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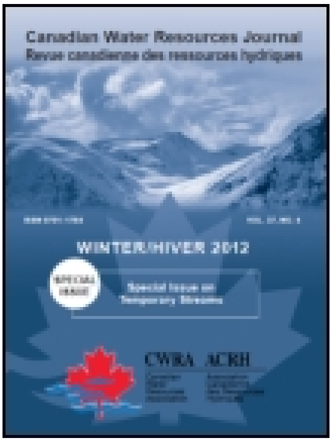

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Influence of Tillage System on Water Quality and Quantity in Prairie Pothole Wetlands

Written comments on this paper will be accepted until December 2001

Jane A. Elliott[1], Allan J. Cessna[2] and Clint R. Hilliard[3]

ABSTRACT

Since zero tillage (ZT) requires more herbicide and fertilizer use than conventional tillage (CT) and may improve water infiltration into soil, the system may negatively impact prairie pothole wetlands. In this paper, the hydrology and water quality of pothole wetlands in zero tillage and conventional tillage systems were compared by monitoring three wetlands (ZT–1, ZT–2 and CT) from 1995 to 1997, and during a runoff–producing summer storm in 1998. Wetland water levels were recorded during snowmelt runoff and throughout the unfrozen period. Water samples from the wetlands were analyzed for total P, ortho P, NO_2–NO_3, NH_3 and a suite of commonly–used herbicides. In each year of the study, similar snow accumulations generated more runoff per unit area from the ZT basins than the CT basin. Water levels were similar in the three wetlands in the spring of 1995, but by 1997 the water depths were less in the ZT wetlands than in the CT wetland. Despite greater fertilizer use in the ZT basins, we did not observe a consistent effect of tillage system on available N and P in the surface soil. Phosphorus concentrations were generally higher in the ZT than the CT wetlands during snowmelt but there was no consistent effect of tillage on NO_2–NO_3 or NH_3 concentrations in the wetlands. The herbicides found in all three wetlands included those that were applied during the study and some that were not. At least one herbicide was detected in trace amounts in approximately 75% of samples from the wetlands.

RÉSUMÉ

Étant donné que le semis direct (SD) exige davantage d'herbicide et d'engrais que le travail du sol classique (TSC) et peut améliorer l'infiltration d'eau dans le sol, le système peut porter préjudice aux îlots de milieux humides des Prairies. Dans le

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présent article, nous avons comparé l'hydrologie et la qualité de l'eau des îlots de milieux humides dans les systèmes de semis direct et de travail du sol classique au moyen de la surveillance de trois marécages (SD–1, SD–2 et TSC) de 1995 à 1997, de même qu'au cours d'une tempête d'été à l'origine d'un ruissellement et pendant toute la période de dégel. Des échantillons d'eau prélevés dans les marais ont été analysés pour le phosphore total, l'ortho–phosphore, le NO_2–NO_3, le NH_3 et une série d'herbicides d'usage courant. Pour chaque année de l'étude, des couches de neige semblables ont produit plus de ruissellement par unité de surface à partir des bassins SD qu'à partir du bassin TSC. Les niveaux d'eau étaient semblables dans les trois milieux humides au printemps de 1995. Cependant, en 1997, les profondeurs d'eau étaient moins grandes dans les milieux humides SD que dans le milieu humide TSC. Malgré une utilisation d'engrais plus grande dans les bassins SD, nous n'avons pas observé d'incidence cohérente du système du travail du sol sur le N et le P disponibles dans le sol de surface. Les concentrations de phosphore étaient en général plus élevées dans les milieux humides SD que dans les TSC pendant la fonte des neiges, mais on n'a pas constaté d'effet cohérent du travail du sol sur les concentrations de NO_2–NO_3 ou de NH_3 dans les milieux humides. Les herbicides trouvés dans les trois milieux humides englobent ceux qui ont été appliqués au cours de l'étude et certains autres qui ne l'ont pas été. Au moins un herbicide en quantités infimes a été découvert dans environ 75 % des échantillons des milieux humides.

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INTRODUCTION

Pothole wetlands, found across the prairies of North America, are valuable habitat for wildlife, especially waterfowl, and play an important role in the surface water and groundwater hydrology of the region. Many pothole wetlands in agricultural regions have been drained to expedite farming operations (Sharrat *et al.*, 1999) and those that remain are sensitive to the land use in their catchments (van der Kamp *et al.*, 1999). The ecological integrity of prairie wetlands can also be threatened by excessive nutrients (Sandilands *et al.*, 2000) and the presence of herbicides (Donald *et al.*, 1999).

