Reduced Tillage in an Irrigated Potato Rotation

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Introduction

Soil erosion continues to be a threat to agricultural productivity worldwide, with soil losses in the United States exceeding 3 billion tons annually. Wind and water erosion have caused dramatic declines in soil productivity. Erosion protection and associated conservation of nutrients, organic matter, soil water holding capacity and biota are significant concerns. Pimentel et al. (1995) estimated the annual total on- and off-site costs of erosion to be over $44 billion. The type of cultivation, hilling and harvesting practices for potato production may increase soil erosion (Auerswald et al., 2006; Ruysshaert et al., 2006) injure potatoes, increase soil compaction (Perrone and Madramootoo, 1994) and bring weed seeds to the soil surface (Eberlein et al., 1997). Despite these undesirable effects of cultivation, 86% of U.S. potato acreage is cultivated for weed control (USDA, 1999).

Conservation tillage is an umbrella term used to describe a range of tillage practices that can reduce soil degradation and soil loss through erosion (Carter et al., 2007). A number of approaches have been developed for small grain and forage production systems, but few have been developed for potato production systems. Growers who have implemented conservation tillage generally do so for two basic reasons: 1) to improve soil and water conservation and 2) to reduce costly inputs and increase profits. Limitations to adoption of conservation tillage in many cropping systems have been poor crop stands due to cool soils, disease and pest problems, poor soil-seed contact, poor weed control, inability to manage crop residues, inability to incorporate fertilizers and pesticides and cost to replace existing equipment. Success of conservation tillage in specialty crop (vegetable) production systems is dependent on adoption of effective weed control strategies, modifications to nutrient delivery, and insect and disease management (Morse, 1999).

Reduced tillage (RT) has had limited testing in potato production (Dallyn and Fricke, 1974; Grant and Epstein, 1973; Hoyt and Monks, 1996; Lanfranconi et al., 1993; Liebman et al., 1996; Mundy et al., 1999; Wallace and Bellinder, 1991). Problems encountered in RT systems have been reduced crop yield, difficulty in planting, difficulty in controlling weeds, increases in weed pressure, and difficulty in harvest. Modern herbicides have largely overcome the inability to manage weeds with reduced cultivation in potatoes. Commercial potato planters, hilling equipment, and reservoir tillage equipment are not designed to handle large amounts of crop residues. Hyde, et al. (1974) in the Pacific Northwest, USA, modified a potato planter capable of handling large amounts of residue that resulted in less soil disturbance during planting. They reported that problems encountered during harvest ranged from none to severe depending on the amount of residue, and the time between harvest and planting. Early harvests had enough un-decomposed residues to cause a problem, while there were few problems with late harvested potatoes. Yields of reduced tillage potatoes equaled or exceeded yields of conventionally planted potatoes, ranging from 54 - 87 Mg ha^{-1}.

Increasing concern about the sustainability of irrigated crop production systems and environmental quality has emphasized the need to develop and implement management strategies that maintain and protect soil, water and air resources. Understanding how soils respond to potato management requires an assessment of changes in key soil properties (Carter et al., 2007). Gregorich et al. (1997) suggested that soil organic matter, particulate organic matter and microbial biomass were good indicators to track changes in soil quality. Soil organic matter, microbial diversity and microbial biomass and activity are known to increase greatly in the surface layer of soils under reduced tillage compared with conventional inversion tillage (Paustian et al., 1997; Honeycutt et al., 1995). Tillage affects the amount of soil organic matter (SOM) buildup in two fundamental ways, (1) through the physical disturbance and mixing of soil and the exposure of soil aggregates to disruptive forces and (2) through controlling the incorporation and distribution of plant residues in the soil profile. Carter et al. (2005) found that total and particulate organic matter C increased and soil bulk density decreased following implementation of conservation tillage in a 3-year rotation. Griffin and Porter (2004), Grandy et al. (2002), and Porter et al. (1999) found that although short-term changes in rotation crop did not alter soil total C and N pools, the annual or intermittent application of organic amendments preferentially enriched the more labile pools of C and N in soil.

The objective of this research was to determine the effect of reduced (RT) and conventional tillage (CT) on soil chemical, biological and physical properties of an irrigated sweet corn – sweet corn – potato (*Zea mays* – *Zea mays* – *Solanum tuberosum*) rotation. Results presented represent changes that have occurred in yields and soil properties after one complete cycle (2004 – 2007) of the three year rotation.

Materials and Methods

A field study was begun in 2003 to characterize the application of reduced tillage within a sweet corn – sweet corn – potato (*Zea mays* – *Zea mays* – *Solanum tuberosum*) rotation on a Quincy fine sand (mixed, mesic Xeric Torripsamments) soil. The study was conducted at the USDA-ARS Integrated Cropping Systems Research Field Station near Paterson, Benton County, Washington (45^o 56’ N, 119^o 29’ W; 114 m above sea level). The site was previously in a native shrub-steppe plant community that had been converted to irrigated agricultural fields in 1990. The shrub-steppe is a portion of the semi-arid, shrub- and bunchgrass-dominated region in the western United States that stretches from British Columbia, Canada, to Mexico (Rogers and Rickard, 1988).

