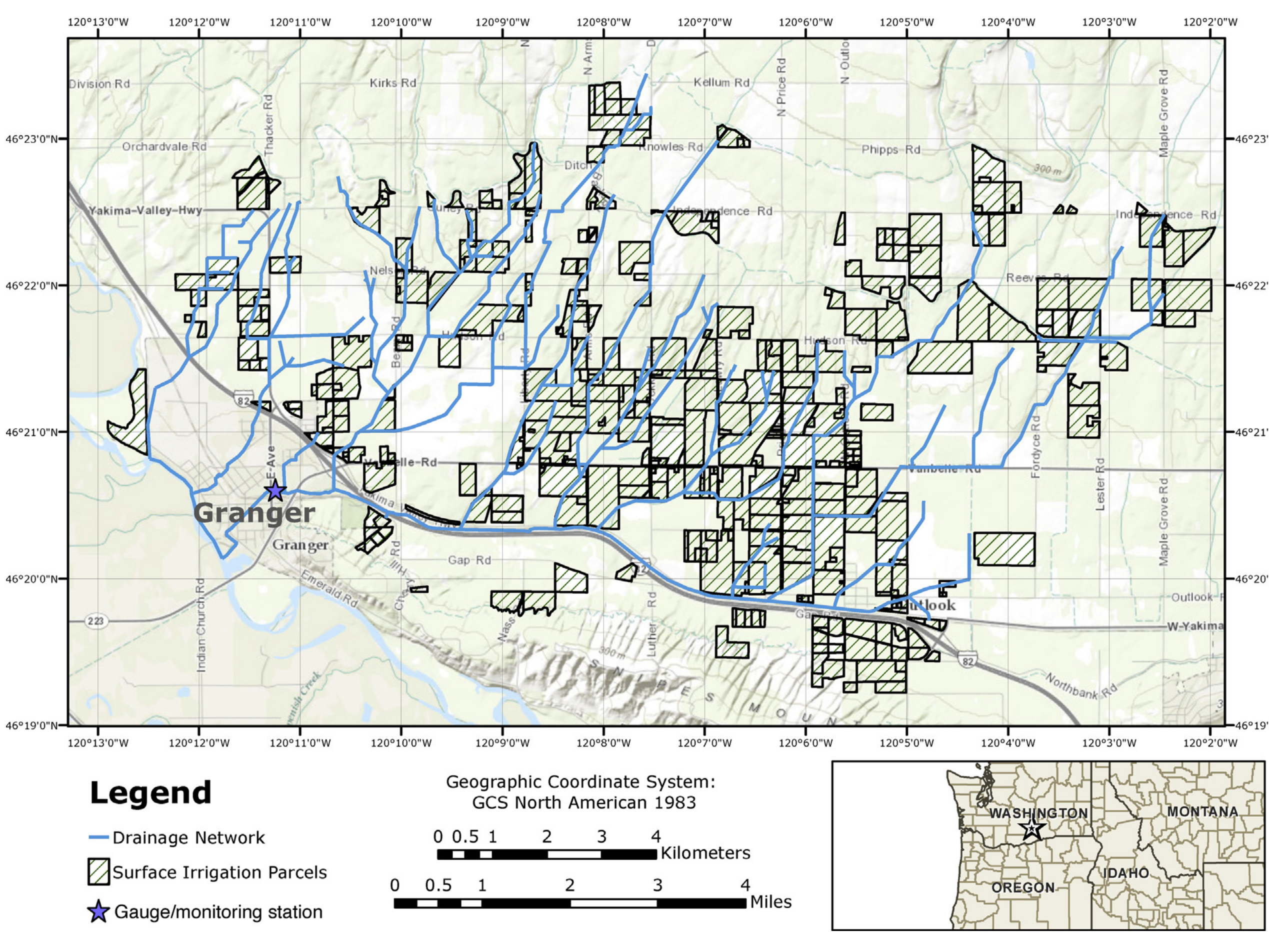

Fig. 1. Granger drain watershed. The inset map on the bottom right shows the geographic location of the watershed.