Van der Kamp *et al.* (1999) found that the conversion of land from conventional dryland cultivation to permanent smooth brome grass (*Bromus inermis*) cover caused prairie pothole wetlands to dry out while wetlands in a neighbouring cultivated area retained water as before. Since melting snow was the main source of water in the wetlands (Hayashi *et al.*, 1998), the drying out of these wetlands was attributed to the trapping of snow on the surrounding uplands by the stiff–stemmed grass and improved infiltration of snowmelt due to dry soil conditions in the fall (Gray *et al.*, 1985). More subtle changes in agricultural management practices could also impact the hydrology of prairie potholes.

Across the Canadian prairies, conservation tillage practices are gaining popularity because they effectively reduce soil erosion and the time and energy required for seedbed preparation. Zero tillage, an extreme form of conservation tillage where the only soil disturbance is to place the seed, was used to plant approximately 25% of Saskatchewan cropland in 1998. The conversion from conventional dryland cultivation (conventional tillage in a crop–summerfallow rotation) to a zero tillage, continuous cropping system could potentially affect hydrology in a manner similar to the conversion to brome grass. Under long–term zero tillage, the capacity of soil to infiltrate water increases because of reduced soil disturbance and the development of a water–stable soil structure with continuous pores (Azooz and Arshad, 1996; Elliott and Efetha, 1999). In addition, elimination of fall cultivation and summerfallow tillage would promote snow–trapping by leaving stubble standing over–winter (Pomeroy and Gray, 1995).

Since weeds cannot be controlled by cultivation in a zero tillage system, more herbicide applications are required, and fertilizer use generally increases as the frequency of summerfallow in the crop rotation decreases (Boehm and Anderson, 1997). Although herbicides are transported in surface runoff water (Cessna *et al.*, 1994), the quantity of agrochemical used does not necessarily reflect the impact on water quality because other aspects of the production system may also influence water quality. Reduced erosion resulting from zero tillage management (Bruce *et al.*, 1990) will decrease the loads of sediments and associated agrochemicals to surface waters while a reduction in runoff volumes, due to hydrological impacts of the zero tillage continuous cropping production system discussed above, may also affect the quality of the runoff water.

While it is clear that zero tillage systems and continuous cropping could potentially impact the quantity and quality of water in prairie pothole wetlands, the effects of tillage on prairie potholes have not previously been studied. The present research compares two prairie pothole wetlands in catchments recently converted to zero tillage, continuous cropping systems with one in a catchment which continues to be conventionally managed. The wetlands were monitored during snowmelt runoff and throughout the following unfrozen period to assess the role of surface runoff from snowmelt and summer storms on wetland water quality and to identify changes in water quality or quantity that could be attributed to the tillage system.

MATERIALS AND METHODS

Site Description

The study site is located at the Conservation Learning Centre near St Louis, Saskatchewan (52°52'N, 105°40'W) on the Nisbet Plain, a kettled glaciolacustrine landscape. The landscape is level to gently undulating and the potholes have moderately sloping sides of 5–10%. Three pothole wetlands were chosen in 1994 and monitored from 1994–1998. The land surrounding two of the potholes (ZT–1 and ZT–2) was converted to a zero tillage, continuous cropping system in 1993 and the other pothole (CT) is on land that continues to be conventionally farmed. Aerial photography showed all three potholes were dry in July 1991 and we measured water depths of approximately 1 m in the three wetlands in the spring of 1995.

Soil surveys in the spring of 1995 characterized the soils surrounding the potholes as Black Chernozems and Humic Gleysols of the Hamlin and Blaine Lake

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Associations (Saskatchewan Soil Survey, 1989). The surface soil texture is quite variable both within and between catchments, ranging from sandy loam to silty clay loam. Clay content ranges between 20 and 40% in the ZT–1 and CT basins but the soils in ZT–2 basin tend to be lighter–textured with clay contents ranging from 15–25%. The average soil organic carbon content was 4.1% in all three basins. Elevation surveys of the areas around the potholes were conducted in the fall of 1995 to delineate the catchments and create digital elevation models. Numerous observations were made within the potholes so that the digital elevation models could be used to accurately convert water depth to water volume. The total basin areas (including wetlands) were 3.2 ha for the ZT–1, 2.1 ha for the ZT–2 and 9.3 ha for the CT. Despite the variability in the size of the basins, all three wetlands were a similar size. At 1 m depth, the ZT–1 and CT wetlands covered approximately 0.35 ha while the area of the ZT–2 wetland was 0.25 ha.