The area is characterized by an annual precipitation of 178 mm, mostly occurring as rain/snow mix during winter months with a mean annual temperature (MAT) of 11.7 ^{o}C. Crops grown in the region require irrigation. The surface soil (0-15 cm) had a bulk density of 1.33 kg m^{-3} and 917 and 56 g kg^{-1} of sand and silt, respectively. Soil organic C and N under the native vegetation were 3.7 Mg ha^{-1} and 0.37 Mg ha^{-1}, respectively, and declined with depth.

The experiment was a strip block design with four replications established under center pivot irrigation in 2003. In-season irrigation water applied during each growing season (March – September) averaged ~ 37 ha-cm. The whole plot consisted of crop (sweet corn or potato). The sub plot was tillage [conventional tillage (CT) and reduced tillage (RT)]. During the study, potato was planted in mid March and harvested late August to early September. Sweet corn was planted at the end of April and harvested mid to late July. Pre-plant fertilizers (N, P_2O_5, K_2O, S, and B) were applied at the rates of 112, 78.4, 212.8, 3.6, and 1.12 kg ha^{-1}, respectively with a tractor using a Valmor™ spreader. Corn plots received 112 kg N ha^{-1} in-season (IS) as urea ammonium nitrate solution (UAN, 32% N) with 5 IS applications of 22.4 kg N ha^{-1} through center pivot irrigation. Potato plots received 224 kg N ha^{-1} as UAN during IS applications, receiving a total of 44.8 kg N ha^{-1}every other week. The IS applications of fertilizer started 4 weeks after potato plant emergence.

Equipment used for field preparation, planting and harvesting methods were as follows. In establishing the tillage treatments we used a Sunflower™- chisel-chopper-packer, a 13-shank bed splitter for potato hill formation, a six-row rod weeder, damer diker, six-row Harriston™ pick potato planter, and a twelve-row John Deere/Orthman™ minimum tillage corn planter. Field preparation under the CT treatment for both corn and potato consisted of two passes with the chisel-chopper-packer to incorporate the previous year's crop residue, apply pre-plant fertilizer and create a smooth seedbed. For the RT sweet corn treatment, no primary tillage was performed.

The potato and sweet corn cultivars used were Ranger Russet and Triple Super Sweet. Corn seed was directly planted into the previous year's residue with the twelve-row John Deere/Orthman™ minimum tillage corn planter. Corn was planted at a seeding rate of 67,000 seeds ha^{-1} on 76-cm row spacing in both tillage treatments. For potato, after the primary tillage, hills were formed with the bed splitter on 81-cm centers, flatted with the rod weeder and then planted. Potato seed pieces were planted to a depth of 15 cm at 25-cm spacing within the hill. The area between hills was Dammer diked™ prior to potato emergence. This reservoir tillage operation created depressions at approximately 30 cm intervals to improve water infiltration and reduced irrigation runoff. For RT potato, hills were formed in the previous year's corn residue with the 13-shank bed splitter and then directly seeded with the six-row planter. The flattening of the hills and reservoir tillage operations were omitted. Potato yield for each plot was determined from a 6 m subsample taken from the center two rows using a one-row potato digger. The remaining plot area was harvested using a commercial 3-row potato digger. Sweet corn yield was determined by hand harvesting 6 m of the two center rows. The remaining treatment area was harvested with a commercial corn combine. Potato and corn residues were determined by collecting duplicate 1 m^2 samples from each field replicate. Residues were oven dried at 60 ^{0}C, weighed, and dry matter per hectare calculated.

Soil samples (0-20 cm depth) were collected in the fall of each year. Sub-samples were used to determine gravimetric moisture content and mineral N (NH_4^+ and NO_3^-) concentrations by extracting with 1M KCl and analyzed colorimetrically using a flow-injection analyzer (QuikChem AE, Lachat Zellweger, Wisconsin). The pH of the soil (soil: DI water ratio 1:2) was measured at the end of each growing season. Soil organic C (SOC) and total N (TN) were determined by dry combustion on a LECO, CNS-2000 Elemental Analyzer (St. Joseph, MI). Soil carbonates were removed prior to analyses by dilute acid extraction.

Soil N-mineralization potential (Robertson et al., 1999) was determined by incubating four sets of 10 g soil samples from each treatment replicate in 100 mL bottles over seven weeks (49 d) at 25º C, adjusted to 70% of field capacity. Water holding capacity was determined for each treatment by a volumetric soil water method described by Elliott et al. (1994). Microbial biomass-C was estimated for soil samples using the chloroform fumigation-incubation method described by Jenkinson and Powlson (1976). Mineralizable soil C was determined during extended laboratory incubations (Zibilske, 1994). The CO_2 evolved was used to determine the size and kinetics of the functional C pools of soil at each treatment. (Collins et al., 1997; Paul et al., 1999). We estimated the size and turnover rates of each pool by curve fitting the CO_2 evolved per unit time (C_t) using a three-component first-order model: $C_t = C_a e^{-kat} + C_s e^{-kst} + C_r e^{-krt}$, the subscripts a, s, and r represent the active, slow and resistant pool respectively.

Three parameters C_a, k_a, and k_s were estimated using the non-linear regression model (NonLIN) of Systat (Systat, Inc., Evanston, IL). The slow pool (C_s) is defined as; $C_s = C_t - C_a - C_r$.

