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Research Article

Crop Residue Biomass Effects on Agricultural Runoff

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High residue loads associated with conservation tillage and cover cropping may impede water flow in furrow irrigation and thus decrease the efficiency of water delivery and runoff water quality. In this study, the biomass residue effects on infiltration, runoff, and export of total suspended solids (TSS), dissolved organic carbon (DOC), sediment-associated carbon (TSS-C), and other undesirable constituents such as phosphate (soluble P), nitrate (NO_3^-), and ammonium (NH_4^+) in runoff water from a furrow-irrigated field were studied. Furrow irrigation experiments were conducted in 91 and 274 m long fields, in which the amount of residue in the furrows varied among four treatments. The biomass residue in the furrows increased infiltration, and this affected total load of DOC, TSS, and TSS-C. Net storage of DOC took place in the long but not in the short field because most of the applied water ran off in the short field. Increasing field length decreased TSS and TSS-C losses. Total load of NO_3^-, NH_4^+, and soluble P decreased with increasing distance from the inflow due to infiltration. The concentration and load of P increased with increasing residue biomass in furrows, but no particular trend was observed for NO_3^- and NH_4^+. Overall, the constituents in the runoff decreased with increasing surface cover and field length.

1. Introduction

The USA, having more than 408 million acres of crop land and an abundant supply of food products, is noted worldwide for its high productivity, quality and efficiency in delivering goods to the consumer [1]. However, the agricultural practices used to produce these quality products are affecting the sustainability of crop production systems and impacting water quality in many regions of the country. Agriculture is the third leading source of pollution in USA estuaries [2]. Specifically, elevated dissolved organic carbon (DOC) concentrations in runoff that finds its way to main drinking water supplies are of significant concern because of serious potential health concerns. During chlorination to produce drinking water, a subgroup of DOC, or disinfection byproduct precursors, form disinfection byproducts (DBPs), of which trihalomethanes and haloacetic acids are the most abundant. These DBPs, stringently regulated by the USEPA, are carcinogenic and mutagenic. Therefore, knowledge of water quality parameters such as nutrients, sediments, and bacterial concentrations of flooded fields is important, because the water released from these fields eventually flows into streams and rivers.

One of the important methods of controlling pollution by agricultural activities is to employ best management practices (BMPs) to reduce sediment and dissolved chemicals in the runoff. Conservation tillage (CT) (no-till or reduced till) and the use of cover crops (CC) can reduce runoff by promoting increased infiltration [3–8]. However, these practices are only slowly being adopted in agriculture due to the increased number of field operations required to maintain furrows for irrigation management. Specifically, CT and CC can leave potentially high residue loads (at least 30%) on fields [9] that impair the movement of water and thus decrease the efficiency of water delivery. The residue encourages the decomposers—especially fungi—and increases food web complexity by providing food and habitat for surface feeders and surface dwellers. Residue protects soil from raindrop impacts, causing loss of soil surface structure and plugging up of macropores, and cycles of freezing thawing and drying wetting [10–12]. The presence of crop residue on the soil surface not only substantially reduces the soil loss from furrows [13, 14] but also may improve irrigation uniformity [14, 15].

Crop residues also slow the rate of evaporation [10, 11, 16] by isolating the soil from heating and elevated air temperature and increasing resistance to water vapor flux by reducing wind speed [11]. The increase in infiltration and the decrease in evaporation generally result in greater soil water storage, depending on amount and type of crop residues left on the soil surface [16] and the duration of the dry period [3, 17, 18]. Crop residue is a convenient and valuable source of organic matter [19, 20]. This improves soil aggregate stability during low rainfall periods and promotes more infiltration through the soil. The increased aggregation might be due to soluble carbohydrates leached from fresh residues [21], or to particulate organic matter [22], to the activity of fungi [23, 24] or microbes.

The amount of crop residues on the soil surface varies with time [23–25] and directly affects soil water characteristics, structural properties [26], and organic matter content [27–30]. The most important reasons for the crop residue variation are tillage and residue decay. Tillage modifies residue cover nearly instantaneously and changes the percentage of residues left on the surface versus buried according to tillage system and intensity [31]. Laboratory studies indicate that water and temperature have a greater effect during early stages of decomposition, when easily utilizable compounds are readily available to microorganisms [32–34]. Greater fluctuations in water and temperature, along with reduced nutrient availability, adversely affect microbes colonizing surface residue, thus slowing decomposition, compared with incorporated crop residues [35–38]. Standing biomass seems to decompose more slowly than flat residues [39].

In addition to the biomass residue, length of the field affects the agricultural discharges. Limited studies have been carried out on the field length effect on runoff and DOC export [8] in furrow- irrigated fields. Increase in field length generally decreases the quantity of agricultural discharge and elevates the concentration of pollutants. However, the total export of the pollutants decreases with increase in the field length due to the decreased runoff [8]. We proposed to consider the advantages of the residue having a beneficial influence on runoff water quality rather than viewing residue as deterrent to implementing furrow irrigation practices. The objectives of the present study are to (i) investigate the effects of varied levels of residue cover on infiltration and runoff at different locations in fields of varying lengths, (ii) characterize the release, transport, and export of DOC, phosphate (soluble P), nitrate (NO_3^-), and ammonium (NH_4^+) at multiple locations in irrigated furrows containing varied amounts of residue, and (iii) assess the effects of residue amount on total suspended solids (TSS) and sediment-associated carbon (TSS-C) during irrigation in fields of varying lengths.

