Comparison of runoff quantity and quality under annual cropping and forages

J. J. Miller, T. Curtis and D. S. Chanasyk

ABSTRACT

Conversion from annual cropping to perennial forages may be a beneficial management practice (BMP) to reduce runoff quantity and improve surface water quality. Runoff variables were determined in two 30 ha producer’s fields over 4 years (2004–2007) using a rainfall simulator. Field 1 was cropped to barley (*Hordeum vulgare* L.) in 2004 and then an alfalfa (*Medicago* sp.) and grass mix used for hay and fall grazing was grown from 2005 to 2007. Field 2 was cropped to barley-winter triticale (*Triticosecale Rimpavi Wittm.*) in 2005 and alfalfa-grass for hay was grown in 2006 and 2007. Runoff variables measured were runoff depth, electrical conductivity, and concentrations and loads of total suspended solids, total N, total P, and dissolved reactive P fractions. Conversion from barley to alfalfa-grass for hay and fall grazing in Field 1 resulted in reductions for only 13% of the 10 runoff variables, 33% of runoff variables were unaffected, and 53% of variables were significantly increased. Conversion from barley-WT to alfalfa-grass used for hay in Field 2 significantly reduced 25% of the 10 variables, 40% were unaffected, and 35% were significantly increased. Converting from annual cropping to forage did not improve the majority of runoff variables.

Key words | alfalfa-grass, annual cropping, barley, forage, runoff quality, runoff quantity

INTRODUCTION

Forage crops generally include annual and perennial legumes and grasses that are consumed by grazing livestock in pastures or else harvested as hay and used as stored feed (*Alberta Agriculture* 1988). In addition, some producers may use forage crops for hay and then use the field for fall grazing. A common crop rotation on irrigated land in southern Alberta is a 6-year rotation of 2 years of annual cropping to barley (*Hordeum vulgare* L.) followed by 4 years of forage such as an alfalfa (*Medicago* sp.) and grass mix used for hay or hay and fall grazing.

Incorporation of perennial forages such as grasses, legumes, and grass-legume mixes into cropping rotations may reduce the use of pesticides, reduce weeds, disrupt plant disease cycles, protect the soil from erosion and protect surface water quality, improve soil quality, and reduce reliance on external inputs of non-renewable energy (*Alberta Agriculture* 1988; Mostaghimi et al. 2001; Entz et al. 2011). Previous research comparing runoff quantity and quality under grass forage versus annual cropping have generally reported lower runoff, less soil erosion, and improved water quality under these sod- or turf-forming forages (Schuman et al. 1973; Jones et al. 1985; Harmel et al. 2009).

In contrast, research comparing runoff quantity and quality under non-sod forming alfalfa versus annual cropping has reported more variable findings. For example, Thomas et al. (1992) found that N and P losses in runoff were lower for alfalfa compared to corn, but others reported that losses from alfalfa and annual cropping were dependent on whether manure was applied to frozen ground (Young & Mutchler 1976), the specific N and P fraction in runoff (Wendt & Corey 1980; Sharpley & Smith 1991), or else it was dependent on the time of year (Wendt & Corey 1980). Soils under alfalfa may also be susceptible to water erosion early in the growing season (i.e., critical period) or after harvest if there is insufficient canopy development or surface

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residue to protect the soil surface and surface seals develop from raindrop or irrigation impact (Sturgul et al. 1990; Thomas et al. 1992). Considerably less water erosion occurs during the growing season (i.e., non-critical period) under alfalfa when there is sufficient crop canopy to protect the soil surface.

Although research has compared runoff quantity and quality under pure alfalfa, alfalfa-grass mixes, and tame grass (Zemenchik et al. 1996, 2002), we are not aware of any research that has compared alfalfa-grass mixes versus annual cropping such as barley or barley-winter triticale (WT). Zemenchik et al. (1996) found that adding smooth bromegrass (Bromus inermis) to alfalfa did not significantly reduce runoff volume, sediment concentration, or total soil loss at any rainfall event at any stage of regrowth. In a subsequent study, they concluded that avoiding excessive defoliation of the forage canopy was more effective at reduced bioavailable P losses than specific forage species selection. The use of annual winter cereals, such as fall-seeded WT (Triticosecale Rimplavi Wittm.), can provide farmers with a valuable alternative to perennial forages and is used for grazing, green feed, and hay in Alberta (Alberta Agriculture and Rural Development 2012). In southern Alberta, WT is sometimes seeded after barley harvest and then harvested for green feed in late fall to maximize forage production.