Mean residence time (MRT) is the reciprocal of the decomposition rate constant (k^{-1}) in first order rate reactions. The MRT derived from laboratory incubation at 25 °C was scaled to the mean annual temperature (MAT) by assuming a Q10 of 2 ($2^{(25-t)/10}$; where t=MAT). Acid hydrolysis was used to determine the size of the resistant C pool (C_r). The acid resistant organic C fraction is determined by refluxing soil in 6 N HCl for 18 h and C measured by dry combustion on a LECO, CNS-2000 Elemental Analyzer (LECO, Corp., St. Joseph, MI).

Results

Potato and Sweet Corn Yields

There were no significant differences in potato or sweet corn yields between tillage treatments, although there were differences among years (Table 20.1). Reducing tillage did not adversely affect potato yields, averaging 74.0 and 73.7 Mg ha^{-1} for the CT and RT, respectively.

Sweet corn yields over the 3-year rotation, averaged 25 and 23 Mg ha^{-1} for the CT and RT in the first year following potatoes, respectively, and were not significantly different. Second year sweet corn yields declined an average of 8% from first year sweet corn in CT and 15% in RT.

Table 20.1. Annual potato and sweet corn yields for conventional and reduced tillage treatments.

	Potato[†]		Sweet Corn yr1		Sweet Corn yr2	
Year	CT[‡]	RT	CT	RT	CT	RT
	------ Mg ha^{-1} ------					
2004	62.9 (4.5)[§]a	60.5 (5.6)a	22.2 (6.3)ab	23.3 (5.7)a	20.8 (3.8)a	21.1 (3.4)a
2005	84.7 (5.8)b	84.5 (5.5)b	28.0 (2.1)b	23.3 (1.8)a	21.6 (2.2)a	15.9 (5.2)a
2006	81.6 (4.7)b	81.0 (5.6)b	22.7 (2.0)a	23.1 (5.2)a	24.9 (3.3)a	20.6 (2.3)a
2007	69.2 (5.4)a	69.1 (4.4)a	26.8 (2.4)ab	23.8 (3.8)a	24.8 (4.1)a	21.0 (3.2)a
Average[¶]	**74.0 (10)**	**73.7 (11)**	**25.2 (3.4)**	**23.4 (0.3)**	**23.0 (2.1)**	**19.6 (2.5)**

[†]Marketable yield exclusive of cull tubers. Potato and Sweet corn yields expressed as fresh weight. [‡]CT- Conventional tillage; RT- Reduced tillage. [§]Values in parentheses are standard error of the mean. Values within a column followed by the same letter are not significantly different at p=0.5. [¶]Averages determined from all data with CT- conventional till (n=12) and RT- Reduced-till (n=12) treatments.

Potato and Sweet Corn Residue Yields

Biomass of potato and sweet corn residues are presented in Table 20.2. Potato vines collected just before tuber harvest averaged 2727 kg ha^{-1} among CT and RT with a range of 2250 to 3000 kg ha^{-1} during this first rotation cycle. Potato vine tissue concentrations of C and N averaged 370 and 25 g kg^{-1}, respectively, with annual C and N soil inputs following harvest of ~1000 kg C ha^{-1} and 65 kg N ha^{-1} for both CT and RT treatments. Potato vine total biomass, C and N concentration, C:N, and inputs of C and N were similar between CT and RT. First year sweet corn stover biomass averaged ~ 5450 and ~ 4900 kg ha^{-1} for CT and RT respectively, and declined 300 – 500 kg ha^{-1} for second year sweet corn. Stover C and N concentrations averaged 415 and 11.5 g kg^{-1}, respectively. Annual C inputs from sweet corn stover were twice that of potato. Annual N inputs from CT corn stover were similar to potato, but RT stover showed an 8 – 10 kg N ha^{-1} reduction compared to CT, which reduction was attributed to lower biomass production. In most years stover C:N in RT was about 6 units higher than CT, but in 2006, C:N in RT was about 14 units higher than in CT.

Table 20.2. Potato and sweet corn residue inputs from 2004 to 2007.