2. Materials and Methods

2.1. Experimental Site. The field experiments were conducted at the Campbell Tract at the University of California, Davis (38° 32′ 09″ N, 121° 46′ 32″ W, 60 ft elevation). The alluvial soils at the experimental site are classified as Yolo silty loam (fine silty, mixed, nonacid, thermic family of Mollic Xerofluvents) containing 24% of sand, 50% of silt, and 26% of clay. The experimental site has 0.2% slope. Prior to the experiments, the fields had been fallow for one year, and prior to the fallow period, corn was grown.

2.2. Residue Biomass Treatments. The research was conducted on two furrowed plots of 91 and 274 m length and 110 m width. Row spacing was 1.5 m, with bed widths of approximately 1 m and depth of furrows about 0.2 m. Four treatments of residue biomass (high, medium, low, and control), each comprising six beds, five irrigated furrows, and one dry furrow on either side of each treatment block, replicated three times, were assigned to the two lengths in a randomized block design. The plots were planted with corn on May 20, 2008. All biomass treatments, including the control, were irrigated three times at an interval of 10 to 15 days. To obtain low, medium and high residue cover, corn plants were chopped 23, 32, and 39 days after planting, respectively. At the time of chopping the average corn height was 0.3, 0.6, and 0.85 m for low, medium, and high residue plots, respectively. The texture of the chopped corn residue was 0.12 to 0.16 m long with a diameter of 0.02 to 0.04 m. The corn residue was left in the field to dry and herbicide was sprayed to control weeds. The amount of residue biomass in a meter length of furrow was collected from five random locations in each replicate and dry weight was measured. Residue biomass found in furrows of control plots due to wind was removed by hand raking.

2.3. Field Experimentation. The treatments of long field were irrigated on 20th and 21st November 2008. The treatments of the short field were irrigated on 24th and 25th November 2008. Each treatment was irrigated through gated pipes for 10 hours using a constant inflow of 1.5 L s^{-1} per furrow. To achieve a uniform inflow rate, the gates were opened to equal width and after measuring the inflow rate at the middle and end gates of each experimental unit (5 irrigated furrows) by using a bucket and stop watch, the gates were adjusted as needed. The outflow from each treatment was monitored using ISCO 6700 dataloggers/water samplers (Teledyne Technologies Inc., Thousand Oaks, CA, USA) (Figure 1).

2.4. Data Collection. From a randomly selected furrow of each treatment, waterfront advance time was measured by a system of clocks placed in the furrows at equal distances from the head end. The clock (Walmart Stores, Inc., Bentonville, AR, USA) power supply was spliced and connected by wire to metal plates attached to the jaws of a clothespin. Before

Figure 1: Runoff sample collection using ISCO autosampler from the short field.

irrigation events, a soluble tablet (e.g., aspirin) was placed between the clothespin jaws to keep the circuit open and the clock set to a predetermined time. The clock circuit was closed when the tablet was dissolved as the water front advanced in the furrow, activating the clock and indicating the time it took for the water to advance in the furrow. More details on waterfront advance measurements using the clock method are given by [8]. The water advance time of a location is determined by the following relation:

$$T_a = T_r - T_c - T_i, \quad (1)$$

where T_a is the water advance time (min), T_i is the irrigation start time (min), T_c is the clock time (min), and T_r is the time that the clock showed (min).

The waterfront advance time patterns represent infiltration characteristics of the treatment plot that is a longer waterfront advance time at the field end indicating greater water infiltration into the soil. The waterfront advance measurements were taken from both long and short fields. From the treatments of the long field, grab samples were collected at 91 and 183 m locations at regular time intervals and the flow rate was determined using the dye method [40]. First, the flow velocity at a location in the furrow was determined by placing a drop of dye upstream of the location and measuring the time to cover a 1 m distance downstream. Second, the flow cross-section was determined by measuring the flow depth and flow width (parabolic shape was assumed). The flow rate at the location was determined by multiplying flow velocity and the flow cross-section. The grab samples' data at different locations were used to analyze the spatial variability in the runoff loads. The water samples were kept on ice and filtered through nominal 0.3 μm glass fiber filters within 6 hours of collection. The mass of total suspended solids (TSS) retained by the filters was measured after drying. The carbon content in the dried sediment retained by the filter was determined *via* combustion by an Elemental Carbon and Nitrogen Analyzer (Costech Analytical Technologies Inc., Valencia, CA, USA). The filtrate was stored at 4°C, and within two days, DOC concentration in the filtrate was measured by the UV-persulfate oxidation method [41]. Furthermore, phosphate (soluble P), nitrate (NO_3^-), and ammonium (NH_4^+) concentrations were measured for all samples. To assess total dissolved phosphorus, a persulfate digestion to convert dissolved P to orthophosphate (PO_4-P) was carried out, and PO_4-P in the filtered subsamples was measured colorimetrically (Shimadzu spectrophotometer, Model UV-Mini 1240) by the ascorbic acid method [42]. Ammonium (NH_4^+) was determined colorimetrically by the phenate (indophenol blue) method [43]. Nitrate in the samples was reduced to NO_2^- with vanadium chloride, followed by analysis of NO_2^- by diazotizing with sulfanilamide followed by coupling with N-(1-naphthyl)ethylenediamine-dihydrochloride and colorimetric analysis [44]. Total load of the water constituents was calculated from their concentration in the water samples and the runoff (short field) and flow rates measured at the 91 and 183 m locations in the long field. The runoff at the end of the long field (274 m) was not used for the analysis because after 24 hours of inflow, the irrigation water did not reach the outflow except in a few of the 60 furrows. The total inflow during the time considered in this experiment (10 hours) was 4000 $m^3\,ha^{-1}$ for the 91 m long field and 2000 $m^3\,ha^{-1}$ for the 183 m location in the longer field.

