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Tillage and Liquid Dairy Manure Effects on Overland Flow Nitrogen and Phosphorus Loss Potential in an Upper Midwest Corn Silage-Winter Triticale Cropping System

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Abstract: Dairy manure is an important crop nutrient source in Wisconsin and other parts of the upper Midwest but can contribute to nitrogen (N) and phosphorus (P) losses in overland flow/surface runoff. Winter cereal grain cover crops can help reduce erosion and nutrient transport in corn systems. However, few studies have compared tillage impacts on nutrient loss in live cover crop systems. The objective of this study was to evaluate vertical (VT) and chisel tillage (CT) effects on overland flow nutrient and sediment loss potential after spring-applied liquid manure. A surface application treatment (i.e., broadcast) and a no manure control were also included for comparison. After corn (*Zea mays* L.) planting into a live triticale (*Triticale hexaploide* L.) cover crop, four artificial rainfall-overland flow events were generated (42 mm h⁻¹ for 30 min) on replicated field-scale plots in central Wisconsin. Mean total P, total N, and suspended solids loads were consistently lower for VT at 2 days post-manure application (with 97 to 99% lower losses than broadcast, respectively). Dissolved reactive P and ammonium-N concentrations for both CT and VT were significantly lower three weeks after manure application compared to broadcast. Results suggest that VT reduced soil/residue disturbance while incorporating manure sufficiently to reduce sediment, N, and P transport potential under simulated high overland flow conditions.

Keywords: dairy systems; cover crops; erosion; manure; nutrient loss; overland flow; planting green; surface runoff; triticale

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1. Introduction

Dairy manure is an important nutrient source for farms. However, careful management is required to reduce nitrogen (N) and phosphorus (P) loss potential in overland (surface runoff) and subsurface flows [1–7]. Applying manure to the soil surface without incorporation (broadcast) dramatically increases the risk of dissolved N and P losses in overland flow [8–12], especially when manure is applied in early spring or fall when soil moisture and overland flow potential are high. Using some form of tillage to increase manure–soil interaction can reduce overland flow nutrient losses compared to surface broadcast. However, erosion and sediment-bound N and P loss potential can increase from greater disturbance associated with tillage practices [7,10,13–15].

In addition to manure management and tillage regimes, cover crops can also contribute to lower erosion and nutrient loss in addition to reducing nitrate-N (NO₃⁻-N) leaching by an average of 35–70% [1,2,16–20]. While some degree of tillage is beneficial for incorporating manure, cover crop integrity and residue coverage can be compromised [21]. Cover crop impacts on overland flow water quality from cropland varies by species, planting density, planting/termination dates, root density, soil type, and overall cropping system [22]. While terminating cover crops closer to the time of annual crop planting is

usually assumed to be detrimental to corn yield potential [23–25], it may contribute to soil quality (lower bulk density, organic carbon additions, decrease erosion potential) without necessarily diminishing corn yield [26–28]. Tillage can sometimes help offset potential corn yield reductions associated with cover crops. Raimbault et al. reported that moving residue from the row in no-till plots reduced negative effects on growth, while Ewing et al. reported that subsoiling improved water availability and increased grain yield where cover crops were present [23,25]. In contrast, Duiker and Curran found no yield benefit of in-row tillage compared to no-till on corn yield or weed control with winter rye terminated in the late boot stage [27].

Planting an annual crop into a living cover crop or ‘planting green’ is a relatively new approach, with only a few studies on corn yield and nutrient loss potential in overland flow. In general, when planting green, cover crop termination is delayed for 1 to 2 weeks after annual crop planting to maintain a soil cover which reduces raindrop impact and erosion [20,26,29–32]. For example, Gyssels et al. found an exponential reduction in soil erosion rates with increasing cover crop biomass [17,33]. In dairy systems where manure is routinely applied, some degree of tillage combined with planting green into a cover crop may provide the dual benefits of offsetting corn yield depression from delayed emergence and competition from the cover crop while reducing nutrient loss potential in overland flow and maintaining higher soil quality.