Cropping records and details of fertilizer and herbicide applications were obtained from the co–operating farmers. The ZT fields were continuously cropped in a rotation which alternated between broadleaved crops (pulses or oilseeds) and cereals. In each year of the study, one of the ZT basins was used to produce a broadleaf crop while the other was seeded to a cereal. A three–year rotation of oilseed, cereal and summerfallow was generally followed on the CT field. Details of the crops grown and fertilizers applied are given in Table 1. From 1994 to 1997 considerably more fertilizer was applied to the ZT fields than the CT field. Annual applications averaged 65 kgN ha^{-1} and almost 30 kgP ha^{-1} on the ZT fields while on the CT field average annual applications of both N and P were less than 10 kg ha^{-1}. Herbicide use in the three basins is detailed in Table 2. A full list is given to illustrate the considerably greater use on the ZT fields than the CT field but of those listed only bromoxynil, MCPA, ethalfluralin, 2,4–D, imazamethabenz, metribuzin and dicamba were monitored in this study.

Monitoring, Sampling and Analyses

Nine samples of surface soil (0–10 cm) were taken from each of the three basins each fall and in the spring of each year after seeding and fertilizer application. In the springs of 1995 and 1996, samples were also taken between snowmelt and seeding. The soil samples were incubated at field capacity with PRS™ ion exchange probes (Western Ag Innovations, Saskatoon, SK) to determine available N and P (Schoneau and Huang, 1992). Snow surveys were conducted just prior to snowmelt in the spring of each year from 1995 to 1998. Snow depth and weight were recorded in dissecting transects and the water equivalent in the snowpack was calculated from the weight of snow for each survey point. In each survey at least 25 points were surveyed including the centre of the basin which was common to both transects. The remaining points were distributed between the wetland and the upland areas of the basin so that three distinct positions in the landscape (upland, wetland edge and wetland) were sampled in accordance with the area of the basin they represented. Average snow accumulation in the basin was calculated as the mean snow water equivalent for all points in the basin.

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Table 1. Cropping histories, fertilizers and rates of fertilizer application for the three watersheds from 1994 to 1998.

ZT – 1		ZT – 2		CT	
1994	Wheat	**1994**	Peas	**1994**	Canola
May 11	26–31–0	May 13	26–31–0	June 1	26–13–0
	28 kgN ha^{-1}		28 kgN ha^{-1}		11 kgN ha^{-1}
	34 kgP ha^{-1}		34 kgP ha^{-1}		6 kgP ha^{-1}
June 9	28–0–0				
	56 kgN ha^{-1}				
1995	Peas	**1995**	Wheat	**1995**	Oats
June 2	20–30–0	May 27	20–30–0	May 23	26–13–0
	12 kgN ha^{-1}		22 kgN ha^{-1}		19 kgN ha^{-1}
	18 kgP ha^{-1}		34 kgP ha^{-1}		9 kgP ha^{-1}
		June 23	28–0–0		
			16 kgN ha^{-1}		
1996	Barley	**1996**	Canola	**1996**	Fallow
May 30	20–20–0	May 29	12–51–0		
	17 kgN ha^{-1}		5 kgN ha^{-1}		
	17 kgP ha^{-1}		23 kgP ha^{-1}		
June 2	28–0–0	June 4	26–0–0–4		
	67 kgN ha^{-1}		78 kgN ha^{-1}		
			11 kgS ha^{-1}		
1997	Canola	**1997**	Barley	**1997**	Canola
May 30	12–51–0	May 22	12–51–0	May 14	12–51–0
	10 kgN ha^{-1}		5 kgN ha^{-1}		5 kgN ha^{-1}
	43 kgP ha^{-1}		23 kgP ha^{-1}		23 kgP ha^{-1}
May 30	26–0–0–3	May 22	28–0–0		
	90 kgN ha^{-1}		84 kgN ha^{-1}		
	11 kgS ha^{-1}				
1998	Barley	**1998**	Flax	**1998**	Wheat

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Table 2. Herbicides applied to the three catchments from 1994 to 1998.

	ZT–1	ZT–2	CT
1994	glyphosate bromoxynil MCPA *ethalfluralin*[zy]	glyphosate metribuzin sethoxydim *diquat*	sethoxydim
1995	glyphosate MCPA sethoxydim *glyphosate*	glyphosate dicamba thifensulfuron–methyl tribenuron–methyl imazamethabenz *glyphosate*	dicamba MCPA
1996	glyphosate tralkoxydim bromoxynil MCPA	glyphosate sethoxydim ethametsulfuron–methyl *glyphosate*	
1997	glyphosate sethoxydim ethametsulfuron–methyl	glyphosate imazamethabenz thifensulfuron–methyl tribenuron–methyl *glyphosate*	sethoxydim
1998	glyphosate difenzoquat 2,4–D *glyphosate*	glyphosate sethoxydim MCPA *glyphosate*	clodinafop–propargyl metsulfuron–methyl