Year	Tillage	Residue	C	N	C-Input	N-Input	C:N
				Potato Residue Inputs			
y		kg ha^{-1}	%	%	----- kg ha^{-1} -----		
2004	CT	2588 (792)	36.3 (0.1)	2.5 (0.2)	940 (287)	65 (19)	14.7
	RT	2260 (471)	37.2 (0.3)	2.4 (0.3)	840 (174)	55 (12)	15.6
2005	CT	2953 (633)	37.3 (0.3)	2.5 (0.3)	1102 (89)	74 (16)	14.9
	RT	2990 (800)	36.8 (0.5)	2.4 (0.4)	1100 (150)	72 (19)	15.3
2006	CT	2750 (601)	38.3 (0.8)	2.6 (0.3)	1053 (230)	72 (16)	14.6
	RT	2438 (714)	36.3 (0.6)	2.4 (0.4)	885 (257)	59 (17)	15.0
2007	CT	2820 (707)	37.2 (0.4)	2.5 (0.3)	1049 (262)	70 (18)	14.9
	RT	2610 (647)	37.2 (0.6)	2.5 (0.4)	970 (240)	64 (16)	15.2
Average‡	**CT**	**2740 (664)**	**37.3 (0.5)**	**2.5 (0.3)**	**1036 (247)**	**69 (17)**	**14.9**
	RT	**2714 (717)**	**36.9 (0.5)**	**2.4 (0.6)**	**949 (242)**	**62 (16)**	**15.3**
				Year 1 Corn Stover Inputs			
2004	CT	5610 (1154)	41.9 (0.3)	1.3 (0.1)	2351 (484)	73 (15)	32.2
	RT	5015 (811)	41.2 (0.8)	1.1 (0.4)	2066 (334)	55 (9)	37.5
2005	CT	6134 (970)	42.8 (0.7)	1.7 (0.3)	2612 (415)	104 (16)	25.2
	RT	5267 (1380)	42.8 (0.9)	1.4 (0.3)	2254 (59)	74 (2)	30.6
2006	CT	4761 (908)	39.8 (0.8)	1.1 (0.2)	1895 (361)	52 (10)	36.2
	RT	4397 (890)	41.1 (1.2)	0.8 (0.1)	1807 (366)	35 (7)	51.4
2007	CT	5435 (793)	41.8 (0.7)	1.4 (0.2)	2278 (330)	76 (11)	31.0
	RT	4860 (687)	41.2 (0.9)	1.1 (0.3)	2006 (280)	54 (7)	38.9
Average‡	**CT**	**5451 (890)**	**41.4 (0.8)**	**1.2 (0.2)**	**2284 (368)**	**67 (11)**	**35.9**
	RT	**4893 (631)**	**41.6 (1.0)**	**1.1 (0.3)**	**2033 (260)**	**55 (6)**	**39.6**
				Year 2 Corn Stover Inputs			
2004	CT	5663 (755)	42.4 (0.7)	1.2 (0.4)	2401 (320)	68 (9)	35.3
	RT	5453 (759)	42.2 (1.6)	1.0 (0.2)	2301 (320)	55 (8)	42.2
2005	CT	5751 (1370)	42.9 (0.6)	1.3 (0.3)	2467 (588)	75 (18)	33.0
	RT	3985 (862)	43.2 (0.7)	1.1 (0.4)	1722 (372)	44 (9)	39.3
2006	CT	4763 (1166)	41.9 (2.3)	1.1 (0.1)	1996 (489)	52 (13)	38.1
	RT	4606 (1063)	41.2 (0.8)	0.8 (0.3)	1898 (438)	37 (9)	51.5
2007	CT	5041 (1038)	42.6 (1.1)	1.2 (0.3)	2146 (442)	60 (12)	36.4
	RT	4702 (963)	42.1 (1.4)	1.0 (0.3)	1979 (405)	47 (10)	42.8
Average‡	**CT**	**5040 (1159)**	**42.2 (1.2)**	**1.1 (0.3)**	**2253 (489)**	**56 (13)**	**39.8**
	RT	**4583 (981)**	**42.3 (1.0)**	**1.0 (0.3)**	**1975 (384)**	**46 (9)**	**43.9**

Values in parentheses are standard error of the mean. Potato and sweet corn residues expressed on a dry weight basis. ‡Averages determined from all data with CT-conventional till (n=12) and RT- Reduced-till (n=12) treatments.

Tillage Effects on Soil Characteristics

Within crop treatment, soil density was unaffected by tillage treatment (Table 20.3). Soil density showed an increase from 1.20 Mg m^{-3} in potato soils to 1.48 Mg m^{-3} in the second year of RT sweet corn. Soil pH was unaffected by treatment, averaging 6.2 among all treatments.

After the first cycle of RT in the 3-year potato rotation there were no significant differences in any of the chemical or biological parameters measured, compared to the CT system

(Table 20.3). Total N concentration averaged 0.5 mg N kg^{-1} soil and ranged from 120 – 157 g N m^{-2} but there was no difference between CT and RT. Nitrogen mineralization averaged 12.5 mg N kg^{-1} soil after 49 d of laboratory incubation in both CT and RT across this first cycle of the 3-year rotation. Concentration of SOC averaged 4.0 g kg^{-1} for the 0-20 cm soil depth increment of each crop and tillage treatment over the rotation cycle (Table 20.4). Comparisons of SOC between CT and RT adjusting for soil density show a trend for small accumulations (~ 30 - 200 g m^{-2}, within and between crops and tillage) of SOC, although still not significant due to high sample variability. Extended laboratory incubations (600 d) showed that for both CT and RT ~ 1000 mg C kg^{-1} soil of SOC was mineralized. As with SOC, soil microbial biomass was not different among tillage treatments, ranging from 150 – 195 mg C kg^{-1} soil that represented 4 – 5 % of the SOC.

Table 20.3. Soil physical, chemical and biological properties (0-20 cm) in conventional tillage and reduced tillage treatments through one rotation cycle at the USDA-ARS, Integrated Cropping Systems Research Field Station located near Paterson, Benton County, Washington.