Given dairy producer interest in improving nutrient use efficiencies and the need for additional tools for mitigating nutrient transport to protect water quality, site-specific manure application and cover crop management systems will be important for reducing overland flow and subsurface hydrologic nutrient loss risk [34]. Winter grains such as triticale and rye have excellent forage yield potential with timely fall seeding and can be left in place prior to planting annual crops or harvested as a high-quality hay crop forage in the spring [35,36]. Winter grains can thus function as effective cover crops while offering a potential double cropping opportunity for farmers and greater economic incentive to plant cover crops. The objective of our study was to evaluate the impact of spring application of liquid dairy manure to a live winter triticale cover crop on overland flow, sediment, and dissolved/particulate N concentrations and loads (runoff volume $\times$ concentration) using artificial rainfall-overland flow simulations. Specifically, we compared spring broadcast manure application/no-till with: (i) broadcast manure application followed by one-pass chisel plow tillage (CT), (ii) broadcast manure application followed by one-pass vertical tillage (VT), and (iii) a no manure control. We hypothesized that VT would increase infiltration, reducing overland flow, while the presence of cover crop biomass would also help to decrease erosion and nutrient losses.

2. Materials and Methods

2.1. Field Site and Experimental Design

This field experiment was conducted on a moderately well-drained Loyal silt loam soil (fine-loamy, mixed, superactive, frigid Oxyaquic Glossudalfs; 1 to 6% slope; USDA-NRCS Web Soil Survey; <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>) located on the University of Wisconsin Marshfield Agricultural Research Station at Stratford, WI (44.758238, -90.100229). The field used was planted with triticale (*Triticale hexaploide* L.) on 12 September 2017 with a grain drill (Landoll Farm Equipment, Brillion, WI, USA) at 224 kg ha⁻¹. Sixteen rectangular plots (4.6 $\times$ 15.2 m) were established within a forage crop production field in a randomized complete-block design (4 blocks/4 treatments). Blocks were set up along two transects oriented along the main field slope with borders around each block to accommodate the size and turning radius of field equipment (border 3 m in width between blocks one and two and between blocks three and four and a border 17 m in width between blocks one and three, and two and four). Plots were positioned with the long side perpendicular to the slope in the same direction of field operations and manure applications. Triticale was hand-cut/sampled (10 cm height) on 29 May 2018

from individual plots, after which the whole field was cut for triticale silage (Case IH, 8830 haybine, Racine, WI, USA).

2.2. Manure Application and Tillage Treatments

Liquid dairy manure was applied to all plots (VT, CT, broadcast) except the no manure controls on 4 June 2018 at approximately 66,200 L ha⁻¹ using a toolbar with 30 cm drop tubes (Yetter Avenger, Yetter Manufacturing, Colchester, IL, USA) applied at 38 cm above the soil surface. In addition to the surface manure application treatment (broadcast) and no manure control, tillage treatments consisted of either chisel plow tillage (CT; Landoll Farm Equipment, Brillion, WI, USA) (15 cm deep) or one-pass with a vertical tillage implement (VT; McFarlane Incite 5000, Manufacturing, Sauk City, WI, USA); VT is designed to reduce compression and shear forces caused by chisel shanks while conserving more residue and was operated at a shallow depth (3.5 cm) and disk angle (3°). Since the heavy silt loam soils were too uneven to plant after chisel tilling, CT plots also had one pass with the VT implement to prepare an acceptable seedbed. Tillage occurred in all CT and VT plots within the first 10 min of manure application.

Manure was sampled twice during the application process, and subsequently analyzed (University of Wisconsin Soil and Forage Laboratory, Marshfield, WI) for total nitrogen (TN), total phosphorus (TP), ammonium-N (NH₄⁺-N), water-extractable P (WEP) and solids content [37,38]. Manure application supplied an average of 15 and 106 kg ha⁻¹ of TP and TN, respectively. Of the total manure N and P applied, an estimated 84 kg ha⁻¹ NH₄⁺-N and 5 kg ha⁻¹ water-extractable P (mainly orthophosphate) were applied.