Evaluation of beneficial management practice (BMP) on producers’ fields and watersheds can be conducted using various experimental designs, including the before-after method (Spooner et al. 1985). This approach has been applied to evaluation of agricultural BMPs on producers’ fields and watersheds by several researchers (Meals 1987; Park et al. 1994; Owens et al. 1996; Sheffield et al. 1997; Brannan et al. 2000). A limitation of the before-after design is that variability in climatic, environmental, and hydrologic factors from year to year may make it difficult to detect differences in water quality due to BMPs (Spooner et al. 1985). Yearly variations in flow volume in surface runoff or rivers and rainfall are generally the major factors that can potentially mask BMP effects (Spooner et al. 1985). However, various methods that correct for river flows or some kind of hydrological adjustment have been proposed to evaluate BMPs and minimize this variability (Spooner et al. 1985; Rice & Izuno 1998). Portable rainfall simulators are also being increasingly used to evaluate BMPs (Mangiafico et al. 2010; Minnesota Department of Agriculture 2011). Rainfall simulators are particularly useful for comparing relative differences in runoff and water quality but they may not give accurate absolute values representative of large fields or watersheds (Cornish et al. 2002). Using a constant rainfall simulator intensity and time of rainfall application can eliminate the potential confounding effects of variable rainfall on BMP evaluation. In addition, using flow-weighted mean concentrations (FWMCs) can remove the potential masking effects of variable flow.

Our hypothesis in this study was that conversion from barley or barley-WT (annual cropping) to alfalfa-grass for hay or hay and grazing (forage) would result in lower runoff quantity and improved (i.e., decreased concentrations and loads) water quality (sediment, N, P) of surface runoff.

MATERIALS AND METHODS

Site description

The study area is located adjacent to the Lower Little Bow River and is about 50 km northeast of Lethbridge in southern Alberta, Canada. The soils are classified as the Alluvium soil series (Walker & Pettapiece 1994). This soil parent material consists of medium to moderately coarse-textured, stratified, fluvial deposits. The surface expression is floodplain and terraces with slopes of 0–5%, with short risers and banks with slopes >9%. Major soils are Rego Brown and Dark Brown Chernozems (50–60%), with Orthic Humic Regosols and Cumulic Humic Regosols (20–40%). Agricultural land use in this region consists of dryland cropping, intensive irrigated cropping, cattle grazing on native rangeland, and confined feeding operations.

Two non-replicated 30-ha producer’s fields with different land use practices were used in this study (Table 1). The two fields are located adjacent to the Lower Little Bow River. The two irrigated fields were generally in a 6-year crop rotation of 2 years of annual cropping to barley (Hordeum vulgare) or barley-WT followed by 4 years of a forage crop consisting of an alfalfa-grass mix that was used for hay and fall grazing (Field 1) or for hay only (Field 2).
Nitrogen (120 kg N ha\(^{-1}\)) and phosphorus (18 kg P ha\(^{-1}\)) inorganic fertilizer were annually applied to the barley crop in the spring. The seeding rate for the alfalfa-grass mix for both fields was 12 kg ha\(^{-1}\) of alfalfa (specific variety unknown), 6 kg ha\(^{-1}\) of orchard grass (\emph{Dactylis glomerata}), and 6 kg ha\(^{-1}\) of meadow brome grass (\emph{Bromus biebersteinii}). The alfalfa seed had been inoculated with \emph{Rhizobium} N-fixing bacteria. For our study period, Field 1 consisted of the cropping rotation of 1 year of annual cropping to barley in 2004 followed by 3 years (2005–2007) of forage (alfalfa-grass mix) with fall grazing by 700 sheep for 10 days in the fall (October) on the 30-ha field. Using the animal equivalent unit (AUE) for sheep of 0.2, this stocking rate was 1.5 AUM ha\(^{-1}\) or 0.6 AUM per acre. The recommended stocking rate for tame pastures to maintain good condition is 2.0 AUM ha\(^{-1}\) or 0.8 AUM per acre (Wroe et al. 1988). Therefore the stocking rate in Field 1 was slightly below the recommended value. For our study period, Field 2 consisted of barley-WT in 2005, and then alfalfa-grass in 2006 and 2007. The WT crop was planted in August after the barley crop was harvested, and the WT was harvested as a green feed crop in the late fall of 2005.

### Rainfall simulations and precipitation data

Rainfall simulations were conducted at 10 locations on Field 1 in 2004, 2005, 2006, and 2007; and at 10 locations on Field 2 in 2005, 2006, and 2007 (Table 2). The locations were chosen to achieve a relatively constant slope among within-field locations, and to have sufficient slope for surface runoff to occur. The 10 locations in Field 1 were at the upper slope position on the southern portion of field. The 10 locations in Field 2 were at the lower slope position on the southern portion of field. Representative photographs of the rainfall simulation plots showing the crop residue and crop canopy present are shown in Figures 1 and 2.