2.5. Data Analysis. Residue biomass treatment effects were assessed by one-way analysis of variance (ANOVA) for the short field and two-factor ANOVA, with location (91 or 183 m from the head end of the furrows) and residue biomass quantity as factors, for the longer field. The effects of field length and biomass in the furrow on runoff, TSS, DOC, soluble P, NO_3^-, and NH_4^+ export were assessed in a split-plot design with length as main effect and biomass as subplot effect. The generalized linear models procedure was used with SAS v. 9.2 (SAS Institute Inc., Cary, NC, USA). The Tukey's test was used for means separation. The interaction effect of field length and biomass was studied using two-factor ANOVA with SAS v. 9.2. Using the measured data, regression analysis was carried out to quantify the predictability of runoff, TSS, DOC, sediment carbon, soluble P, NO_3^-, and NH_4^+ export using length scale and biomass residue quantity.

3. Results and Discussion

3.1. Residue Biomass in the Furrows. In the short field (91 m), the average mass of residue biomass present in the furrows was 10, 15.2, and 26.6 $Mg\,ha^{-1}$, and in the long field (274 m), it was 4.4, 12.3, and 19 $Mg\,ha^{-1}$ for low, medium, and high residue treatments, respectively. The residue biomass was negligible in the control plots in both short and long fields. The residue biomass in the furrows was significantly higher in the short than in the long field ($P < 0.001$). In each field, residue biomass in the furrows was significantly different among the treatments ($P < 0.001$).

3.2. Waterfront Advance. The waterfront advance time (Figure 2) was similar among the residue treatments both at the end of short field (91 m) and at the 91 m location in the long field. However, with increasing field length, at the 122, 152, and 183 m locations, the waterfront advanced more slowly in the furrows with high residue than that in the low residue

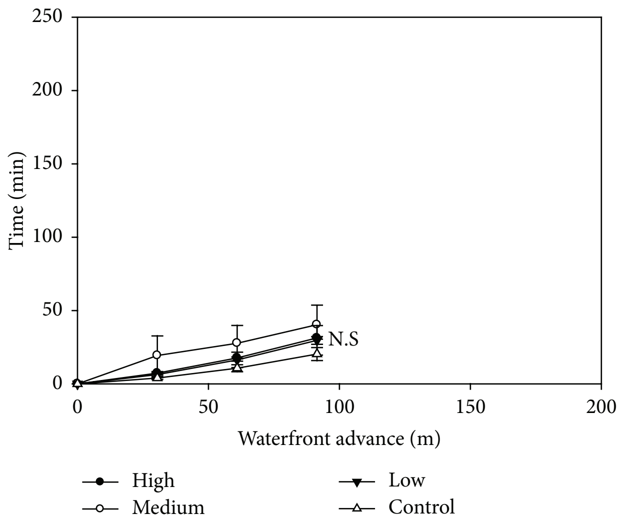

Figure 2: The waterfront advance time at 30, 61, and 91 m from the inflow of the 91 m long field. The error bars represent the standard error. The High, Medium, Low, and Control residue treatments represent varying amounts of residue biomass in the furrow. NS = nonsignificant differences.

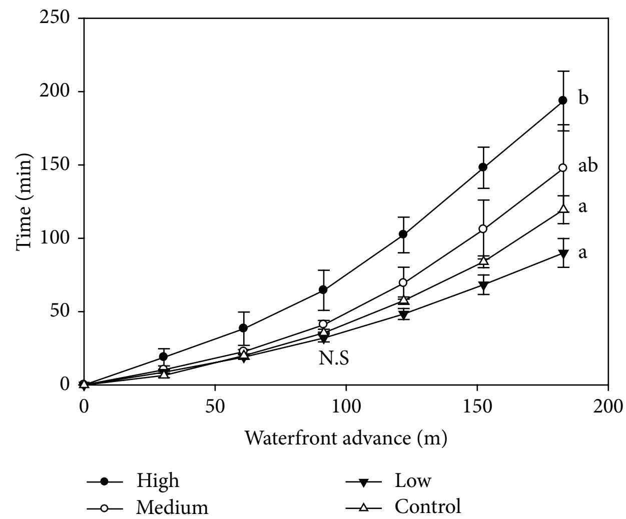

Figure 3: The waterfront advance time for the 274 m long field at varying locations from the inflow end. The error bars represent the standard error. The High, Medium, Low, and Control residue treatments represent varying amounts of residue biomass in the furrow. Means represented by symbols with same letters are not significantly different ($P < 0.05$). NS: nonsignificant differences.

and control treatments (Figure 3). These results suggest that the presence of residue resulted in greater water residence time, which also increased the infiltration opportunity time.