Plots were planted to silage corn (*Zea mays* L.) (Prairie Estates C-2908 hybrid, Middleton, WI, USA) (FAO CPC 01121) immediately after manure application and incorporation (where utilized) on 4 June 2018 with a six-row corn planter (1750 MaxEmerge, John Deere, Moline, IL, USA) at a rate of 69,000 seeds ha⁻¹ along with banded application of a liquid fertilizer formulation of 7-9-13-2(S) applied 50 mm to the side and 50 mm beneath seed rows at a rate of 93.5 L ha⁻¹. Triticale stubble was sprayed on 25 June 2018 with Roundup® (Monsanto, St. Louis, MO, USA) and Status® (BASF, Florham Park, NJ, USA) to terminate the cover crop and reduce competition with corn.

2.3. Rainfall-Overland Flow Simulations

Four rainfall-overland flow simulations were performed in 2018 with individual events performed over two consecutive days (2 blocks simulated/day) following the general procedures of Humphrey [39]. Dates for individual events were: (i) 2 days after manure application on 6–7 June (Event 1), (ii) 27–28 June (Event 2), (iii) 17–18 July (Event 3), (iv) 30–31 July (Event 4). Runoff was collected from a 2 × 2 m area bordered on three sides by steel panels (15 cm wide) driven 7.5 cm into the soil. A PVC gutter at the lower end of the plot collected runoff, which was pumped from a small collection pail into a 132 L plastic drum placed on a platform scale. The average plot slope was 4.4% and frame locations were identical for all events. Water was pumped through the rainfall simulator (average flow rate = 125 mL s⁻¹) and applied to plots at an average rate 42 mm h⁻¹ for 30 min. Simulated rainfall was applied through TeeJet® #30 nozzles (Spraying Systems Co., Wheaton, IL, USA) positioned 305 cm above the soil surface (Joerns, Inc., West Lafayette, IN, USA). Time to initiation of overland flow was recorded and 1 L subsamples were collected, weighed and mixed thoroughly after 30 min. Samples were analyzed for total dissolved solids (TDS) (Method 2540C) [40], suspended solids (SS) (Method 3977-97B) [41], volatile solids (VS) (Method 2540E) [39], TN and TP (acid persulfate/autoclave method) [42]. A second sample (60 mL) was passed through a 0.45 µm pore size filter followed by analysis of dissolved reactive P (DRP) [43], NO₃⁻-N [44] and NH₄⁺-N [45] by automated flow injection analysis. Solids and nutrient loads were estimated by multiplying event overland flow volumes by their corresponding concentrations.

2.4. Plant and Soil Measures

Before each rain simulation, photographs were taken (2 per plot, 2.25 m²) for subsequent digital imagery analysis (SamplePoint Software) to estimate the plot area covered with soil, residue (desiccated corn or triticale biomass), live corn/triticale stubble, and manure coverage [46]. Just outside the runoff area, ten 2 cm diameter soil cores were collected to a 10 cm depth for nutrient analysis. Samples were dried, ground (2 mm) and analyzed for plant-available P, and potassium (K) using the Bray soil test solution [38]. Soil TN and total carbon (TC) were determined by high temperature combustion (Elementar VarioMax CN analyzer, Elementar Americas Inc., Mt. Laurel, NJ, USA). Soil NO₃⁻-N, and NH₄⁺-N were analyzed by flow injection analysis after extraction in a 5:1 (solution:soil) 2 M potassium chloride (KCl) solution [47,48]. Soil organic matter (OM) was estimated by loss on ignition [49] and converted to OM equivalents by regression [50]. Initial soil moisture was determined by averaging 6 samples taken immediately outside the runoff area by a capacitance sensor (ML2 ThetaProbe, Delta-T Devices, Cambridge UK) prior to rain simulations and periodically throughout the growing season. Weather conditions were monitored throughout the season with a portable unit at the edge of field (Spectrum Technologies, Aurora, IL, USA).