[z] products in italics are fall–applied
[y] not incorporated

From the fall of 1994 to the fall of 1997, the wetlands were routinely monitored for water quantity and quality every 2 days during snowmelt and approximately every 2 weeks during the unfrozen period (approximately 100 samples were collected during snowmelt and 50 samples were taken in the unfrozen period). From May until August in 1998, we continued to monitor the wetlands in an effort to observe a summer runoff event. Samples collected during this period were pre–treated as described below but only samples taken on the sampling day prior to the runoff event and the day after runoff were submitted for analysis. To determine water quantity,

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the water level in each wetland was monitored by reading a centrally located staff gauge attached to a sampling station. The depths measured using the staff gauge were confirmed by wading each spring to ensure that the sampling station had not moved during the spring thaw. The water levels were converted to water volumes using the digital elevation models. During snowmelt, water samples were taken using automated water–samplers programmed to take hourly sub–samples that were composited over each 24–h period to give daily samples. Grab samples were taken for the rest of the sampling period. All water samples were collected from the centre of the wetland at mid–depth in the water column. The samples were transferred to 1–L amber glass bottles, transported to Saskatoon and stored overnight at 4 °C. The following day, sub–samples were submitted for nutrient analysis while the remaining sample was stabilized for pesticide analysis by adding 5 mL of concentrated sulphuric acid and stored at 4°C until extraction.

Nutrient analysis was performed by Environment Canada's Water Quality Laboratory in Saskatoon using standard colourimetric methods. Total P and ammonia (NH_3) were determined on unfiltered samples but aliquots for nitrite–nitrate (NO_2–NO_3) and ortho P were filtered through a Whatman glass microfibre filter that had been baked for 4 h at 525°C. Phosphorus was measured as ortho P by reduction using stannous chloride (Environment Canada, 1979a). For the determination of total P, the aliquot was treated with a sulphuric acid–persulphate mixture to release organically bound phosphates and hydrolyze polyphosphates to ortho P prior to reduction (Environment Canada, 1979b). The automated cadmium reduction method described by Clesceri *et al.* (1989) was used to determine NO_2–NO_3. Sulphuric acid was used to stabilize the final aliquot prior to ammonia determination by reaction with hypochlorite and alkaline phenol (Skougstad *et al.*, 1979).

The water samples were extracted for herbicide analysis using the method described by Cessna *et al.* (1985). Since the sample size (500 mL) was only half that used in the original method, all extraction solvent and reagent volumes were reduced accordingly. The extracts were analyzed on a Hewlett–Packard model 5890A gas chromatograph equipped with the model 5970B mass selective detector using the procedure summarized by Elliott *et al.* (1998). The analytes were bromoxynil, MCPA, ethalfluralin, 2,4–D, imazamethabenz, metribuzin, dicamba, mecoprop, diclofop, clopyralid, triallate and trifluralin. Trace concentrations for all herbicides were reported if the amount of herbicide detected was below the limit of quantification (0.05 $\mu g\ L^{-1}$) but above the detection limit (approximately 0.01 $\mu g\ L^{-1}$).

RESULTS AND DISCUSSION

Hydrology

Snow water equivalents in the snowpack measured prior to melt in 1995, 1996 and 1997 are shown in Table 3. The amount of snow accumulated depended primarily on the winter weather conditions and was least in 1996. Within each year, there was little difference in average snow accumulation among the three basins indicating

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that the groundcover and tillage treatment did not affect the total water accumulated in the snowpack in the basins.

Table 3. Means (and coefficients of variation, %) of water equivalents in the snowpack for the three basins in 1995, 1996 and 1997.

	Snow Water Equivalent, mm		
	ZT–1	ZT–2	CT
1995	35 (39)	39 (60)	36 (45)
1996	19 (67)	20 (32)	22 (52)
1997	47 (56)	41 (42)	45 (59)

The variability within each basin did appear to be affected by basin management. The coefficients of variation for the snow water equivalents ranged from 32–67% indicating a high degree of within–basin variability. Since snowpack variability will depend on weather conditions in each year, it is hard to compare among years, but comparisons can be made among basins for each year. In 1995, the snowpack was more variable in the ZT–2 basin which had been cropped to peas in 1994 than in the other basins cropped to wheat and canola. Peas are generally cut only 3–5 cm from the ground and leave shorter stubble and less capacity for snowtrapping than cereals (wheat, barley and oats) or canola which are generally cut at heights between 15 and 30 cm (Pomeroy and Gray, 1995). Similarily in 1996 there was less variability on the wheat stubble (ZT–2) than the pea stubble (ZT–1) or the oat stubble that had been incorporated into the soil by cultivation in the fall of 1995 (CT). The least variability in 1997 was observed on canola stubble (ZT–2) with snow accumulation on both barley stubble (ZT–1) and summerfallow (CT) being much more variable. A high degree of variability in snow accumulation would be expected due to poor snowtrapping in the summerfallowed basin but snowtrapping also appeared to be surprisingly poor on the barley stubble. Harrowing of the barley stubble in the fall of 1996 would have broken the cereal stalks, smoothing the surface and allowing for more snow redistribution than would have occurred had the stubble been left untouched.