3.3. Residue Biomass Effects on Runoff. In the short field, the amount of runoff did not differ among the treatments, but in the longer field, the high residue treatment significantly reduced the total amount of water flow in the furrow (Tables 1 and 2). Between the 91 and 183 m sampling locations, the amount of water flowing through the furrow decreased significantly (Table 2). In addition to the greater infiltration opportunity with increasing furrow length, runoff was also decreased in the high residue treatment. The runoff/flow measurements confirmed that greater water residence time increased infiltration, as the waterfront advance data predicted. The runoff measure also allowed calculation of total load of DOC, sediment, and other water quality parameters for each treatment and location within the furrow.

3.4. Length and Residue Biomass Effects on DOC Concentration. The mean concentration of DOC in the inflow was 2.7 mg C L^{-1}. The water source for this experiment was predominantly Campbell tract (Davis, CA, USA) well water with a small supplement from a storage reservoir with lake Berryessa water. For all treatments, the DOC concentration at each grab sample location was initially the highest and decreased nonlinearly to a constant value with time (Figures 4 and 5). The initial maximum DOC concentration increased with increasing amounts of residue in the furrows. The DOC concentration was higher at the 183 m than at the 91 m location, indicating increasing DOC concentration downstream in the furrows. This suggests that the released carbon is transported in convective flow down the furrow. The interaction between location and biomass residue effects on DOC concentration was highly significant (Table 2).

In the short field, DOC concentration tended to be higher with increasing amounts of residue biomass in the furrows, and in the longer field increasing amounts of residue significantly increased DOC concentration. These results strongly suggest that surface plant residue is a major source of DOC. Doane and Horwáth [44] also concluded that plant residue enriches DOC in tailwater by reporting DOC values of 1 mg L^{-1} from soil solution, 4.7 mg L^{-1} in irrigation canal water, and 7.8 mg L^{-1} in runoff water.

Differences in DOC export and net storage were due to field length and residue treatment effects (Tables 1 and 2). In the short field, there were no differences in DOC export among residue treatments, and high runoff volumes relative to inflow resulted in net losses of DOC. In the longer field, additional infiltration of irrigation water between the 91 and 183 m location and thus low water flow at the 183 m location relative to inflow resulted in net storage of DOC over the 183 m long furrow. The DOC storage values for this irrigation event are similar to those reported in comparable studies of this area [45]. There were no differences in DOC export and storage value among the residue treatments, but residue biomass in the furrows influenced DOC storage by increasing infiltration and reducing runoff volume, as evidenced by the significantly decreased runoff in the high residue treatment.

3.5. Effects of Residue Treatments and Field Length on Sediment Export. Sediment or total suspended solids (TSS) concentration in the furrow water also increased with furrow length (Table 2). However, the total amount of sediment transported (total load is the time integral of the product of TSS concentration and flow rate) decreased with increasing

Table 1: Biomass effect on runoff, TSS, DOC, and TSS-C in the short (91 m long) field. Shown are means (standard error). $n = 3$.

Treatment	Runoff (m^3 ha^{-1})	TSS export (kg ha^{-1})	DOC conc (mg L^{-1})	DOC export (kg ha^{-1})	DOC storage (kg ha^{-1})	TSS-C export (kg ha^{-1})
Control	3380 (30)	2298 (72)^a	4.3 (0.6)^e	12.9 (1.1)	−2.9 (1.1)	100 (17)
Low	3520 (1010)	789 (223)^b	6.0 (1.3)^{de}	16.0 (2.6)	−6.0 (2.6)	72 (35)
Medium	3370 (310)	628 (79)^b	9.3 (1.8)^d	18.6 (3.4)	−8.6 (3.4)	67 (16)
High	2770 (390)	419 (145)^b	9.5 (1.7)^d	15.4 (1.8)	−5.4 (1.8)	41 (12)
	NS	***	*	NS	NS	NS

NS: nonsignificantly different; $^*P < 0.1$; $^{**}P < 0.01$; $^{***}P < 0.001$; for each variable, values with same letters are not significantly different.

Table 2: Biomass residue and field length effects on runoff, TSS, DOC, and TSS-C in the 274 m long field. Shown are means (standard error), as well as analysis of variance results. $n = 3$.

Location (m)	Treatment	Runoff (m^3 ha^{-1})	TSS conc (mg L^{-1})	TSS export (kg ha^{-1})	DOC conc (mg L^{-1})	DOC export (kg ha^{-1})	DOC storage (kg ha^{-1})	TSS-C export (kg ha^{-1})
91	Control	4140 (289)^b	343 (119)	712 (142)^b	2.5 (0.2)^c	9.1 (0.9)	0.9 (0.9)	111 (13)
	Low	3579 (847)^b	213 (50)	508 (141)^a	4.4 (0.6)^{bc}	10.5 (1.8)	−0.6 (1.8)	85 (17)
	Medium	3702 (381)^b	234 (54)	469 (41)^a	5.1 (1.0)^b	13.4 (0.6)	−3.4 (0.7)	90 (25)
	High	2373 (149)^a	309 (34)	447 (75)^a	8.7 (0.8)^a	13.1 (1.3)	−4.5 (2.1)	90 (23)
183	Control	905 (166)^y	963 (242)	507 (50)^x	3.2 (0.2)^z	2.3 (0.2)	2.7 (0.2)	33 (10)
	Low	870 (146)^y	191 (33)	95 (6)^y	5.8 (1.1)^{yz}	3.5 (0.1)	1.5 (0.0)	21 (2)
	Medium	503 (199)^y	654 (292)	155 (45)^y	12.2 (3.5)^y	3.5 (0.4)	1.5 (0.4)	18 (9)
	High	135 (45)^x	507 (104)	51 (4)^y	30.5 (3.6)^x	2.7 (0.9)	2.3 (0.8)	5 (3)
				Two-way ANOVA results				
	Biomass	*	NS	**	***	NS	NS	NS
	Length	***	*	***	***	***	***	**
	Biomass × length	NS	NS	NS	***	NS	NS	NS

For each variable and length, values designated with the same letters are not significantly different ($P > 0.05$).