2.5. Statistical Analysis

Plots were arranged in a randomized complete-block design with tillage method as the main treatment effect. Analysis of variance via the mixed modeling procedure in SAS (proc mixed) was used to test the fixed effect of manure application/tillage (CT or VT); block and simulation event (time) were treated as random effects. Least square means were separated using the “PDIF” option. Dependent variables included overland flow volume, solids and nutrient concentrations/loads, and percent residue and live crop coverage. Data were tested for normality (proc univariate) and transformed as needed (log10 or square root) to achieve normality and homogeneity of variance. However, all data are presented as back-transformed means for ease of interpretation. Overland flow data had significant treatment × rainfall event interactions, therefore events were analyzed individually. Because of the high inherent variability associated with soil hydrology and nutrient dynamics, significance was declared at $p \leq 0.10$ [4,5,9,14,15,35]. Linear associations were assessed with Pearson correlation coefficients (proc corr) and linear regressions (proc reg) were also performed for pairs of select variables.

3. Results and Discussion

3.1. Weather

Average temperatures in June through August were within 5% of the 40 year average (20 °C, Jason Cavadini, personal communication, 2017). Rainfall varied from long-term averages and was 139%, 67% and 150% of the 40 year average for June, July, and August, respectively, and the total over the three months was 389 mm. Most of the rain for 2018 fell in a few large events in June and the end of August, with a few smaller events the rest of the season (Figure 1). This growing season rainfall amount was 1.2-fold greater than the average of the last 10 years but similar (within 3% on average) to four of the last ten years, suggesting that 2018 was similar to recent weather patterns. During the growing season, soil temperature averaged 20.5 °C, with fluctuations reflecting air temperature changes, and volumetric moisture content averaged 22.4%, with marked increases after rain events. There were few significant differences in soil temperature or moisture content among treatments. However, CT tended to be warmer and drier than other treatments (data not shown).

Figure 1. Daily precipitation totals (mm), air temperature (°C), and volumetric soil moisture content (%) near the study site located at the Marshfield Agricultural Research Station, Stratford, Wisconsin, USA.

3.2. Manure and Tillage Effects on Soil Nutrient Concentrations and Total Carbon

Compared to the control, labile K and P concentrations in addition to soil TC, TN, and OM contents were greater where manure remained on or closer to the surface (Table 1). Mean soil OM, TC, and TN were all significantly lower for CT, presumably because of deeper incorporation of manure and triticale stubble/residue (to 15 cm). The fact that OM, TC, and TN for CT were lower than control plots (which have only minor N-P-K inputs from fertilizer) suggests that CT more effectively mixed surface soil layers with manure and mixed C and N deeper into the soil than the sampled layer. Average soil $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ concentrations were numerically higher for manure treatments but did not differ from control (data not shown). In general, results indicate the importance of manure as a labile source of C, N, K, and P in addition to the tendency for greater dilution effects on soil nutrients and OM from CT compared to surface broadcast and VT.

Table 1. Treatment averages for select soil nutrient characteristics.

Treatment	OM †	Total N	Total C	Bray-1-P	Bray-1-K
	%	g kg^{-1}		mg kg^{-1}	
Control	4.7 b‡	2.4 a	24.5 b	32.3 bc	235 b
Broadcast	4.9 a	2.5 a	25.4 a	36.6 ab	302 a
Vertical	4.8 ab	2.5 a	25.4 a	36.8 a	285 a
Chisel	4.4 c	2.2 b	22.5 c	28.8 c	227 b
CV ††	6	6	5	6	3
p-value ‡‡	<0.001	<0.001	<0.001	0.008	<0.001

† OM = soil organic matter, Bray-1 soil extract; used by University of Wisconsin Extension for assessing plant availability and making crop nutrient recommendations. ‡ values with the same letter are not significantly different at $p \leq 0.10$. †† Coefficient of variation. ‡‡ p-value for main effect of incorporation method.