Snowmelt runoff was calculated as the difference between fall and spring water volumes in the wetlands and expressed in units of mm ha^{-1} to correct for basin area (Table 4). Runoff accounted for between 9 and 46% of the water present in the snowpack with the least runoff and the lowest proportion of the snowpack lost in runoff in 1996 when snowcover was least. The CT basin generally had less runoff than the ZT basins but the difference was greatest in 1995, the second year of zero tillage, and decreased in subsequent years. In 1997, the CT basin and ZT–2 had the same amount of snowmelt runoff.

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Table 4. Snowmelt runoff in mm ha^{-1} for the three basins in 1995, 1996 and 1997.

	Runoff, mm ha^{-1}		
	ZT–1	ZT–2	CT
1995	12	18	4
1996	3	4	2
1997	16	11	11

Since the three wetlands have similar shapes, water level rather than water volume was used in Figure 1 to illustrate changes in storage in the basins during the unfrozen period. Although the snowmelt data (Tables 3 and 4) indicate that more runoff was generated per unit area in the ZT basins than in the CT basin, Figure 1 shows water levels in the ZT wetlands are decreasing relative to those in the CT wetland. This is not surprising because although the runoff per unit area was less on the CT than the ZT (Table 4), the actual volume of runoff was similar for all basins in 1995 and greater on the CT than the ZT in 1996 and 1997. In these gently–sloping landscapes some outlying areas of the basin may not contribute all of the generated runoff to the wetland because some runoff water may infiltrate in concavities on the way to the wetland. If this occurs runoff reported in mm ha^{-1} may not reflect the hydrology of the basin. The distances between the point of runoff generation and the wetland, and hence the probability of non–contributing area, would be greatest in the largest (CT) basin. The water level in the CT basin has probably been maintained historically by runoff from a contributing area considerably less than its delineated watershed. If the contributing area of the CT basin was assumed to be similar to the area of the ZT–1 basin then runoff would have been calculated to be 11 mm ha^{-1} in 1995, 5 mm ha^{-1} in 1996 and 31 mm ha^{-1} in 1997.

Figure 1 shows that the water levels in all three wetlands were similar during snowmelt in 1995. However, from June 1995 onward, water levels in the ZT–2 wetland were lower than in the other wetlands and the difference increased with time. For most of 1995, water levels in the ZT–1 wetland were greater than those in the CT wetland and although the water was slightly deeper in CT wetland during snowmelt in 1996 for the rest of year the two wetlands had similar water levels. In 1997, the CT wetland had higher water levels throughout the year than either of the ZT wetlands. Summerfallow in the CT basin in 1996 would have led to higher soil moisture in the fall and subsequently this basin would be expected to generate more runoff than the cropped basins in the spring of 1997. Water levels in the wetlands were also measured in May 1999 when the depth was 1.17 m in ZT–1, 0.89 m in ZT–2 and 1.34 m in the CT. Routine monitoring of spring and fall water levels in the three wetlands recommenced in the fall of 2000 and water levels on October 24, 2000 were 0.70 m in wetland ZT–1, 0.32 m in ZT–2 and 1.01 m in the CT wetland.

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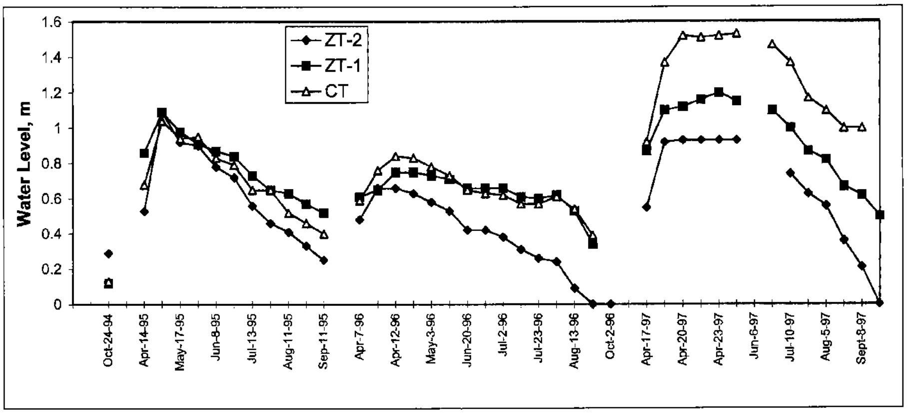

Figure 1. Wetland Water Levels in the Three Basins in 1994, 1995, 1996 and 1997. (Note that the time axis is not linear but reflects the different sampling frequencies during snowmelt and the unfrozen period.)