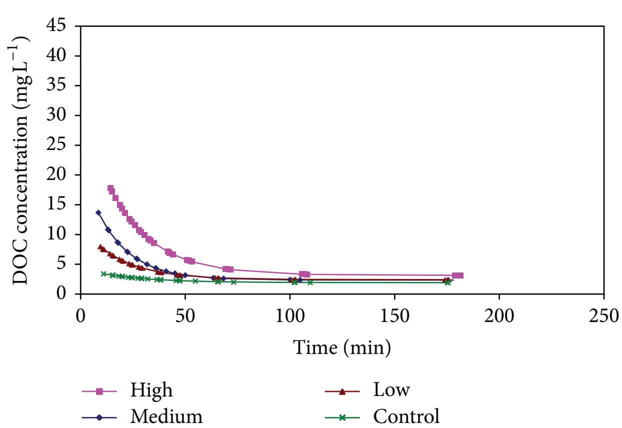

Figure 4: The DOC concentration at the 91 m location. The labels High, Medium, Low, and Control refer to the amount of residue biomass in the furrow.

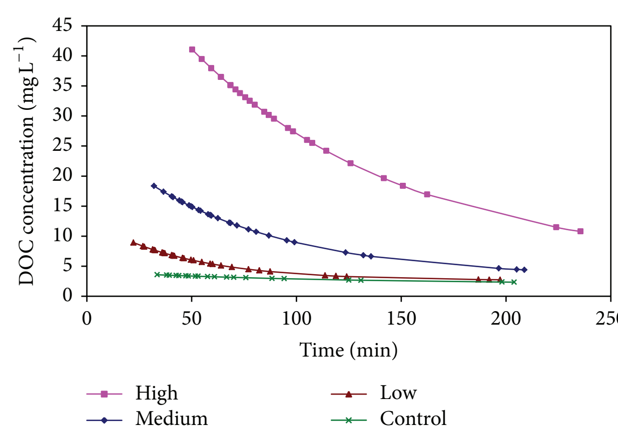

Figure 5: The DOC concentration at the 183 m location. The labels High, Medium, Low, and Control indicate the amount of residue biomass in the furrow.

length because flow rate decreased with length. Biomass residue in the furrows reduced sediment load since furrows without residue (control) had significantly greater sediment concentrations (Tables 1 and 2). The concentration of carbon (C) in the sediment was similar among the treatments, and hence the load of sediment carbon carried in the furrow water (total sediment carbon is the time integral of the product of C concentration in the sediment, the concentration of sediment in water and flow rate) depended on the TSS load, a notion supported by the highly significant regression of TSS-C on TSS ($P < 0.001$, $r^2 = .93$).

Table 3: Biomass residue and field length effects on soluble P, NO_3^--, and NH_4^+- in the 274 m long field. Shown are means (standard error), as well as analysis of variance results. $n = 3$.

Location (m)	Treatment	Soluble P conc ($mg L^{-1}$)	Soluble P exp ($kg ha^{-1}$)	NO_3^- conc ($mg L^{-1}$)	NO_3^- exp ($kg ha^{-1}$)	NH_4^+ conc ($mg L^{-1}$)	NH_4^+ exp ($kg ha^{-1}$)
91	Control	0.06 (0.01)^b	0.14 (0.03)	2.46 (0.20)^c	9.60 (1.36)^b	0.11 (0.03)^b	0.36 (0.06)
	Low	0.07 (0.02)^b	0.23 (0.10)	3.27 (0.19)^b	10.07 (1.35)^b	0.18 (0.11)^b	0.48 (0.31)
	Medium	0.09 (0.03)^b	0.25 (0.06)	3.70 (0.38)^{ab}	12.80 (2.40)^b	0.16 (0.09)^b	0.41 (0.18)
	High	0.20 (0.05)^a	0.35 (0.09)	3.32 (0.31)^a	6.50 (0.86)^a	0.22 (0.10)^a	0.36 (0.15)
183	Control	0.08 (0.01)^y	0.06 (0.02)	2.69 (0.21)^z	2.20 (0.10)^y	0.13 (0.02)^y	0.08 (0.03)
	Low	0.11 (0.03)^y	0.07 (0.02)	3.73 (0.27)^y	2.60 (0.45)^y	0.21 (0.10)^y	0.09 (0.03)
	Medium	0.24 (0.11)^y	0.06 (0.01)	4.62 (0.80)^{xy}	1.73 (0.56)^y	0.45 (0.25)^y	0.10 (0.02)
	High	0.74 (0.23)^x	0.07 (0.03)	5.40 (0.34)^x	0.57 (0.19)^x	1.32 (0.50)^x	0.09 (0.04)
	Analysis of variance						
	Biomass	**	NS	**	*	*	NS
	Length	*	***	**	***	*	**
	Biomass × lenght	*	NS	NS	NS	*	NS

For each variable and length, values designated with the same letter are not significantly different.