#### Table 1 | Crop types, canopy height, and area of bare soil visible for rainfall simulations in Fields 1 and 2 from 2004 to 2007

<table>
<thead>
<tr>
<th>Field 1*</th>
<th>Field 2*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>Canopy height (cm)</td>
</tr>
<tr>
<td>2004 Barley</td>
<td>0</td>
</tr>
<tr>
<td>2005 Alfalfa-grass fall grazed</td>
<td>20–30</td>
</tr>
<tr>
<td>2006 Alfalfa-grass fall grazed</td>
<td>≤5</td>
</tr>
<tr>
<td>2007 Alfalfa-grass fall grazed</td>
<td>≤5</td>
</tr>
</tbody>
</table>

*Crop rotation for Field 1 is 2 years of barley (2003, 2004) followed by 4 years of alfalfa with fall grazing (700 head for 10 days) by sheep (2005 to 2008).


#### Table 2 | Precipitation at Iron Springs 30 days before and during (start and end dates when rainfall simulations conducted) rainfall simulation periods for Fields 1 and 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop*</th>
<th>Before rainfall simulations</th>
<th>During rainfall simulations</th>
<th>Total precipitation mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Dates</td>
<td>Precipitation mm</td>
<td>Dates</td>
</tr>
<tr>
<td>Field 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>B</td>
<td>10 Aug–8 Sep</td>
<td>30.8</td>
<td>9–15 Sep</td>
</tr>
<tr>
<td>2005</td>
<td>A-G</td>
<td>21 Aug–19 Sep</td>
<td>185.3</td>
<td>20–26 Sep</td>
</tr>
<tr>
<td>2007</td>
<td>A-G</td>
<td>11–30 Jul</td>
<td>0.5</td>
<td>31 Jul–8 Aug</td>
</tr>
<tr>
<td>Field 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>B-WT</td>
<td>21 Aug–19 Sep</td>
<td>185.3</td>
<td>20–26 Sep</td>
</tr>
<tr>
<td>2006</td>
<td>A-G</td>
<td>8 Sep–4 Oct</td>
<td>22.8</td>
<td>5–19 Oct</td>
</tr>
<tr>
<td>2007</td>
<td>A-G</td>
<td>23 Jun–22 Jul</td>
<td>2.3</td>
<td>23–30 Jul</td>
</tr>
</tbody>
</table>

*B, barley; A-G, alfalfa-grass; B-WT, barley–winter triticale.
portable Guelph rainfall simulator and collection system (Tossell et al. 1987) was used to generate artificial rainfall and runoff on a 1 m² area. A rainfall intensity of 110 mm h⁻¹ was used in this experiment, which represents a greater than 50-year return period storm for 30 min. Lower rainfall intensities were initially tried on these fields, but runoff could not be generated, and testing found that runoff could only be generated at this higher rainfall intensity. However, this rainfall intensity was close to the range of values (100–103 mm h⁻¹) used by other researchers in this region (Little et al. 2005; Miller et al. 2006). A stainless-steel apron was constructed and installed on the lower slope of the rainfall simulation area to collect runoff and direct water into a funnel opening. A small hole was dug in the ground below the funnel opening and plastic 500-mL containers used to collect runoff.

After the antecedent soil properties had been determined prior to rainfall, the rainfall simulator was turned on. When runoff commenced, total runoff for the following four successive time intervals (0–5, 5–10, 10–20, 20–30 min) was collected and measured. Sub-samples of runoff volumes from each of these four sampling intervals were taken for selected physical and chemical analysis. The exception was for Field 1 in 2004, where one composite runoff sample was collected over 30 min.

Precipitation data from the Alberta Agriculture and Rural Development IMCIN (Irrigation Management Climate Information Network) weather station at Iron Springs were used for this study. Iron Springs is within 5 km of the watershed. Weather data from the long-term weather station at the Lethbridge Research Center, which is approximately 28 km from the WEBs (Watershed Evaluation of Beneficial Management Practices project) watershed, were used for missing data at Iron Springs.

**Soil sampling and analyses**

Three grab samples of surface soil were taken adjacent to the rainfall simulation area and one composite soil sample formed to determine selected chemical properties of the soil (total C, total N, and soil test P). Three undisturbed soil cores were also taken to determine bulk density and gravimetric moisture content determined by oven-drying. Volumetric soil moisture was calculated as the product of...
bulk density and gravimetric moisture. Disturbed soil for nutrient analysis was air-dried and ground to pass through a 2-mm sieve. Total C and N in soil were determined using the Dumas automated combustion technique (McGill & Figueiredo 1996) using a CNS analyzer (Carla Erba, Milan, Italy). Soil test P in soil was determined using a 1:10 (2.5 g soil:25 mL extract) Kelowna extract (Van Lierop 1992), and ortho-P analyzed on the autoanalyzer using the automated ascorbic acid method (Method 4500-P, Standard Methods for the Examination of Water and Wastewater 1998).