Crop	Potato		Sweet corn y-1		Sweet corn y-2	
	CT[†]	RT	CT	RT	CT	RT
Soil density (Mg m^{-3})	1.2 (0.02)[‡]	1.2 (0.02)	1.3 (0.02)	1.3 (0.02)	1.4 (0.03)	1.5 (0.03)
pH	6.2 (0.03)	6.3 (0.05)	6.2 (0.16)	6.2 (0.05)	6.2 (0.10)	6.2 (0.05)
SOC (g kg^{-1})	4.0 (0.8)	4.0 (0.6)	4.0 (0.7)	4.0 (0.6)	4.1 (0.7)	4.1 (0.6)
SOC (g C m^{-2})	940 (200)	990 (157)	996 (176)	1045 (167)	1134 (195)	1202 (187)
C-Min. (600d) (mg CO_2-C kg^{-1} soil)	990 (150)	1014 (159)	951 (153)	942 (133)	905 (108)	1051 (110)
Ratio C-min/SOC (%)	24.5	25.4	24.1	23.6	22.2	25.8
Microbial Biomass (mg C kg^{-1} soil)	159 (11)	165 (15)	164 (15)	153 (10)	185 (15)	195 (12)
Ratio MB/SOC (%)	4.0	4.1	4.1	3.9	4.5	4.8
Total N (mg N kg^{-1} soil)	540 (20)	490 (60)	520 (40)	490 (80)	510 (10)	530 (50)
Total N (g N m^{-2})	130 (5)	121 (15)	131 (10)	130 (21)	142 (3)	157 (15)
N-mineralization[§] mg NO^3-N kg^{-1} soil	11.4 (3)	13.3 (2)	12.1 (3)	10.0 (2)	13.5 (5)	14.5 (4)
Soil C:N	7.5	8.1	7.6	8.1	8.0	7.7

[†] CT – Conventional; RT- Reduced Tillage. [‡] Values in parentheses are standard error of the mean. [§] N-mineralization based on 49-day incubation.

Table 20.4. Soil organic carbon by year, tillage and crop.

	Potato		**Sweet corn y-1**		**Sweet corn y-2**	
Year	**CT**[†]	**RT**	**CT**	**RT**	**CT**	**RT**
y	------------------------------- g kg^{-1} -------------------------------					
2004	3.9 (0.8)	3.9 (0.5)	3.6 (0.8)	3.9 (0.7)	3.9 (0.8)	4.0 (0.5)
2005	4.0 (0.8)	3.9 (0.6)	4.1 (0.4)	4.0 (0.6)	4.2 (0.5)	4.1 (0.5)
2006	4.2 (0.8)	4.2 (0.8)	4.1 (0.9)	4.0 (0.6)	4.2 (0.8)	4.1 (0.9)
Average[‡]	**4.0 (0.8)**	**4.0 (0.6)**	**4.0 (0.7)**	**4.0 (0.6)**	**4.1 (0.7)**	**4.1 (0.6)**

[†] CT- Conventional tillage; RT- Reduced tillage. [‡] Values in parentheses are standard error of the mean. [‡] Averages determined from all data with CT- conventional till (n=12) and RT- Reduced-till (n=12) treatments.

Carbon Pool Kinetics

Measurements of CO_2 from extended laboratory incubations of soil were used to determine the size and turnover of the active (C_a) and slow (C_s) functional C pools of soil organic matter. We used a double exponential pool model to describe the turnover of soil organic matter as a function of tillage. Carbon mineralized during the early stages of incubation represent the active pool that consists primarily of labile C derived from potato and sweet corn residues. Figure 20.1 shows the rates of C-mineralized during extended laboratory incubations for the CT and RT of the potato, incubations for the CT and RT of the potato, corn year 1, and corn year 2 treatments in 2005.

Analyses and curve construction were similar for the other sample years (curves not shown). The size of the C_a doubled from 125 mg kg^{-1} in 2004 to 260 mg kg^{-1} by the end of the first cycle of the rotation in 2006 (Table 20.5). The C_a pool comprised 3% of the total C with an average laboratory MRT of ~ 25 d and a field MRT of ~ 55d in 2004, compared to 6% of the total C and an average laboratory MRT of 37 days and field MRT of 90 days in 2006. There were no differences in the size of the C_a pool between tillage treatments or any crop phase in rotation in any year. There was no difference in the size of the C_s pool between tillage treatments or for any crop phase in rotation in any year. The slow pool (C_s) contained 44-46 % of the total C and had field MRTs averaging 8 y that did not significantly change from initiation of the study (Table 20.5).