The percentage of total C in the sediment ranged from 4 to 22%. This proportion of C in sediment is much larger than C values in the range of 2 to 5% reported in sediment of district irrigation canal water or in sediment from runoff [45]. In our experiments, the analyzed sediment samples may have contained a substantial amount of light fraction C, especially in the grab samples. The C concentration in the sediment of the runoff samples from the control treatment in the 91 m long field, by comparison, was 4.6% and more in range of values reported elsewhere [45]. Therefore these results, which indicate that a far greater amount of C is potentially lost as sediment than as DOC, may not be broadly generalizable. However, if well water is used for irrigation, it is likely that TSS-C loss is greater than DOC-C loss since well water contains very little sediment, and any sediment in runoff represents a loss of C, whereas this and other studies show that, during irrigation, DOC is generally contributing to an increase in field C [46, 47]. In the present study, sediment in the inflow water was below our detection limit.

3.6. Residue Treatments and Field Length Effects on Nutrient Concentration and Export. Soluble P concentration and load in the runoff water followed the trend of DOC. The soluble P concentration increased with increasing biomass residue in the furrows (Table 3). However, the response of biomass residue on NO_3^- and NH_4^+ concentrations in runoff did not follow a particular trend. Total load of these ions decreased with increasing distance from the inflow due to reduced water flow caused by infiltration. Overall, concentrations of nutrients in runoff and furrow water were low.

3.7. Regression Analysis. The observed data were fitted to the following linear regression model with field length and residue biomass as independent variables and runoff or total load of water quality as dependent variable:

$$z = z_0 + a \times x + b \times y, \tag{2}$$

where z is the output variable, x is the field length (m), y is the biomass ($g m^{-1}$ furrow), and a, b, and z_0 are the fitting parameters.

Table 4: Constants, standard error, and coefficients of variation of the regression analysis.

Parameter (z)	z_0	a	b	Standard error	R^2
Runoff ($m^3 ha^{-1}$)	6838.72	−31.41	−3.55	685.84	0.82
TSS ($kg ha^{-1}$)	1633.62	−6.47	−1.89	401.78	0.45
DOC ($kg ha^{-1}$)	23.44	−0.12	0.0015	4.12	0.63
NO_3^- ($kg ha^{-1}$)	17.61	−0.078	−0.0015	2.6	0.64
Soluble P ($kg ha^{-1}$)	0.37	−0.002	0.0004	0.1	0.56
NH_4^+ ($kg ha^{-1}$)	0.79	−0.004	0.0001	0.21	0.43
TSS-C ($kg C ha^1$)	152.29	−0.56	−0.154	31.24	0.49

The model parameters are useful in explaining the output trend based on the variations in the inputs (Table 4).

The positive sign of z_0 and negative sign of b indicate that the output variable is the highest for the control treatment (no residue biomass). High residue cover in the furrow and/or long furrow lengths decrease the total runoff, TSS, and TSS-C. The positive sign of b for DOC, soluble P, and NH_4^+ export indicates that increased biomass in the furrow increases the export of these variables. The values of the parameters apply to our experimental conditions (constant inflow rate and slope). The general format of the model illustrates the expected effects of field length and biomass residue for each variable.

4. Conclusions

The data of this study showed that biomass residue in the furrows increases infiltration, and this affects total load of constituents in runoff, such as dissolved organic carbon (DOC), sediment, and sediment-associated C. Even though biomass residue releases DOC into the irrigation water, infiltration of the irrigation water stores the solutes in the soil profile. Biomass residue increases the water residence time in the furrow and thus the infiltration opportunity time. This study also showed that irrigated fields are likely sinks of DOC. Because even though well water contains DOC, net storage of DOC occurs during irrigation. Net storage of DOC did not occur in the short (92 m) field because most of the applied water ran off. In contrast to DOC, most sediment (TSS) and C associated with sediment are lost if well water, containing little sediment, is used for irrigation. Thus, in the present study, irrigation led to a loss of sediment and TSS-C, and the presence of biomass residue in sufficiently high quantity reduced these losses by increasing the water residence time in the furrows, which presumably led to deposition of TSS within the furrow. Increasing field length also decreased TSS and TSS-C losses, probably by increasing the opportunity time for sediment to settle. Other studies showed that irrigation can increase sediment and the C balance in the irrigated field because the irrigation water can contain significant amounts of sediment [45]. This is apparently the case when canal water is used to irrigate. It would seem that a redistribution of sediment and C occurs as surface runoff water is recirculated at the water district level.

An important conclusion from the present and other studies is that DOC, C, and sediment loss due to irrigation will likely be a loss from agricultural fields as runoff is exported via ditches to streams and rivers. However, the presence of biomass residue that affects irrigation efficiency was only partially evaluated in this research work. The fact that the waterfront in any treatment residue did not reach the end of the long (274 m) field implies that other factors, such as low initial soil moisture, played a role at this site. Our results are useful because the data demonstrate the relationships between management and field length on DOC, C, and sediment storage and transport processes that are of critical concern in the San Francisco Bay Delta and other agricultural regions in California.

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References

[1] N. Cynthia, R. Ebel A Borchers, and F. Carriazo, "Major uses of land in the United States—2007," Economic Information Bulletin EIB-89, USDA, 2011.

[2] US Environmental Protection Agency (USEPA), National water quality inventory: 2000 report to congress. EPA841-R-02-001. Office of Water, August, 2002.

[3] R. J. Godwin, *Agricultural Engineering in Development: Tillage for Crop Production in Areas of Low Rainfall*, FAO, Rome, Italy, 1990.

