List of supplementary materials

Supplementary material 1. Description of study site instrumentation and data collection

Supplemental Figure 1. Comparison of annual and seasonal overland flow (OF) depths and tile flow (TF) depths during the study years.

Supplemental Figure 2. Relationships between (a) total phosphorus and nitrate-N in overland flow (OF); (b) soluble reactive phosphorus and nitrate-N in OF; (c) soluble reactive phosphorus and total phosphorus in OF; (d) total phosphorus and nitrate-N in tile flow (TF); (e) soluble reactive phosphorus and nitrate-N in TF; and (f) soluble reactive phosphorus and total phosphorus in TF.
Contribution of overland and tile flow to runoff and nutrient losses from vertisols in Manitoba, Canada


Supplemental material 1.

Additional details related to field instrumentation and data collection

Overland flow depths were monitored at 15-minute intervals at the outlets of two surface swales using V-notch weirs, each equipped with an ultrasonic depth sensor (50A, Campbell Scientific Ltd.) and a capacitance sensor (Odyssey, Dataflow Systems Ltd.). Sensor estimates were validated using manual measurements. Within the ephemeral ditch adjacent to the field, capacitance sensors were installed in stilling wells both upstream and downstream of the ditch to record water levels at 15-minute intervals (Odyssey, Dataflow Systems Ltd.). In 2016, a depth-velocity sensor (Flo-tote 3 and FL 900 series logger, Hach Ltd.) was deployed at the downstream sampling location of the ephemeral ditch to develop a rating curve for converting water depths to flow values, and to estimate the volume of water that was leaving the field during lateral flow reversal conditions from ditch to field, which are common in the region (Cordeiro et al., 2017). Tile drain discharge was measured at 15-minute intervals at the tile drain main outlet using a Flo-tote 3 and FL 900 series logger (Hach Ltd.). A pressure transducer (HOBO U20, Onset Corp.) was also placed into the tile to monitor water levels during periods when the flow sensor did not function. During periods when the tile outlet was submerged in the collection pond or the lifting station did not work, manual pumping was used to transfer the collected tile water to the on-site retention pond. In 2016, when the lifting station was added, an automatic water level logger was deployed in the station to record water levels for comparison with measured tile discharge rates (Mini Orpheus, Campbell Scientific Ltd.). A standard meteorological station (CR10x, Campbell
Scientific Ltd.) was established at the site to take hourly measurements of precipitation (TE525M, Texas Electronics) and air temperature (HMC45C, Campbell Scientific Ltd.).

**Water sampling and analysis**

Tile and overland flow water samples were collected with programmable autosamplers (AS950, Hach Ltd.) from March 1st to September 30th in each of the study years (2015 to 2017), capturing the annual spring freshet (snowmelt), spring storms and summer thunderstorms. However, events in September 2015 and 2016 were not sampled for water chemistry due to logistical issues. No significant rain events occurred between late September and early March in any of the study years. Indeed, daily precipitation was below <10 mm and mean air temperatures were below 0°C from mid-November through the onset of spring snowmelt runoff (early-March in 2015, mid-March in 2016 and late-March in 2017) (Figure 1). Thus, although sampling was not conducted during these periods, no flow at the site occurred. Periodic field visits were done to validate this. Between snowmelt and freeze up in each of the study years, a 2 to 4-hour sampling interval was employed to capture the rising and recession limbs of storm hydrographs, while 6 to 12-hour sampling intervals were employed during periods of water stagnation or impeded flow. Autosamplers collected samples in acid washed 1 L polyethylene bottles. Manual grab samples were collected in acid washed 0.5 L polyethylene bottles when the flow was too low for autosamplers to capture.

Upon return to the laboratory, a 200 mL subsample was promptly filtered through a 0.45 μm filter paper, (Whatman, 47 mm), and stored at 4°C. Samples were analyzed for soluble reactive phosphorus (SRP) (QuikChem Method 10-115-01-1-A) and nitrate nitrogen (NO₃-N) (QuikChem Method 10-107-04-4-C) with a QuikChem 8500 series 2 FIA system (Lachat instruments) through flow injection analysis colorimetry (Lachat Applications Group, 2007) and flow injection analysis
(Lachat Applications Group, 2008) within 48 hours of collection. A final 200 ml subsample was frozen at -18 °C and subsequently processed and analyzed for total phosphorus (TP) (QuikChem Method 10-115-01-4-C, Lachat Applications Group, 2014) with QuikChem 8500 series 2 FIA system. Standard checks were used per 20 samples as a mean for quality control. Samples that exceeded the standard spectrum were diluted and re-analyzed.

**Overland flow estimation during peak flow periods with backflow**

Due to the flat landscape, there were periods during which the adjacent ditch was full and field was flooded. During such periods, surface runoff can become stagnant (backwater effects). Such periods were differentiated from more conventional flow periods (i.e., when surface water ran freely into ditch) using the difference between water levels at the weirs and the culvert in the ditch exit. When flow resumed or initiated from inundation, overland flow was assumed to be equal to ditch flow until ditch and surface weirs were disconnected. It was safe to make this assumption at our site as the ephemeral ditch essentially received all of its runoff water from our study site (Kokulan et al., 2019) and all of this water flows through the culvert where the flow meter was installed. Two different rating curves were developed for spring ($r^2 = 0.96$) and summer ($r^2 = 0.78$) when estimating flows for 2015 and 2017 events with backwater effects/stagnation. This method might have slightly overestimated runoff volumes by accounting already available ditch water as overland flow. Over error estimates, considering the water available prior to flow resumption, were 2.6, 3.5 and 4.5% of annual overland flow estimations for 2015, 2016 and 2017. We also considered the possibility of overestimation from subsurface flow that may have seeped in the ditch. Possibilities for subsurface dilution are lower in this landscape during snowmelt runoff due to frozen soils. Moreover, ion concentrations in the ditch water (not shown) did not show higher concentrations during snowmelt backflow periods, despite the fact that subsurface water in fields
was found to be ion-rich, suggesting that minimal subsurface seepage was received by the ditch. Currently, there are no established methods to measure flow during inundation periods, nor are there estimates of acceptable error ranges to enable a direct comparison with existing hydrometric literature (Environment Canada 1980; Kiang et al., 2018). This is an area where additional research is needed.

References


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