The 1999 and 2000 data indicate that the differences in water levels observed in 1997 have persisted and the water levels in the ZT wetlands continue to be lower than in the CT wetland. The combination of continuous cropping and improved soil structure under zero tillage could have resulted in reduced recharge of the ZT wetlands. The absence of summerfallow in the zero tillage rotation could reduce runoff because cropped soils are usually drier in the fall than soils that have been summerfallowed and hence have higher infiltration capacities during snowmelt (Gray *et al.*, 1985). Infiltration has also been shown to improve under zero tillage as more stable aggregates and a more continuous pore structure develop in soil that is not disturbed by tillage (Azooz and Arshad, 1996; Elliott and Efetha, 1999). The difference in water levels observed between the ZT–1 and ZT–2 wetlands may have resulted from greater infiltration capacity in the ZT–2 basin since the soils found there are lighter–textured than those in the ZT–1 and CT basins.

Water Quality

Despite considerably greater fertilizer use in the ZT basins, there was no consistent accumulation of plant available N and P in the surface soil (Table 5). The highest available N levels were measured after fertilization on the ZT plots with levels in 1996 being exceptionally high. However, in the fall and in the spring prior to fertilizer application there were no consistent differences in available N between the ZT and CT basins. The additional N–fertilizer applied to the ZT basins appears to have either been utilized by the crop or leached below 10–cm depth. In the spring following summerfallowing (1997), available N on the CT plot was high. There were no consistent differences in available P between ZT and CT basins.

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Table 5. Means (and coefficients of variation, %) of available N and P in surface soil (0–10 cm) in the three basins from 1994 to 1997.

	Available N, μg 10 cm^{-2} 24 h^{-1}			Available P, μg 10 cm^{-2} 24 h^{-1}		
	ZT–1	ZT–2	CT	ZT–1	ZT–2	CT
Fall 1994	29 (81)	24 (100)	12 (45)	0.4 (47)	0.3 (75)	0.2 (39)
Spring 1995	22 (74)	30 (36)	14 (34)	0.6 (42)	0.6 (68)	0.3 (47)
Spring 1995*	35 (72)	66 (47)	28 (49)	0.6 (43)	0.8 (61)	0.6 (53)
Fall 1995	90 (47)	37 (77)	50 (41)	0.4 (0)	0.4 (25)	0.4 (12)
Spring 1996	36 (31)	40 (49)	54 (47)	0.4 (45)	0.4 (54)	0.8 (95)
Spring 1996*	190 (62)	201 (91)	45 (50)	0.7 (57)	0.7 (47)	0.7 (16)
Fall 1996	31 (59)	59 (39)	48 (51)	0.3 (98)	0.8 (63)	0.3 (50)
Spring 1997*	59 (74)	104 (64)	84 (67)	0.4 (43)	0.8 (95)	0.5 (45)

* Sample taken after fertilizer had been applied.

Figure 2 summarizes nutrient concentrations in water samples from the wetlands during snowmelt and in the period from May to October. The highest P concentrations measured during snowmelt were 2.0 mgP L^{-1} for total P and 1.72 mgP L^{-1} for ortho P. Both concentrations were measured in a sample taken from the ZT–1 wetland at the beginning of runoff in 1997. Phosphorus concentrations in the three wetlands were similar during snowmelt runoff in 1995, but by 1997 concentrations of P during runoff were greater in the ZT wetlands than the CT wetland. Ammonia concentrations in the wetlands during snowmelt tended to be variable showing no consistent effect of time or tillage management. The greatest NH_3 concentration was measured in the ZT–2 wetland midway through snowmelt in 1996. Nitrate concentrations in the wetlands during snowmelt in 1996 were low in comparison to 1995 and 1997. Since NO_2–NO_3 concentrations in snow measured at a nearby site averaged 0.4 mgN L^{-1}, it is possible that all of the NO_2–NO_3 measured in the wetlands during melt in 1996 originated in the snow. The highest NO_2–NO_3 concentration, 8.71 mgN L^{-1}, was measured in the CT wetland in 1997 when it received snowmelt from summerfallow.

Total and ortho P concentrations were higher in the wetlands between May and October than they were during snowmelt with median concentrations commonly falling between 1 and 2 mgP L^{-1} (Figure 2). Unlike the melt period, there did not appear to be any trend of rising P concentrations in the ZT wetlands relative to the CT in the unfrozen period. Nitrate and NH_3 concentrations were lower in the unfrozen period (Figure 2) than they were during melt. Although there were occasional high NH_3 concentrations during the summer months, median values for the unfrozen period were <0.3 mgN L^{-1}. Nitrate present in the wetlands during the summer was frequently less than the detection limit (0.01 mgN L^{-1}) and the maximum NO_2–NO_3 concentration measured between May and October was 0.03 mgN L^{-1}.