3.3. Manure and Tillage Effects on Overland Flows

Overland flows did not differ among treatments for any simulation event (Table 2). A lack of overland flow differences among treatments was not unexpected, since the field as a whole was in one crop rotation with similar management prior to the present study. Other studies have also similarly reported little impact on overland flow after applying differing liquid manure application methods, including low-disturbance application in hay and corn fields [9–11]. Notwithstanding, the broadcast treatment had 4- to 30-fold greater overland flow than other treatments. Yague et al. also reported larger overland flow from broadcast

liquid manure treatments possibly due to the manure creating a sealing effect on surface soil pores, thus limiting infiltration of manure and water during rainfall simulations [15]. Other studies have reported that fall CT increased surface roughness, resulting in lower overland flows in corn systems [11]. However, overland flow for subsequent simulations in our trial tended to increase for CT (8 to 14-fold greater than other treatments), suggesting that a lack of cover/residues and disruption of surface soil structure may have contributed to lower infiltration and correspondingly greater overland flow potential for CT in the later events.

Table 2. Overland flow and nutrient loads for each simulation.

Treatment	Runoff	TP †	TN	DRP	NO ₃ [−] -N	NH ₄ ⁺ -N	SS	TDS	VS
	mm			g ha ^{−1}				kg ha ^{−1}	
Simulation 1									
Control	0.05	0.19 bc ‡	3.19 b	0.07 b	1.38	0.42	0.08 bc	0.32 b	0.17 b
Broadcast	0.31	7.25 a	36.3 a	3.72 a	12.2	9.95	1.95 a	2.62 a	1.39 a
Vertical	0.01	0.06 c	0.84 c	0.03 b	0.37	0.20	0.05 c	0.08 c	0.06 c
Chisel	0.08	0.32 b	4.60 b	0.13 ab	2.86	0.72	0.16 b	0.34 b	0.20 b
CV	43	65	103	51	5216	159	40	65	44
<i>p</i> -value	NS	0.05	0.06	0.10	NS	NS	0.05	0.07	0.07
Simulation 2									
Control	0.07	0.51	3.96	0.31	2.70	0.14	0.15	0.35 b	0.29
Broadcast	0.08	1.99	14.4	0.54	3.70	0.39	0.40	1.37 b	1.19
Vertical	0.52	2.59	26.3	0.83	20.1	0.03	1.28	2.43 ab	2.00
Chisel	0.98	7.69	55.5	1.17	36.6	0.01	6.97	6.19 a	4.65
CV	96	168	92	112	147	41	258	2692	554
<i>p</i> -value	NS	NS	NS	NS	NS	NS	NS	0.03	NS
Simulation 3									
Control	0.17	1.26	27.2	0.54	16.9	1.01	0.42	1.33	0.82
Broadcast	0.36	3.11	35.7	0.64	21.7	0.96	2.92	3.12	2.17
Vertical	0.27	2.46	34.1	0.56	20.7	0.69	1.58	1.83	1.26
Chisel	1.37	11.8	120	1.44	67.6	2.26	25.8	11.4	8.04
CV	112	112	126	146	170	233	1258	1251	818
<i>p</i> -value	NS	NS	NS	NS	NS	NS	NS	NS	NS
Simulation 4									
Control	0.42	2.54	32.4	0.76	25.8	0.18	1.45	2.78	1.15
Broadcast	0.75	7.20	68.3	1.10	48.6	0.40	9.81	3.87	2.22
Vertical	0.30	1.79	22.5	0.22	17.0	0.02	1.36	1.95	0.91
Chisel	4.26	31.5	271	2.67	164	0.46	63.8	26.1	13.7
CV	167	253	54	204	62	67	437	175	324
<i>p</i> -value	NS	NS	NS	NS	NS	NS	NS	NS	NS

† TP = total P, TN = total N, DRP = dissolved reactive P, NO₃[−]-N = nitrate-N, NH₄⁺-N = ammonium-N, SS = suspended solids, TDS = total dissolved solids, VS = volatile solids; ‡ values with the same letter are not significantly different at *p* ≤ 0.10, NS = not significant.