[4] K. N. Potter, H. A. Torbert, and J. E. Morrison Jr., "Tillage and residue effects on infiltration and sediment losses on vertisols," *Transactions of the American Society of Agricultural Engineers*, vol. 38, no. 5, pp. 1413–1419, 1995.

[5] J. E. Gilley, "Tillage effects on infiltration, surface storage, and overland flow," in *Soil, Water Conservation Society, Farming for a Better Environment*, pp. 46–47, Ankeny, Iowa, USA, 1995.

[6] D. McGarry, B. J. Bridge, and B. J. Radford, "Contrasting soil physical properties after zero and traditional tillage of an alluvial soil in the semi-arid subtropics," *Soil and Tillage Research*, vol. 53, no. 2, pp. 105–115, 2000.

[7] J. Guérif, G. Richard, C. Dürr, J. M. Machet, S. Recous, and J. Roger-Estrade, "A review of tillage effects on crop residue management, seedbed conditions and seedling establishment," *Soil and Tillage Research*, vol. 61, no. 1-2, pp. 13–32, 2001.

[8] D. R. Mailapalli, W. W. Wallender, M. Burger, and W. R. Horwath, "Effects of field length and management practices on dissolved organic carbon export in furrow irrigation," *Agricultural Water Management*, vol. 98, no. 1, pp. 29–37, 2010.

[9] CTIC (Conservation Tillage Information Center), *Crop Residue Management Executive Summary*, Conservation Technology Information Center, West Lafayette, Ind, USA, 1998.

[10] P. W. Unger, B. A. Stewart, J. F. Parr, and R. P. Singh, "Crop residue management and tillage methods for conserving soil and water in semi-arid regions," *Soil and Tillage Research*, vol. 20, no. 2–4, pp. 219–240, 1991.

[11] R. L. Blevins and W. W. Frye, "Conservation Tillage: an ecological approach to soil management," *Advances in Agronomy*, vol. 51, pp. 33–78, 1993.

[12] S. F. Wright, J. L. Starr, and I. C. Paltineanu, "Changes in aggregate stability and concentration of glomalin during tillage management transition," *Soil Science Society of America Journal*, vol. 63, no. 6, pp. 1825–1829, 1999.

[13] M. J. Brown, "Effect of grain straw and furrow irrigation stream size on soil erosion and infiltration," *Journal of Soil & Water Conservation*, vol. 40, no. 4, pp. 389–391, 1985.

[14] M. J. Brown and W. D. Kemper, "Using straw in steep furrows to reduce soil erosion and increase dry bean yields," *Journal of Soil and Water Conservation*, vol. 42, no. 3, pp. 187–191, 1987.

[15] R. D. Berg, "Straw residue to control furrow erosion on sloping, irrigated cropland," *Journal of Soil & Water Conservation*, vol. 39, no. 1, pp. 58–60, 1984.

[16] D. E. Smika and P. W. Unger, "Effect of surface residues on soil water storage," *Advances in Soil Science*, vol. 5, pp. 111–138, 1986.

[17] T. M. McCalla and T. J. Army, "Stubble mulch farming," *Advances in Agronomy*, vol. 13, pp. 125–196, 1961.

[18] J. J. Bond and W. O. Willis, "Soil water evaporation: long-term drying as influenced by surface residue and evaporation potential," *Soil Science Society America Journal*, vol. 35, pp. 984–987, 1971.

[19] S. D. Logsdon and T. C. Kaspar, "Tillage influences as measured by ponded and tension infiltration," *Journal of Soil and Water Conservation*, vol. 50, no. 5, pp. 571–575, 1995.

[20] M. A. Arshad, A. J. Franzluebbers, and R. H. Azooz, "Components of surface soil structure under conventional and no-tillage in northwestern Canada," *Soil and Tillage Research*, vol. 53, no. 1, pp. 41–47, 1999.

[21] B. C. Ball, M. V. Cheshire, E. A. G. Robertson, and E. A. Hunter, "Carbohydrate composition in relation to structural stability, compactibility and plasticity of two soils in a long-term experiment," *Soil and Tillage Research*, vol. 39, no. 3-4, pp. 143–160, 1996.

[22] W. J. Gale, C. A. Cambardella, and T. B. Bailey, "Root-derived carbon and the formation and stabilization of aggregates," *Soil Science Society of America Journal*, vol. 64, no. 1, pp. 201–207, 2000.

[23] H. Bossuyt, K. Denef, J. Six, S. D. Frey, R. Merckx, and K. Paustian, "Influence of microbial populations and residue quality on aggregate stability," *Applied Soil Ecology*, vol. 16, no. 3, pp. 195–208, 2001.

[24] F. Ghidey and E. E. Alberts, "Residue type and placement effects on decomposition: field study and model evaluation," *Transactions of the American Society of Agricultural Engineers*, vol. 36, no. 6, pp. 1611–1617, 1993.

[25] B. Singh, D. S. Chanasyk, W. B. McGill, and M. P. K. Nyborg, "Residue and tillage management effects on soil properties of a typic cryoboroll under continuous barley," *Soil and Tillage Research*, vol. 32, no. 2-3, pp. 117–133, 1994.

[26] A. J. Franzluebbers, "Water infiltration and soil structure related to organic matter and its stratification with depth," *Soil and Tillage Research*, vol. 66, no. 2, pp. 197–205, 2002.