**Water sampling and analyses**

Electrical conductivity (EC) of runoff water was measured in the field using a portable water quality meter and associated probe (MultiLine P4, Wissenschaftlich-Technische, Werkstätten, Germany). Total suspended solids (TSS) was determined by filtering a water sample through a standard glass-fiber filter and weighing the residue dried at 103–105°C (Method 2540-D, Standard Methods of the Examination of Water and Wastewater 1998). Water samples for N and P analyses were transported to the laboratory, preserved with H2SO4 (N analyses), and stored at −20°C until analyzed. Dissolved reactive P (DRP) was determined on filtered (0.45 μm) water samples using the ascorbic acid method (Technicon Industrial Systems 1973). Total N (TN) and total P (TP) were determined on unfiltered water samples. Total N in water was extracted using the persulfate digestion method (Method 4500-N, Standard Methods for the Examination of Water and Wastewater 1998), followed by analysis of NO3-N using the automated hydrazine reduction method on the auto-analyzer (Method 4500-NO3, Standard Methods for the Examination of Water and Wastewater 1998). Total P in water was extracted using the persulfate digestion method (Method 4500-P B; Standard Methods for the Examination of Water and Wastewater 1998), and ortho-P analyzed as described above for DRP.

The FWMCs of chemicals in runoff were determined from the sum of total mass (mg) divided by the total volume of runoff (L) for the 30 min or runoff. Mass loads (g ha−1 h−1 or kg ha−1 h−1 for TSS) of chemicals in runoff
were calculated from the total mass loss per unit area and time.

Statistical analyses

The statistical analysis of the soil and runoff variables was conducted using a MIXED model analysis in SAS (SAS Institute 1989) using year as a random effect and rainfall simulator location as a fixed effect. Probability values ≤0.05 were considered significantly different. We used a before-after BMP analysis commonly used in water quality research on producers’ field and watersheds (UNESCO 1978; Spooner et al. 1985; Mostaghimi et al. 2001; Mesner & Paige 2011). Three yearly comparisons were made for Field 1 (annual cropping in 2004 vs forage BMP in 2005, 2006, or 2007) and two comparisons (annual cropping in 2005 vs forage BMP 2006 or 2007) made for Field 2.

Correlations were conducted among the runoff variables (data not shown). The correlations were done for each of the two fields and over all years. Correlations between selected soil and runoff variables were conducted for each field over all years.

RESULTS

Precipitation

Total precipitation in 2004 (337.6 mm) was 89% of the long-term average value (378.8 mm), indicating a relatively normal year (data not shown). In 2005, total precipitation (598.4 mm) was 158% of the long-term average, indicating a wetter than normal year. In 2006, total precipitation (282.3 mm) was 75% of the long-term average, indicating a drier than normal year. In 2007, total precipitation (263.6 mm) was 70% of normal, indicating a drier year.

Precipitation 30 days prior to the start of rainfall simulations and during the period of rainfall simulations was greatest in 2005 for Field 1, followed by 2004, 2006, and 2007 (Table 2). Total precipitation before and during the rainfall simulation period for Field 2 was greatest for 2005, followed by 2006, and then 2007.

Soil chemical and physical properties

Total soil carbon (organic + inorganic C) and nitrogen in Field 1 were lower \((P ≤ 0.05)\) by 16–36% for the soil cropped to alfalfa-grass in all 3 years (2005–2007) compared to barley in 2004 (Table 3). In contrast, total C and N in Field 2 were similar for alfalfa-grass (2006–2007) and barley-WT (2005). Soil test P in Field 1 was greater \((P ≤ 0.05)\) for alfalfa-grass in all 3 years compared to barley by two- to four-fold. In Field 2, soil test P was similar for alfalfa-grass in 2006 and barley-WT in 2005, and it was six-fold greater \((P ≤ 0.05)\) for alfalfa-grass in 2007 compared to barley-WT in 2005. Soil bulk density for Field 1 was similar for alfalfa-grass and barley for all years except 2007, where it was 11% greater \((P ≤ 0.05)\).