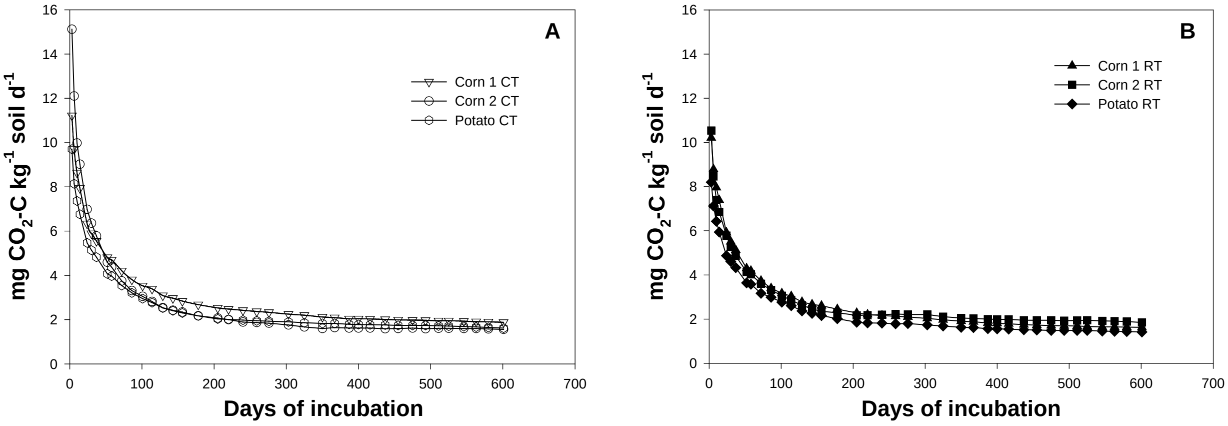

Figure 20.1. Rate of CO_2 evolution during extended laboratory incubation of soils from the conventional (A) and reduced tillage (B) treatments in a sweet corn-sweet corn-potato rotation sampled in 2005.

Table 20.5. Pool sizes and C-mineralization kinetics of soil for the active and slow C pools from the 0-20 cm depth increment of the conventional (CT) and reduced tilled (RT) treatments at USDA-ARS, Integrated Cropping Systems Research Field Station located near Paterson, Benton County, WA.

			Active Pool			Slow Pool		
Year	Crop	Tillage	C_a	Lab MRT(k_a)	Field MRT†	C_s	Lab MRT (k_s)	Field MRT†
			mg kg^{-1}	------ d ------		mg kg^{-1}	------ y ------	
2004	Potato	CT	221 (54)	35 (3)	87	1700	3.3 (1.0)	8.3
		RT	138 (37)	19 (2)	48	1782	3.1 (0.5)	7.7
	Corn 1	CT	116 (11)	19 (3)	49	1524	2.2 (0.5)	5.8
		RT	102 (8)	19 (4)	47	1788	2.4 (1.0)	6.1
	Corn 2	CT	114 (9)	24 (5)	61	1766	2.6 (0.4)	6.2
		RT	138 (37)	23 (3)	57	1862	3.4 (0.7)	8.8
	Average‡	**CT**	**125 (41)**	**23 (6)**	**58**	**1688**	**2.7 (0.6)**	**6.7**
		RT	**126 (32)**	**21 (4)**	**53**	**1810**	**3.2 (0.9)**	**8.0**
2005	Potato	CT	204 (23)	21 (4)	54	1816	3.6 (0.3)	8.7
		RT	130 (35)	19 (5)	48	1790	3.9 (0.4)	9.9
	Corn 1	CT	187 (79)	18 (5)	44	1953	2.1 (0.6)	5.8
		RT	192 (70)	19 (5)	52	1828	3.5 (0.9)	7.4
	Corn 2	CT	147 (40)	18 (4)	46	2053	3.9 (0.4)	10.1
		RT	186 (54)	15 (3)	47	1934	2.8 (0.5)	6.7
	Average	**CT**	**196 (81)**	**19 (8)**	**48**	**1924**	**3.2 (0.9)**	**8.0**
		RT	**167 (76)**	**18 (7)**	**46**	**1853**	**3.4 (0.9)**	**8.7**
2006	Potato	CT	346 (136)	51 (18)	128	1905	3.4 (0.5)	8.4
		RT	256 (54)	38 (3)	96	1944	3.4 (0.6)	8.6
	Corn 1	CT	240 (58)	34 (4)	86	1900	3.9 (0.3)	9.8
		RT	212 (54)	36 (12)	93	1810	3.8 (0.6)	9.5
	Corn 2	CT	176 (18)	28 (4)	71	2044	3.2 (0.6)	8.1
		RT	362 (96)	36 (8)	90	1758	3.0 (0.6)	7.5

Average	**CT**	**254 (92)**	**36 (9)**	**90**	**1950**	**3.4 (0.6)**	**8.4**
	RT	**264 (85)**	**37 (7)**	**93**	**1850**	**3.2 (0.7)**	**8.1**

†MRT-Mean residence times converted to field rates using a Q_{10} of 2; ($2^{(25-t)/10}$); where t=Mean annual temperature. ‡Averages determined from all data with CT- conventional till (n=12) and RT- Reduced-till (n=12) treatments. Standard errors of the mean in parentheses.

Discussion

Tillage is primarily used in potato production to control weeds, facilitate planting, and increase the ease of later cultivation and harvest (Carter et al., 2007; Eberlein et al., 1997; Hoyt and Monks, 1996). Reduced tillage has had limited testing in potato production systems under center pivot irrigation. A number of studies have been published on conservation tillage in potato in rain-fed regions of North America and Europe (Auerswald et al., 2006; Ruysshaert et al., 2006; Carter et al., 2005; Carter and Sanderson, 2001; Liebman et al., 1996; Mundy et al., 1999; Pierce and Burpee, 1995). A reduction in tillage changes the distribution of crop residues, reduces soil disturbance, and alters the decomposition rate resulting in changes in soil properties, biological activity and soil organic matter, all which have the potential to influence yield (Paustian et al., 2007).