Between July 5 and July 9, 1998, almost 100 mm of rainfall fell and generated 28 mm of runoff into the ZT–1 wetland, 27 mm of runoff into the ZT–2 wetland and 23 mm of runoff into the CT wetland. The influx of water resulted in increased P concentrations in all three wetlands (Table 6) but concentrations remained below the maxima measured between 1994 and 1997 (Figure 2). The highest P concentration after the runoff event was measured on the ZT–1 wetland, and the increases in P concentration in the ZT wetlands were somewhat larger than in the CT wetland.

Table 6. Nutrient concentrations in three wetlands on June 28 and July 9, 1998.

	Nutrient Concentrations, mg L^{-1}					
	ZT–1		ZT–2		CT	
	June 28	July 9	June 28	July 9	June 28	July 9
Total P	0.36	1.00	0.17	0.43	0.31	0.43
Ortho P	0.19	0.84	<0.01	0.34	0.17	0.32
NH_3	1.38	0.24	0.57	0.12	2.76	0.28
NO_2–NO_3	<0.01	0.27	1.45	0.58	<0.01	0.02

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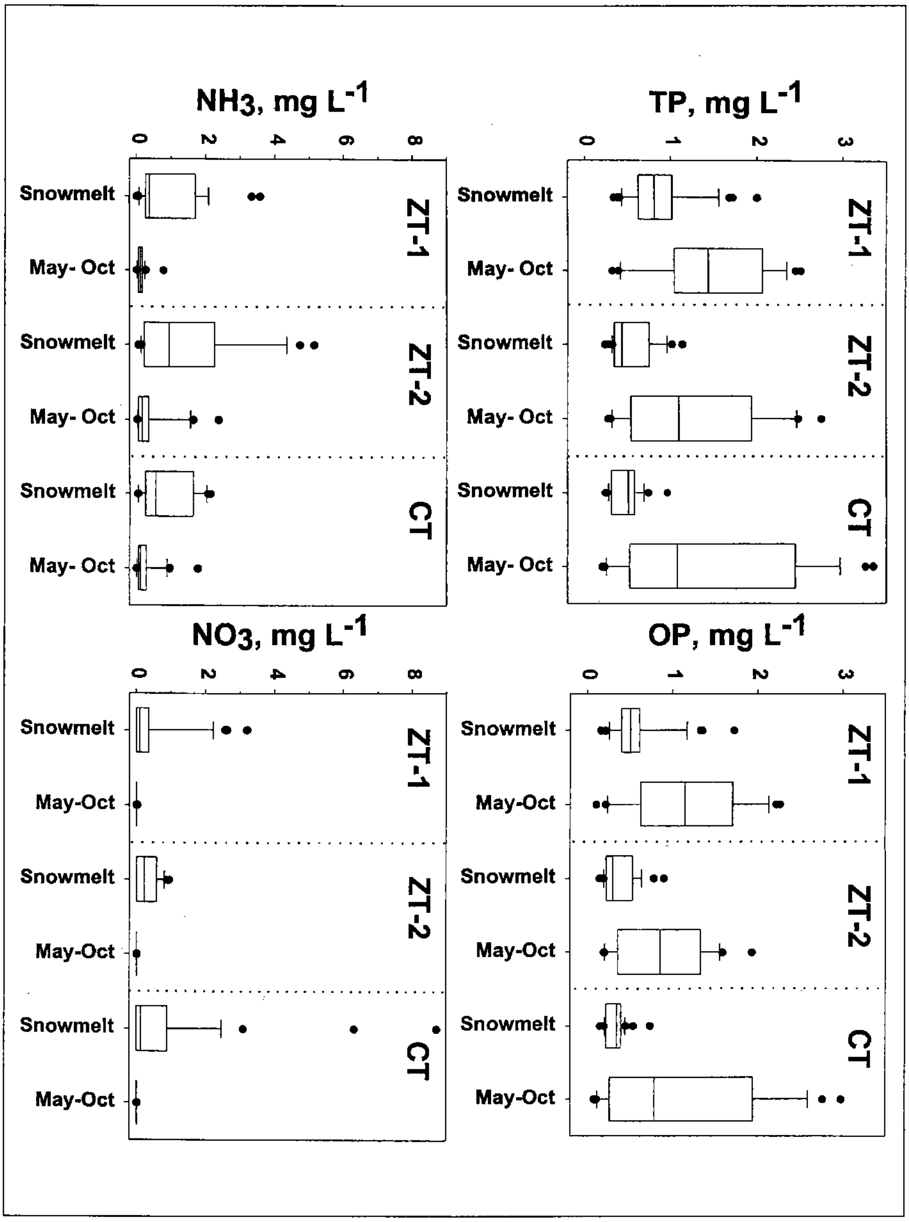

Figure 2. Concentrations of Total P, Ortho P, NH_3 and NO_2–NO_3 in the Three Wetlands During Snowmelt and From May to October in the Period From 1995 to 1997. (The boxes show the median, 25th and 75th percentiles, the whiskers illustrate the 10th and 90th percentiles and • represents points lying outside the 10th or 90th percentile.)