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>Total C g kg⁻¹</th>
<th>Total N g kg⁻¹</th>
<th>Soil test P mg kg⁻¹</th>
<th>Bulk density g cm⁻³</th>
<th>Soil moisture (volume) m³ m⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>B</td>
<td>2.5 ± 0.1 aᵇ</td>
<td>2.4 ± 0.1 a</td>
<td>9.2 ± 0.7 c</td>
<td>1.35 ± 0.02 b</td>
<td>0.082 ± 0.005 b</td>
</tr>
<tr>
<td>2005</td>
<td>A-G</td>
<td>1.6 ± 0.1 c</td>
<td>1.5 ± 0.1 c</td>
<td>20.5 ± 2.3 b</td>
<td>1.30 ± 0.04 b</td>
<td>0.129 ± 0.015 a</td>
</tr>
<tr>
<td>2006</td>
<td>A-G</td>
<td>2.1 ± 0.2 b</td>
<td>2.0 ± 0.2 b</td>
<td>28.9 ± 6.1 ab</td>
<td>1.52 ± 0.03 b</td>
<td>0.100 ± 0.011 ab</td>
</tr>
<tr>
<td>2007</td>
<td>A-G</td>
<td>1.8 ± 0.1 bc</td>
<td>1.9 ± 0.1 b</td>
<td>34.1 ± 3.1 a</td>
<td>1.51 ± 0.01 a</td>
<td>0.072 ± 0.008 b</td>
</tr>
<tr>
<td>Field 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>B-WT</td>
<td>2.0 ± 0.1 a</td>
<td>1.7 ± 0.1 a</td>
<td>9.9 ± 1.8 b</td>
<td>1.33 ± 0.01 b</td>
<td>0.090 ± 0.004 a</td>
</tr>
<tr>
<td>2006</td>
<td>A-G</td>
<td>2.0 ± 0.1 a</td>
<td>1.7 ± 0.1 a</td>
<td>11.8 ± 3.7 b</td>
<td>1.14 ± 0.03 c</td>
<td>0.063 ± 0.007 b</td>
</tr>
<tr>
<td>2007</td>
<td>A-G</td>
<td>2.1 ± 0.1 a</td>
<td>1.7 ± 0.1 a</td>
<td>58.5 ± 9.6 a</td>
<td>1.40 ± 0.03 a</td>
<td>0.069 ± 0.004 b</td>
</tr>
</tbody>
</table>

ᵇBarley; A-G, alfalfa-grass; B-WT, barley-winter triticale.

⅛Means within each column for each field are significantly different \((P ≤ 0.05)\).

Table 3 | Selected soil properties of two fields with different land use practices
for forage than barley in 2004. Bulk density in Field 2 was 14% lower for alfalfa-grass in 2006 than barley-WT in 2005 and the reverse trend occurred in 2007 where it was 5.2% greater for alfalfa-grass than barley-WT. Volumetric soil water content for Field 1 was similar for alfalfa-grass compared to barley except in 2005 where it was 1.6-fold greater ($P \leq 0.05$) for alfalfa-grass (2005) than barley (2004). Soil water in Field 2 was 23–30% lower ($P \leq 0.05$) for alfalfa-grass in 2006 and 2007 compared to barley-WT in 2005.

**Runoff depth**

Cumulative runoff in Field 1 for the 30 min was similar for alfalfa-grass in 2005 and 2006 compared to barley in 2005, but in 2007 it was two-fold greater ($P \leq 0.05$) for alfalfa-grass compared to barley (Figure 3(a)). Cumulative runoff for Field 2 was three-fold lower ($P \leq 0.05$) for alfalfa-grass in 2006 compared to barley-WT in 2005, but it was similar for alfalfa-grass in 2007 and barley-WT in 2005 (Figure 4(a)).

**Electrical conductivity**

Conversion to alfalfa-grass for Field 1 in 2005 had no significant effect on EC or salinity values compared to barley in 2004 (Figure 3(b)). However, EC values were two- to four-fold greater ($P \leq 0.05$) for alfalfa-grass in 2006 and 2007 compared to barley in 2004. Conversion to alfalfa-grass for Field 2 significantly increased EC values two- to three-fold for alfalfa-grass in 2006 and 2007 compared to barley-WT in 2005 (Figure 4(b)).
Total suspended solids

Mean FWMC of TSS in runoff for Field 1 was 1.5-fold lower ($P \leq 0.05$) for alfalfa-grass in 2005 compared to barley in 2004, but there was no difference between alfalfa-grass in 2006 and 2007 compared to barley in 2004 (Figure 3(c)). Mean mass loads of TSS for Field 1 were similar for alfalfa-grass in 2005 and 2006 compared to barley in 2004, but it was 1.4- to 1.7-fold greater ($P \leq 0.05$) for alfalfa-grass in 2006 and 2007 compared to barley in 2004 (Figure 3(d)).

Mean TSS concentration values in runoff for Field 2 were three- to eight-fold lower ($P \leq 0.05$) for alfalfa-grass in 2006 and 2007 compared to barley-WT in 2005 (Figure 4(c)). Mean mass loads of TSS for Field 2 were seven- to nine-fold lower ($P \leq 0.05$) for alfalfa-grass in 2006 and 2007 compared to barley-WT in 2005 (Figure 4(d)).

Mean FWMC of TSS in runoff for Field 1 over the 4 years exceeded the aquatic life guideline of 0.025 g L$^{-1}$ (British Columbia Ministry of Environment 2008) by 48-fold for barley in 2004 and by 32- to 52-fold for forages from 2005 to 2007. In Field 2, mean TSS concentrations exceeded the guideline by 132-fold for barley-WT in 2005 and by 16- to 44-fold for forages in 2006 to 2007.