3.4. Manure and Tillage Effects on Overland Flow Nitrogen Loss

Many of the differences noted among treatments occurred in the first simulation event, with consistently higher TN loads for broadcast relative to CT, VT, and control (Tables 2 and 3). Though not significant given the high variability in the data, greater overland flows from broadcast treatment invariably contributed to the higher N losses than VT and CT. Manure application increased TN concentrations, with greater concentrations for unincorporated treatments (broadcast and VT) where manure was closer to the surface and could interact with overland flow (Table 3). In contrast, TN concentrations for CT were reduced 12% from broadcast and similar to the control. Loads of TN also differed among treatments with CT similar to control. Average TN loads for VT and CT were 87 and 98% lower than broadcast, respectively (Table 2), demonstrating the critical importance of incorporating manures to increase N retention while mitigating overland flow loss potential. While differences in dissolved inorganic N (NO₃[−]-N and NH₄⁺-N) concentrations were

similar and loads did not differ significantly, NO_3^- -N loads were reduced by 77% and 97% for CT and VT, respectively; NH_4^+ -N loads were reduced by 93% and 98%, respectively.

Table 3. Concentrations in runoff for each simulation.

Treatment	TP †	TN	DRP	NO_3^- -N	NH_4^+ -N	SS	TDS	VS
mg/L								
Simulation 1								
Control	0.30	5.36 b ‡	0.20	3.04	1.00	126	514	274 c
Broadcast	1.12	7.41 a	0.51	3.30	1.69	375	518	281 bc
Vertical	0.57	7.57 a	0.25	3.53	1.92	335	703	485 a
Chisel	0.65	6.49 ab	0.29	3.16	1.12	372	559	384 ab
CV	72	16	53	14	50	10	21	21
p-value	NS	0.10	NS	NS	NS	NS	NS	0.03
Simulation 2								
Control	0.97	5.91	0.66 b	3.95	0.23 b	274	531	495
Broadcast	1.45	6.14	1.23 a	9.11	0.38 a	172	584	510
Vertical	0.66	5.42	0.25 b	3.91	0.04 c	357	526	513
Chisel	0.93	5.63	0.18 b	3.95	0.02 c	522	490	653
CV	54	19	102	28	31	69	9	7
p-value	NS	NS	0.03	NS	0.0003	NS	NS	NS
Simulation 3								
Control	0.53	11.4	0.19	6.24	1.37	433 b	1011	596
Broadcast	0.73	8.27	0.18	4.83	0.23	509 b	592	393
Vertical	0.87	12.6	0.23	7.76	0.25	582 b	801	671
Chisel	0.75	9.09	0.12	5.55	0.24	1158 a	608	423
CV	27	32	23	40	73	28	25	5
p-value	NS	NS	NS	NS	NS	0.06	NS	NS
Simulation 4								
Control	0.54	7.38	0.17	5.69	0.07	296	644	224
Broadcast	0.81	7.48	0.13	5.01	0.07	854	618	304
Vertical	0.51	6.73	0.08	5.00	0.02	375	666	293
Chisel	0.70	6.48	0.06	4.21	0.01	1236	591	309
CV	44	24	48	31	105	14	8	22
p-value	NS	NS	NS	NS	NS	NS	NS	NS

† TP = total P, TN = total N, DRP = dissolved reactive P, NO_3^- -N = nitrate-N, NH_4^+ -N = ammonium-N, SS = suspended solids, TDS = total dissolved solids, VS = volatile solids, ‡ values with the same letter are not significantly different at $p \leq 0.10$, and NS = not significant.