Herbicides were detected in approximately 90, 70 and 60% of water samples collected from the ZT–1, CT and ZT–2 watersheds, respectively, but the majority of these were trace concentrations (<0.05 μg L^{-1}). Unfortunately, the study did not provide a comparison of the effect of tillage system on wetland water quality with respect to herbicides transported in surface runoff. However, with the exception of metribuzin and imazamethabenz, herbicides applied to the three watersheds were generally detected in the corresponding wetlands in concentrations >0.05 μg L^{-1}.

In addition to the herbicides applied to the three basins, clopyralid, mecoprop, 2,4–D, diclofop, triallate and trifluralin, which were not applied to the basins during the 1994 to 1997 period, were also detected in some or all of the wetlands. Mecoprop and diclofop were detected only in trace concentrations, whereas clopyralid, triallate, trifluralin and 2,4–D were present in concentrations >0.05 μg L^{-1}. Of these latter herbicides, 2,4–D was detected in the greatest frequency. The herbicide was detected in about 30% of samples from the ZT–2 and CT wetlands, with quantifiable concentrations accounting for around one–third of the detections. In the ZT–1 wetland, 2,4–D was detected in almost 50% of the samples with more than half of the detections being greater than the limit of quantification. The widespread and long–term use of herbicides such as 2,4–D, MCPA, bromoxynil, dicamba, mecoprop, triallate and trifluralin on the Canadian prairies has resulted in detections of such herbicides in wetlands (Donald *et al.*, 1999), farm dugouts (Grover *et al.*, 1997) river water (Lindeman and Shaw, 1997), and rainfall and air (Waite *et al.*, 1999; Cessna *et al.*, 2000). Atmospheric deposition may account for a portion of the concentrations of these herbicides detected in the wetlands, but the variability in the magnitude of these herbicides between wetlands during the 3–year study suggests that herbicide applications made prior to this study have also contributed to the accumulation of herbicides within the wetlands. For this reason, it was not possible to assess the effect of zero tillage versus that of conventional tillage on wetland water quality with respect to herbicide content.

CONCLUSIONS

Tillage and cropping system did not affect snow accumulation in the basins but the surface cover did affect snow distribution. Snow distribution was more dependent on crop management than tillage treatment or cropping frequency as pea and harrowed barley stubble were no better at trapping snow than summerfallow. The amount of snowmelt runoff did appear to be affected by tillage system. In all years of the study, there was more snowmelt runoff per unit area from the ZT basins than the CT basin. However the differences between the basins decreased with time suggesting infiltration was improving in the soils in the ZT basins. Wetland water levels were similar in all basins at the start of the study, but by 1997 the water levels were greater in the CT wetland than in the ZT wetlands and this difference was still present in the fall of 2000.

Considerably more fertilizer was used in the ZT basins than on the CT but this did not result in any consistent differences in available N or P in the surface soil.

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However P concentrations in the ZT wetlands during snowmelt runoff tended to be greater than those in the CT wetland and the increase in P concentration in the ZT wetlands following the summer runoff event in 1998 exceeded that measured for the CT wetland. Concentrations of NO_2–NO_3 and NH_3 were not consistently different between the wetlands and tended to be much lower in the unfrozen period than during snowmelt. Phosphorus concentrations were generally higher in the unfrozen period than during snowmelt.

With the exception of metribuzin and imazamethabenz, all of the herbicides in the suite of analytes applied to the basins were detected in the wetlands. We also detected herbicides in the wetlands that were not applied to the basins during the study period. Although more herbicides were applied to the ZT basins than the CT basin, the frequency of detections measured in this study reflected historical applications and atmospheric inputs rather than applications made during the study period. The most frequently detected herbicide (2,4–D) was found in approximately 35% of samples although it was not applied between 1994 and 1997.

Although we have found differences in hydrology between two wetlands in basins converted to zero tillage and one in a basin that continues to be conventionally farmed, our findings are from a single study site and a short monitoring period. Further research is required to determine the general applicability of our results and to confirm the existence of a long–term effect. A similar caveat should be applied to our water quality findings.

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