Nitrogen

The FWMCs of TN in Field 1 were two- to six-fold greater ($P \leq 0.05$) under alfalfa-grass in 2005, 2006, and 2007 compared to barley in 2004 (Figure 5(a)). The TN loads in Field 1 were two- to six-fold greater ($P \leq 0.05$) for alfalfa-grass in all 3 years compared to barley in 2005 (Figure 5(b)). The FWMC of TN in Field 2 was three-fold greater for alfalfa-grass in 2006 compared to barley-WT
in 2005, and mean values were similar for alfalfa-grass in 2007 and barley-WT in 2005 (Figure 6(a)). The TN loads in Field 2 were similar for alfalfa-grass in 2006 and barley-WT in 2005, but values were three-fold greater \( (P \leq 0.05) \) for alfalfa-grass in 2007 compared to barley-WT in 2005 (Figure 6(b)).

Mean FWMCs of TN for Field 1 exceeded the surface water quality guideline in Alberta (Alberta Environment...
(1999) for protection of aquatic life (1.0 mg L⁻¹) by 1.4-fold for barley in 2004 and by three- to eight-fold for alfalfa-grass in the following 3 years. For Field 2, the guideline was exceeded 1.5-fold for barley-WT in 2005 and by three-fold for alfalfa-grass in the following 2 years.

**Phosphorus**

Mean FWMC of TP in runoff for Field 1 was three- to six-fold lower ($P \leq 0.05$) for alfalfa-grass in 2005 and 2006, and it was four-fold greater ($P \leq 0.05$) for alfalfa-grass in
2007 (Figure 5(c)). Loads of TP in Field 1 were five-fold lower for alfalfa-grass in 2005 compared to barley in 2004, values were similar for alfalfa-grass in 2006 and barley in 2004, and then they were three-fold greater for alfalfa-grass in 2007 compared to barley in 2004 (Figure 5(d)).

Mean FWMC of TP for Field 2 was similar for alfalfa-grass in 2006 and barley-WT in 2005, and it was five-fold greater for forage in 2007 compared to barley-WT (Figure 6(c)). Mass loads of total P in Field 2 were similar for alfalfa-grass in 2006 and barley-WT in 2005, but mean values were six-fold greater \((P \leq 0.05)\) for alfalfa-grass in 2007 compared to barley-WT in 2005 (Figure 6(d)).

Mean FWMCs of TP for Field 1 exceeded the surface water quality guideline in Alberta (Alberta Environment 1999) for protection of aquatic life \((0.05 \text{ mg L}^{-1})\) by 126-fold for barley in 2004 and by 22- to 466-fold for alfalfa-grass in the following 3 years. For Field 2, the guideline was exceeded 14-fold for barley-WT in 2005 and by 30- to 74-fold for alfalfa-grass in the following 2 years.

The DRP FWMCs in Field 1 were similar for alfalfa-grass in 2005 and 2006 compared to barley in 2004, but mean values were 116-fold greater for alfalfa-grass in 2007 compared to barley in 2005 (Figure 5(e)). The DRP loads in Field 1 were similar for alfalfa-grass in 2005 and barley in 2004, and then values were 5- to 153-fold greater for alfalfa-grass in 2006 and 2007 compared to barley in 2004 (Figure 5(f)).

The DRP FWMCs in Field 2 were similar for alfalfa-grass in 2006 and 2007 compared to barley-WT in 2005 (Figure 6(e)). The DRP loads in Field 2 were similar for alfalfa-grass in 2006 compared to barley-WT in 2005, and mean values were 17-fold greater \((P \leq 0.05)\) for alfalfa-grass in 2007 compared to barley-WT in 2005 (Figure 6(f)).

Correlations between runoff variables

In Field 1, strong \((r \geq 0.70)\) correlations with EC occurred for TN, TP, and DRP (data not shown). Moderate and significant positive correlations occurred between TN versus TSS; and weak \((r \text{ values between 0.2 and 0.4) positive correlations between the TP and DRP versus TSS.}

In Field 2, there were strong positive correlations between TN and TP with EC. A moderate and positive correlation occurred between TN and TSS, and weak \((r \text{ values between 0.2 and 0.4) positive correlations were found between TP and TSS.}

Correlations between selected soil properties and runoff variables

There was a moderate and significant \((P \leq 0.05)\) positive correlation between soil bulk density and runoff depth for Field 1 \((r = 0.51)\) and Field 2 \((r = 0.41)\). No significant correlations were found for total N in soil versus the concentrations of TN in runoff. A significant and positive correlation was found for soil test P versus total P concentration in runoff for Field 2 \((r = 0.47)\) but not for Field 1. Significant positive correlations occurred for soil test P versus DRP concentration in runoff for Field 1 \((r = 0.28)\) and Field 2 \((r = 0.38)\).