The large overall yet variable decrease in overland flow N loss potential with tillage indicates the important role different types and degrees of tillage have on N loss. Our findings support others showing variable overland flow N loss depending on manure application management system and other site-specific factors, with some showing no tillage effects on TN, NO_3^- -N, or NH_4^+ -N [9,10,14,51]. While not significant, TN and NO_3^- -N loads for CT increased with subsequent rainfall simulation events and likely associated with higher runoff quantities. We hypothesize that the presence of live triticale biomass may have contributed to maintenance of soil structure immediately after manure incorporation, thus helping to retain water infiltration and N more effectively than situations where cover crops are terminated earlier or subject to winter kill.

3.5. Manure and Tillage Effects on Overland Flow Phosphorus and Sediment Loss

Similar to N results, incorporating manure reduced mean P loads to levels similar to the control. Compared to broadcast treatment, VT and CT reduced TP and DRP loads by >96% on average (Tables 2 and 3). Greater P losses from surface manure application compared to manure application with tillage incorporation is similar to results reported elsewhere, although TP and DRP concentrations and loads in our study were generally lower than those reported elsewhere [4,5,9,52]. Both CT and VT substantially reduced DRP losses in overland flow compared to broadcast only which is supported by other studies [3,9,13,52]. Some studies report larger TP losses in overland flow with tillage

presumably due to greater erosion and particulate-P transport [13,14,52]. However, this did not appear to be the case with the first event after manure application. Among other possible confounding factors, low runoff volumes for the first event could have limited overland flow TP transport in our study. Additionally, lower erosion potential in the live triticale (compared to bare soil more typical of annual systems) may have also contributed to more limited particulate-P mobilization to overland flow. Similar to TN trends, we speculate that larger TP loads for CT with later events could be related to altered surface soil structure from greater compaction/disturbance potential of CT shanks compared to broadcast or VT in these fine-textured silt loam soils.

Results indicate that both CT and VT helped to limit P transport in overland flow in the presence of live triticale after spring liquid dairy manure application. Based on previous trials and our results here, a low-intensity form of tillage incorporation while maintaining maximum residue/cover is an important factor affecting overland flow P loss potential. Overland flow SS concentrations did not differ significantly among treatments for the first event. However, loads were higher for broadcast and probably again related to higher average overland flow volumes (Table 3). Additionally, overland flow from soils receiving broadcast manure applications can sometimes contribute substantially to total SS loads via organic matter “flocs” and total particulate OM transport [53,54]. Compared to surface broadcast, SS loads for CT and VT were reduced by 92% and 97%, respectively and similar to the control.

The large reduction in apparent erosion and sediment-bound P transport potential with tillage could also be related to greater short-term infiltration and a concomitant decrease in overland flow. It is of note that the SS concentrations and loads in our study were lower than numerous others examining the effects of different tillage practices on overland flow water quality and could be related to multiple factors including live triticale, small plot runoff volumes, and inherent limitations of rainfall-runoff simulations [9,10,13,15].

Events after the first simulation also showed some evidence of sediment, N, and P transport as CT had consistently greater TN and TP (5-fold greater) and TDS and SS loads (6- and 10-fold greater, respectively) compared to other treatments. VT evidently caused less soil structure disruption than CT from the combined effects of greater downforce and shear stress imposed by CT shanks. Moreover, VT left more surface stubble/residues than CT. While there were only minor concentration differences for the first event, DRP and NH_4^+ -N were greater for broadcast compared to CT or VT three weeks later (6- and 13-fold greater, $p = 0.03$ and $p = 0.0003$, respectively). While loads did not differ, the greater bioavailable N and P concentrations indicate that manure was an important contributor to overland flow nutrient loss and suggest that some level of incorporation may be needed to adequately reduce overland flow N and P loss risk where transport to surface waters is a concern. Results further suggest that the presence of a live cover crop was insufficient to adequately mitigate overland flow DRP concentrations and thus some incorporation may be necessary for fields with overland flow potential and close to surface waters.