Minor modifications to equipment and cultural practices to maintain residue cover by RT were implemented in this study. The primary pieces of equipment used include: flail chopper, Sunflower™- chisel-chopper-packer, 13 shank bed splitter mark-out implement, six-row Harriston™ pick potato planter, and twelve-row reduced tillage corn planter. Compared to CT potato systems that leave little crop residue on the soil surface, our system maximized residue retention (Figure 20.2).

Figure 20.2. Residue distribution in the reduced tillage plots following potato hilling operations prior to planting, 2005.

Within RT potato, the majority of soil disturbance resulted from the 13-shank bed splitter used in hill formation, the six-row planter and disturbance at harvest resulting from the potato digger. This strategy reduced the total number of soil disturbance operations from seven to four, including harvest, compared to those used in the conventional tilled treatments. For RT sweet corn, field operations were reduced 100% during corn years as corn seed was directly planted into the previous year's residue with the twelve-row John Deere/Orthman™ minimum tillage corn planter. Soil protection by residues observed in RT plots after a wind storm in April 2005 following emergence is shown in Figure 20.3. Note the shifting of hills in CT vs. the effect of residues on hill integrity in RT. Potato plants were damaged by the blowing sand in the CT but recovered, with minimal damage observed in RT plots.

Figure 20.3. Potato emergence from conventional tilled and reduced tilled plots. Pictures taken following a period of high winds in April, 2005.

Tillage differences did not adversely affect yield or yield parameters. Yields of potato after the first rotation cycle were not different, averaging 74.0 and 73.7 Mg ha^{-1} for the CT and RT, respectively. Alva et al. (2002a) in an earlier study on the Quincy soil type found no significant tillage effect on total or U.S. No. 1 tuber yields of two varieties (Russet Burbank and Umatilla) under CT, modified or flat planting. Since RT and CT in the current study produced similar yields RT provided added benefits of less tillage (trips across the field) and improved soil conservation as similarly reported by Carter and Sanderson (2001) and Alva et al. (2002a). By leaving a substantial cover of corn stover (~5000kg ha^{-1}) early in the potato phase of the rotation there is a potential to protect soil in the spring of the year when wind is characteristically high in the Pacific Northwest. Sweet corn yields were reduced by 15% in the 2nd year sweet corn, likely the results of secondary factors associated with the RT system and not a direct results from less tillage. Although not measured in this study we suspect a build up of N-limited soil organisms in conjunction with more surface residues in RT may have immobilized greater N and thereby reduced 2nd year sweet corn yield. Fertilizers were applied through the center pivot irrigation in small applications of 22.4 kg N ha^{-1}, which may have been intercepted by the surface stover and N immobilization exaggerated by microbial populations decomposing the residues. Additional study is necessary to confirm this hypothesis.

Compaction can be a detriment to tuber crops such as potatoes in RT at least in the short term (D'Haenne et al., 2008; Carter et al., 2005; Brussaard and van Faassen, 1994). This can be especially true of no-tillage which by definition includes only tillage needed to place and cover the seed. If a soil is compacted before the start of no-tillage, there is no mechanical intervention to alleviate the compacted soil condition. This is not the case for RT in potato cropping systems, as potato planting and potato harvest create enough disturbances to reduce compaction. Soil density increased from 1.20 g cm^{-3} in potatoes to 1.48 g cm^{-3} in the second year of sweet corn in the RT system. This higher density should be reduced in successive crop years because the RT potato treatments include the operation using the 13-shank bed splitter at hilling. The shanks of the bed splitter rip to a depth of 30 cm (12 in.) reducing compaction.

Organic C and N concentrations and microbial biomass and activity are known to increase in the surface layer of soils under reduced tillage more than under conventional inversion tillage (Paustian et al., 1997). Differences in SOM between no-till and conventional till are most extreme near the soil surface, primarily due to differences in the distribution of residue inputs. The increase in SOM under conservation tillage averages about 3000 kg ha^{-1} or 5 to 20% after 5 years for soils managed without irrigation, dependent upon soil type and the amount of initial soil organic matter (Paustian et al., 1997). After the first cycle of RT (3 y) no change in SOC has been measured.

Our study site had been irrigated and cultivated with 18 years of crops including potato, corn, and wheat prior to the establishment of this study. In that 18 years the soil organic carbon increased 30% (1.0 g kg^{-1}). Native shrub-steppe soil adjacent to the study site contains 3.0 g kg^{-1} compared to 4.0 g kg^{-1} in the plot area at the beginning of this tillage study.

After the first cycle of RT in the current 3-year potato rotation there were no significant differences in any of the chemical or biological parameters measured, compared to the CT system. Soil organic carbon still averaged 4.0 g kg^{-1}among all treatments. Statistical analyses showed a high degree of sample variability among field replicates. Standard deviations among replicates were close to 1.0 g SOC kg^{-1} soil with a coefficient of variation exceeding 50%.

Carter and Sanderson (2001) found that SOC increased 17% after 6 years of reduced tillage in a 3 year potato rotation in eastern Canada. The Canadian Charlottetown fine sandy loam soil contained 534, 280, and 165 g kg^{-1} of sand, silt and clay, respectively, and had a high degree of water stable aggregates. This contrasts to the Quincy soil with 917, 56 and 27 g kg^{-1} sand, silt and clay, respectively, and no aggregation.