DISCUSSION

Our hypothesis was that conversion from barley or barley-WT to alfalfa-grass would decrease runoff quantity and improve runoff quality. To summarize the overall findings, we considered all 10 runoff variables for each field and the 3-yearly comparisons for Field 1, and the 2-yearly comparisons for Field 2. Conversion from barley to alfalfa-grass for hay and fall grazing in Field 1 resulted in reductions for only 13% of the 10 runoff variables, 33% of runoff variables were unaffected, and 53% of variables were significantly increased. Conversion from barley-WT to alfalfa-grass used for hay in Field 2 significantly reduced 25% of the 10 variables, 40% were unaffected, and 35% were significantly increased. In addition, the magnitude of exceedances of water quality guidelines by concentrations of TSS, total N, and total P were similar or greater for alfalfa-grass compared to barley in Field 1. The magnitude of the exceedances for these four runoff variables in Field 2 was considerably greater for alfalfa-grass compared to barley-WT.

Therefore, these results do not support the hypothesis that conversion from barley or barley-WT to alfalfa-grass significantly decreased the majority of runoff variables or decreased the magnitude of exceedances for water quality guidelines. Rather, the majority of runoff variables were either unaffected or increased by conversion to...
alfalfa-grass, suggesting a neutral or negative effect on runoff quantity and quality. A few runoff variables were improved by alfalfa-grass, but it was dependent on the field and year of study. Specifically, the TSS concentration in Field 1 was reduced by alfalfa-grass in 2005, TP FWMC was reduced in 2005 and 2006, and TP loads were reduced in 2005. Runoff quantity in Field 2 was reduced by alfalfa-grass in 2006, and TSS concentration and load were reduced in 2006 and 2007. The lack of positive forage effects was not masked by combining the runoff results into the 30-min time interval, as the runoff results for the four collection periods during the 30 min were generally similar, suggesting no interaction with time period of collection (data not shown).

We attributed the lack of positive forage effects on runoff variables in Field 1 to the greater surface residue or mulch present on the soil surface under barley compared to alfalfa-grass, to the lack of canopy development and increased bare soil for alfalfa-grass in 2006 and 2007 and rainfall simulations being conducted during critical periods, as well as to fall grazing of alfalfa-grass by sheep that likely contributed N and P to the soil through fecal material and urine. The lack of positive effects on runoff variables in Field 2 was attributed to the fall-seeded WT that increased the crop canopy development resulting in little or no bare soil visible, as well as to the lack of canopy development and increased bare soil under alfalfa-grass (2006, 2007). The moderate and significant correlation between soil bulk density and runoff depth suggested that soil factors may also have masked possible crop-type effects. The poor correlation between N and P in soil and runoff may have been due to the high spatial variability of soil nutrients in these large fields. Most of our rainfall simulations in both fields were conducted in the fall, except in 2007 when they were conducted in the summer. The timing of our rainfall simulations mostly in the fall period when the crop canopy is absent or poorly developed under alfalfa-grass, may have been a major factor causing poor BMP performance of forage. In addition, there was no or a poorly developed sod- or turf-layer in the soil surface with considerable bare soil under alfalfa-grass, and this was also a likely major factor contributing to lack of positive BMP response. Yearly variations in precipitation and antecedent soil moisture of the surface soil, and variations in antecedent soil moisture within each field, may also have affected BMP performance. Finally, within-field variability in runoff variables may also have been a contributing factor.

Cropping systems that leave some or all the previous crops’ residue on the soil surface are effective in reducing cropland soil erosion (Mueller et al. 1984; Andraski et al. 1985; Sauer & Daniel 1987). This occurred in Field 1 for barley in 2004 when straw from the previous crop harvest was left on the soil surface instead of being baled as hay. The lack of canopy development and increased bare soil for alfalfa-grass in all years (except 2005 in Field 1) occurred because most rainfall simulations were conducted after harvesting of forage and removal of the forage canopy and this is the critical period when forages are susceptible to water erosion. The critical period for runoff and erosion is defined as periods when the soil is least protected and more vulnerable to erosion by excess runoff than during times when the crop canopy or residue protects the soil (Laflen & Tabatabai 1984; Yoo & Touchton 1988). Greater runoff and soil loss has been reported for alfalfa compared to corn during critical than non-critical periods (Thomas et al. 1992). In Field 1, 30% of the 10 runoff variables were significantly reduced or improved by alfalfa-grass in 2005 compared to barley in 2004 when the forage crop had the most well-developed crop canopy with no bare soil visible. In comparison, 10% of the 10 runoff variables were significantly reduced by alfalfa-grass in 2006 and no variables reduced in 2007 when the forage canopy was virtually absent and considerable bare soil visible. In addition, the percentage of runoff variables significantly increased (i.e., negative effect) by alfalfa-grass was considerably lower in 2005 (20%) under full crop canopy compared to no crop canopy in 2006 (50%) and 2007 (90%). However, the finding that only 30% of runoff variables in 2005 for Field 1 were significantly improved even with a well-developed crop canopy and no bare soil visible may be related to the crop residue protecting the soil under barley in 2004 rather than the crop canopy being ineffective.