[27] C. A. Campbell, V. O. Biederbeck, G. Wen, R. P. Zentner, J. Schoenau, and D. Hahn, "Seasonal trends in selected soil biochemical attributes: effects of crop rotation in the semiarid prairie," *Canadian Journal of Soil Science*, vol. 79, no. 1, pp. 73–84, 1999.

[28] C. A. Campbell, G. P. Lafond, V. O. Biederbeck, G. Wen, J. Schoenau, and D. Hahn, "Seasonal trends in soil biochemical attributes: effects of crop management on a Black Chernozem," *Canadian Journal of Soil Science*, vol. 79, no. 1, pp. 85–97, 1999.

[29] J. C. Franchini, F. J. Gonzalez-Vila, F. Cabrera, M. Miyazawa, and M. A. Pavan, "Rapid transformations of plant water-soluble organic compounds in relation to cation mobilization in an acid Oxisol," *Plant and Soil*, vol. 231, no. 1, pp. 55–63, 2001.

[30] C. S. Dominy and R. J. Haynes, "Influence of agricultural land management on organic matter content, microbial activity and aggregate stability in the profiles of two oxisols," *Biology and Fertility of Soils*, vol. 36, pp. 298–305, 2002.

[31] H. Kok and J. Thien, "Crop residue conservation and tillage management software," *Journal of Soil Water Conservation*, vol. 49, pp. 551–553, 1994.

[32] D. E. Stott, L. F. Elliott, R. I. Papendick, and G. S. Campbell, "Low temperature or low water effects on microbial decomposition of wheat residue," *Soil Biology and Biochemistry*, vol. 18, no. 6, pp. 577–582, 1986.

[33] M. M. Roper, "Straw decomposition and nitrogenase activity (C_2H_2 reduction): effects of soil moisture and temperature," *Soil Biology and Biochemistry*, vol. 17, no. 1, pp. 65–71, 1985.

[34] H. H. Schomberg, J. L. Steiner, and P. W. Unger, "Decomposition and nitrogen dynamics of crop residues: residue quality and water effects," *Soil Science Society of America Journal*, vol. 58, no. 2, pp. 372–381, 1994.

[35] P. L. Brown and D. D. Dickey, "Losses of wheat straw residue under simulated field conditions," *Soil Science Society America Journal*, vol. 34, no. 1, pp. 118–121, 1970.

[36] C. L. Douglas, R. R. Allmaras Jr., P. E. Rasmussen, R. E. Ramig, and N. C. Roager Jr., "Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest," *Soil Science Society America Journal*, vol. 44, no. 4, pp. 833–837, 1980.

[37] V. Gaillard, C. Chenu, and S. Recous, "Carbon mineralisation in soil adjacent to plant residues of contrasting biochemical quality," *Soil Biology and Biochemistry*, vol. 35, no. 1, pp. 93–99, 2003.

[38] C. Poll, J. Ingwersen, M. Stemmer, M. H. Gerzabek, and E. Kandeler, "Mechanisms of solute transport affect small-scale abundance and function of soil microorganisms in the detritusphere," *European Journal of Soil Science*, vol. 57, no. 4, pp. 583–595, 2006.

[39] J. L. Steinera, H. H. Schomberga, P. W. Ungerb, and J. Cresapb, "Crop residue decomposition in no-tillage small-grain fields," *Soil Science Society of America Journal*, vol. 63, no. 6, pp. 1817–1824, 1999.

[40] D. R. Mailapalli, N. S. Raghuwanshi, R. Singh, G. H. Schmitz, and F. Lennartz, "Spatial and temporal variation of manning's roughness coefficient in furrow irrigation," *Journal of Irrigation and Drainage Engineering*, vol. 134, no. 2, pp. 185–192, 2008.

[41] APHA (American Public Health Association), "Method 5310-C," in *Standard Methods For the Examination of Water and wasteWater*, 20th edition, 1998.

[42] J. Murphy and J. P. Riley, "A modified single solution method for the determination of phosphate in natural waters," *Analytica Chimica Acta*, vol. 27, pp. 31–36, 1962.

[43] J. C. Forster, "Soil nitrogen," in *Methods in Applied Soil Microbiology and Biochemistry*, K. Alef and P. Nannipieri, Eds., pp. 79–87, Academic Press, San Diego, Calif, USA, 1995.

[44] T. A. Doane and W. R. Horwáth, "Spectrophotometric determination of nitrate with a single reagent," *Analytical Letters*, vol. 36, no. 12, pp. 2713–2722, 2003.

[45] R. M. Poch, J. W. Hopmans, J. W. Six, D. E. Rolston, and J. L. McIntyre, "Considerations of a field-scale soil carbon budget for furrow irrigation," *Agriculture, Ecosystems and Environment*, vol. 113, no. 1–4, pp. 391–398, 2006.

[46] A. P. King, K. J. Evatt, J. Six, R. M. Poch, D. E. Rolston, and J. W. Hopmans, "Annual carbon and nitrogen loadings for a furrow-irrigated field," *Agricultural Water Management*, vol. 96, no. 6, pp. 925–930, 2009.

[47] D. R. Mailapalli, W. R. Horwath, W. W. Wallender, and M. Burger, "Infiltration, runoff, and export of dissolved organic carbon from furrow-irrigated forage fields under cover crop and no-till management in the arid climate of california," *Journal of Irrigation and Drainage Engineering*, vol. 138, no. 1, pp. 35–42, 2011.