3.6. Plot Surface Coverage and Overland Flow Water Quality

Digital plot imagery showed that mean percent triticale stubble coverage was reduced by approximately 50% of the control for VT and 75% for CT ($p < 0.0001$) (Figure 2). Manure coverage was also reduced with VT and CT to 16% and 10%, respectively, of broadcast levels, ($p < 0.0001$). In addition, manure was positively correlated with concentrations of TP ($r = 0.25$, $p = 0.09$) and NH_4^+ -N ($r = 0.34$, $p = 0.01$) and loads of TP ($r = 0.25$, $p = 0.09$), DRP ($r = 0.59$, $p < 0.0001$), and NH_4^+ -N ($r = 0.77$, $p < 0.0001$) in overland flow. Previous studies have similarly reported significant correlations among measures of plant/residue and manure coverage and SS, N, and P in overland flow [4,9,13,55]. While several studies also indicate correlations between labile soil P measures (i.e., soil test and water-extractable P) and overland flow DRP concentrations [56–58], there was no correlation in our study ($p = 0.47$) which could be related to the relatively high SS losses for CT (which had the

lowest Bray-P concentration) in addition to a relatively small overall range in Bray-P concentrations.

Figure 2. Average plot surface coverage (%) by treatment for soil, manure, residue, corn, and triticale stubble. † values with the same letter are not significantly different at $p \leq 0.1$. †† letters to the right of the bar represent % residue differences and letters to the left represent % manure differences.

When the first event was analyzed alone, there was no significant correlation between Bray-P and overland flow DRP or TP concentrations, suggesting that labile P from manure was likely a more important P source to overland flow than soil P. Bray-P concentrations would likely be more important for DRP release to overland flow for later events after manure P has been more fully integrated into the soil P pool. Interestingly, total live plus dead plant material was negatively correlated with cumulative overland flow ($r = -0.48$, $p = 0.0002$), suggesting that residue coverage was important for reducing overland flow. Total plant material was also negatively correlated with DRP ($r = -0.29$, $p = 0.03$) and SS ($r = -0.52$, $p = 0.0001$) concentrations in addition to loads of TP ($r = -0.47$, $p = 0.0005$), TN ($r = -0.49$, $p = 0.0002$), DRP ($r = -0.26$, $p = 0.05$), NO_3^- -N ($r = -0.51$, $p < 0.0001$), SS ($r = -0.46$, $p = 0.0009$), TDS ($r = -0.47$, $p = 0.0007$), and VS ($r = -0.497$, $p = 0.0003$). Collectively, these relationships support the idea that residue coverage is an important factor affecting SS and overland flow P mobilization, even after cover crop termination.

4. Conclusions

Both vertical (VT) and chisel tillage (CT) operations conducted after liquid dairy manure application to the soil surface of corn-triticale plots substantially mitigated overland flow nutrient concentrations compared to broadcast application alone. Compared to VT, CT resulted in numerically larger overland flow in subsequent rainfall-overland flow simulations and slightly larger TN and SS loads. A live triticale cover crop was not sufficient to adequately mitigate nutrients and SS in overland flow immediately after manure application. Results showed that VT significantly reduced TP, TN, and SS losses to 99, 98, and 97% of broadcast levels, respectively. Additionally, VT maintained greater triticale stubble/residue coverage that may have aided infiltration of overland flow after manure application. Overall, our results suggest that some tillage after liquid dairy manure application to the soil surface may be required when planting green into a live cover crop to reduce overland flow sediment and nutrient loss risk in addition to helping to prepare a more favorable seed bed in some conditions. However, additional research is needed to determine combinations of cover crops and tillage that are most suitable across a range of growing environments in order to maximize the potential benefits of this practice.

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