To examine the effect of fall grazing on runoff variables from alfalfa-grass, we compared mean values for the 10 runoff variables for alfalfa-grass in 2006 and 2007 for Field 1 (hay and fall grazing) versus Field 2 (hay). The soils in these two adjacent fields are similar. The mean values for runoff variables were greater for Field 1 compared to Field
2 for 80–90% of the variables in both years, indicating the negative effect of fall grazing on runoff variables. The exceptions where mean values were lower for Field 1 than Field 2 were EC in 2006, and runoff depth and EC in 2007. Environmental degradation by grazing animals on forage is caused by treading, defoliation, and excretion of feces and urine (Bilotta et al. 2007). Although soil compaction by sheep is less than cattle (Murphy et al. 1995; Bilotta et al. 2007), sheep can still cause an increase in soil bulk density with higher stocking rates (Stephenson & Veigel 1987). Sheep also defoliate the forage crop canopy closer to the ground than cattle, and this was evident for alfalfa-grass in 2006 for Field 1. Excretion of feces and urine by livestock on pastures may be a major contributor of N and P to the soil and runoff (Haynes & Williams 1995; Chen et al. 2001). Erosion and sediment transport on grazed forages is primarily associated with high-density stocking or poor forage stands (Hubbard et al. 2004), but our stocking rate was slightly lower than recommended and the forage in generally good condition. Grazing by sheep can increase runoff quantity and nutrient concentrations (McColl & Gibson 1979). However, some studies have reported that intensive grazing by sheep on grass-legume pastures did not increase runoff losses compared to recommended grazing intensity (van Doren et al. 1940).

Our rainfall simulations on alfalfa-grass in 2006 were conducted in late fall in Field 1 (September 20–26) and Field 2 (October 5–19) after the first frost on September 17. Concentrations and loads of TN in runoff for Field 1 were significantly greater for alfalfa-grass in 2006 after the first frost compared to barley in 2004 prior to the first frost. In Field 2, TN and TP concentrations for alfalfa-grass in 2006 after the first frost were significantly greater compared to barley-WT in 2005 before the first frost. Some studies have reported increased release of N and P (mainly dissolved or inorganic P) to surface runoff after freezing or freezing and thawing of growing forage crops because of rupturing of plant cells (Timmons et al. 1970; Wendt & Corey 1980; Sharpley & Smith 1991; Miller et al. 1994; Bechmann et al. 2005).

The dramatic increase in soil test P in 2007 for Field 2 compared to the previous 2 years was consistent with large increases in concentrations and loads of the various P fractions. We believe the high soil test P in 2007 was likely related to sampling in a large field and encountering ‘nutrient hot-spots’ since no livestock or inputs of P were applied to this field between 2006 and 2007.

CONCLUSIONS

Conversion from barley or barley-WT to alfalfa-grass resulted in no significant effect or a significant increase for the majority of runoff variables, resulting in rejection of our hypothesis that forages would reduce runoff quantity and improve surface water quality compared to annual cropping. However, a few runoff variables were significantly improved by alfalfa-grass, but it was dependent on the field and year of the study. We attributed the lack of positive effects on runoff variables in Field 1 to the greater surface residue or mulch present on the soil surface under barley compared to alfalfa-grass, to the lack of canopy development and increased bare soil for alfalfa-grass in 2006 and 2007, as well as to fall grazing by sheep under alfalfa-grass that likely contributed N and P to the soil through fecal material and urine. The lack of positive effects on runoff variables in Field 2 was attributed to fall seeding of WT which increased the crop canopy development resulting in little or no bare soil visible, as well as to the lack of canopy development and increased bare soil under alfalfa-grass (2006, 2007). The timing of rainfall simulations in relation to canopy cover, crop residue cover, and bare soil exposure, as well as lack of turf or sod development under alfalfa-grass, and yearly variations in weather and environmental factors, may also have been contributing factors to poor BMP performance.

Further research needs to compare runoff quantity and quality for these cropping systems during the growing season when the crop canopy is well-developed for alfalfa-grass as this might result in more positive forage effects compared to annual cropping. Further research could also evaluate this BMP on smaller replicated plots which might help reduce variability on non-replicated fields and aid in separating the BMP effects from environmental factors. As an alternative to rainfall simulators in non-replicated fields, edge-of-field runoff could also be used to collect runoff from entire fields with specific BMPs.
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REFERENCES


Alberta Environment 1999 Surface Water Quality Guidelines for Use in Alberta. Environmental Science Division, Alberta Environment, Edmonton, AB.


Little, J. L., Bennett, D. R & Miller, J. J. 2005 Nutrient and sediment losses under simulated rainfall following manure incorporation by different methods. J. Environ. Qual. 34, 1883–1895.


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