Organic materials in Quincy soil undergo a high decomposition rate of residues due to adequate water applied through irrigation and a high mean annual soil temperature (11.5 ^{o}C) compared to other regions. These conditions have most likely limited C accumulation in this soil. Alva et al. (2002b) reported that potato and corn residues incorporated in the surface 30 cm of the Quincy sand soil lost 85 - 90% of their C between the months of January and September.

Potato vine and sweet corn stover annual inputs average 2700 and 5300 kg ha^{-1} with C soil inputs of 1000 and 2300 kg C ha^{-1}, respectively. Applying a 90% decomposition rate, 100 to 230 kg C ha^{-1} of the added residue C would remain after the year of incorporation. Soil physical properties of texture and aggregation are also important. Physical protection through aggregation (Jastrow et al., 1996), accumulation of particulate organic matter and the light fraction (Cambardella and Elliott, 1993; Bremer et al., 1994) and interactions with soil primary particles (Amelung et al., 1998) provide the formation of stable SOC pools that is especially important to the dynamics of the slow (C_s) carbon pool.

The measurement of CO_2 evolution from soil has been widely used to determine the effect of environmental variables on the oxidation of SOM. The C-mineralization coefficient, i.e. the percentage of total organic C evolved as CO_2, has been used to compare soils under varying management (Collins et al., 1992; Collins et al., 2000; Paul et al., 1999). The C-mineralization coefficients of CT and RT over a 600-d incubation were both ~25%. This further substantiates the rapid turnover of SOC, lack of significant difference between treatments and difficulty in sequestering C in this soil.

Long-term incubations of soil with measurements of the CO_2 evolved have been used to differentiate functional C pools in soil (Collins et al., 1997). This method constitutes a biological fractionation of organic matter, whereby the most labile fractions (C_a) are the most rapidly depleted by soil microbial activity where stable forms of soil C (C_s) are more slowly mineralized. By analyzing the CO_2 release rates, estimates for functional C pool sizes and their turnover rates were derived. There were no differences in the size of the C_a pool between tillage treatments or any crop phase in rotation in any year. There was no difference in the size of the C_s pool between tillage treatments or for any crop phase in rotation in any year. That there were no differences in turnover of the C_s pool is not surprising since SOC mineralization rates were not different among treatments.

Compared to previous studies these values of pool sizes are lower and MRT are shorter than many soils of the mid-western U.S. Balesdent et al. (1988) estimated a mean residence time of 36 years for the C_3-C in the Ap horizon in a field cropped to continuous corn for 13 years. Gregorich et al. (1995) reported an MRT of 35 years for C_3-C remaining in a forest soil cropped to continuous corn for 25 years. They further indicated that soil texture had a significant influence on the turnover of soil C. Collins et al. (2000) determined SOC pool sizes and fluxes in U.S. Corn Belt soils derived from both forest and prairie vegetation. Active pools (C_a) comprised 3 to 8% of the SOC with an average field MRT of 100 days. The slow pools (C_s) comprised 50% of SOC in the surface and up to 65% in subsoils with field MRTs of 40 to 80 years for SOC depending on soil type and location. No-till management increased the MRT 10±15 y above conventional tillage.

Mineralization of SOM plays a fundamental role in soil fertility through the release of nutrients and subsequent influence on net primary productivity. Of particular importance in conservation tillage systems is the decreased decomposition of surface residues and potential for increased immobilization of surface fertilizer N applications (broadcast or through irrigation). Where residues remain on the surface and crops are directly planted into residues of high C/N ratio, i.e. greater than 20:1, (wheat residue approximately 100:1, C:N; corn residues 50:1), the immobilization of soluble N will be greater in reduced-tilled than tilled surface soils. The distribution of crop residues, soil organic matter and soil organisms with reduced tillage management slows the cycling of N compared with conventional tillage operations until a new equilibrium is reached. Surface soil levels of organic matter, microbial biomass, and potentially mineralizable N are all significantly higher with reduced-tilled as compared with inversion tillage systems. As a result of increased residue and organic matter levels and more optimal water status, greater microbial biomass in surface reduced tillage soils is associated with greater reserves of potentially mineralizable N.

Nitrogen mineralized in a 49-day incubation corresponded to a conversion of soil organic matter N, in the surface 0-20 cm depth increment, of 31 kg N ha^{-1}, 30 kg N ha^{-1} and 40 kg N ha^{-1} for potato, 1st year sweet corn and 2nd year sweet corn, respectively, regardless of tillage. These values are similar to data reported by Alva et al. (2002b) in a study evaluating crop residue decomposition within a potato rotation in Eastern Washington State. They found that N mineralized in the field from corn, wheat and potato residues during May – September were 32, 51, and 25 kg N ha^{-1}.

Conclusion

Adopting conservation tillage to reduce erosion, increase nutrient retention, and build organic matter should improve soil and environmental quality under irrigated farming systems. The RT compared to the CT did not adversely affect crop yields, soil chemical, biological, physical properties or the turnover of soil organic C, nor did it enhance any of these parameters through the first cycle of the 3 yr rotation. This study indicates that under the soil and climatic conditions in the Pacific Northwest reduced tillage appears to be a promising form of management in high value potato production systems. As management under RT continues, C may be stabilized and sequestered in successive cycles of the rotation.

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