Soil Quality Improvement through Conversion to Sprinkler Irrigation

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Conversion from furrow to sprinkler irrigation is a recommended conservation practice for improved water-use efficiency (and erosion control), but effects on soil quality indicators are unknown. Several soil quality indicators were therefore quantified within a northwestern United States Conservation Effects Assessment Project (CEAP) watershed after changing from long-term furrow to sprinkler irrigation. Four on-farm sites were identified where producers were growing irrigated barley (*Hordecum vulgare* L.) using both irrigation practices. Climate, soil type, and management were similar between sites. Soil samples were collected from the upper and lower ends of furrow irrigated fields at three in-field positions (bed, shoulder, and furrow); fields converted to sprinkler irrigation were sampled where the upper and lower ends were when the field was furrow irrigated. Soil quality indices (physical, chemical, biological, nutrient, and overall) were computed using the Soil Management Assessment Framework (SMAF). Regardless of in-field position, furrow irrigated field bottoms had higher soil quality index scores than field tops because of long-term erosional deposition. Within sprinkler irrigated fields, soil quality indices for field tops and bottoms showed minimal differences. Overall, when all sampling locations and in-field positions were combined, soil quality was similar for both irrigation methods. However, as compared with furrow irrigation, sprinkler irrigation had greater soil quality indices in the field tops, suggesting that sprinkler irrigation improved soil quality of historically eroded furrow irrigated fields.

Abbreviations: BG, β-glucosidase; CEAP, Conservation Effects Assessment Project; EC, electrical conductivity; EQIP, environmental quality incentives program; GPS, global positiong system; PMN, potentially mineralizable N; SMAF, Soil Management Assessment Framwork; SOC, soil organic C; SQI, soil quality index; USR, Upper Snake River/Rock Creek;WSA, water-stable aggregates.

Core Ideas

- **Long-term furrow irrigation has caused soil erosional losses.**
- **Sprinkler irrigation is considered a water conservation practice.**
- **Conversion from furrow to sprinkler irrigation improves soil quality in degraded field areas.**

The 820 km^2 Upper Snake River/Rock Creek (USR) watershed in south-central Idaho, where all of the cropland is irrigated (Bjorneberg et al., 2008), is the only United States Department of Agriculture (USDA)-Agricultural Research Service CEAP watershed focused on quantifying environmental impacts of irrigated agricultural conservation practices. Since the 1990s, the United States Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) and other specialty projects have increased sprinkler irrigated acreage to approximately 40% (Richardson et al., 2008). Research within the watershed has focused primarily on water quantity and quality (i.e., improvements in sediment, N, P, and soluble salts) in response to shifts from furrow to sprinkler irrigation (Bjorneberg et al., 2008, 2002; Carter et al., 1971, 1974). Reductions in runoff and erosion are important anticipated benefits of converting to sprinkler irrigation (Bjorneberg et al., 2007), but effects of this change on soil quality indicators have not been quantified.

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The definition of soil quality (or soil health) used by the USDA-NRCS is "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" (NRCS, 2017). The concept of quantifying soil quality, based on various soil indicators, has been explored within a variety of ecosystems worldwide. In New Zealand, Stevenson et al. (2015) found that soil quality clustered under varying land use and soil orders, and that overall soil quality was mostly affected by soil organic C (SOC) and macroporosity. Rousseau et al. (2012) identified abiotic soil quality indicators, such as bulk density (ρ_b), sum of exchangeable bases, pH, and soil C content, that were able to separate cacao (*Theobroma bicolor* Humb. & Bonpl.) agroforestry systems and forest systems along a low to high soil quality gradient in Costa Rica. Tripathi et al. (2016) compared soil quality between some of India's mangrove forests and their adjacent cultivated rice (*Oryza sativa* L.) fields. The authors identified the most important soil indicators (total N, pH, electrical conductivity (EC), Cl, denitrifying bacteria population, aerobic heterotrophs, nitrite oxidizers, and urease activity), then showed that although mangrove (*Rhizophora mangle* L.) forest soils were more physically, chemically, and biologically heterogeneous, the calculated soil quality index was greater under mangrove forests as compared with cultivated rice fields. Their results suggested greater soil degradation under rice cultivation. Zhang et al. (2016) evaluated short-term flooded, seasonal flooded, and tidal flooded regions of China's Yellow River Delta using a soil quality index approach. The authors found that soil salt content, total C, Mg, NO_3–N, and total S comprised the minimum component dataset needed to successfully quantify soil quality. In Brazil, Cherubin et al. (2016) identified soil indicators (i.e., pH, SOC, available P and K, and a visual inspection of soil structure) that could be used to describe soil quality following land use change from native vegetation to pasture to sugarcane (*Saccharum officinarum* L.) production.

The aforementioned research suggests that soil quality assessment could be used to quantify land use changes, but most studies used relatively complex statistical analyses (e.g., principal component, cluster, discriminate, multivariate) followed, in some cases, by unitless indicator scoring to arrive at a final soil quality index value. For end users, it would be simpler if computer tools were in place where these more complex permutations were: either previously accounted for or analyzed in the background; where unitless values were automatically assigned to indicators based on sound and logical principles; and output produced was in an easy-to-follow format. The SMAF was designed to follow such an approach.

The SMAF provides an easy-to-use spreadsheet for indicator selection, interpretation, and integration into a series of indices (Andrews et al., 2004; Wienhold et al., 2009; Stott et al., 2010). Indicators typically include clay content, SOC, water-stable macroaggregates (WSA), microbial biomass C (MBC), potentially mineralizable N (PMN), pH, EC, extractable P and K, ρ_b, and β-glucosidase (BG) activity. Indicators are input into the SMAF, and the SMAF assigns unitless values for the indicators based on a series of pre-tested algorithms or scoring functions (e.g., more is better, optimum, less is better). For a soil quality assessment, the SMAF can generate physical, chemical, biological, and nutrient index scores. These scores can be evaluated individually or combined to produce an overall soil quality index (SQI). For more details on the SMAF, readers should see Andrews et al. (2004).

The SMAF has recently been used to identify soil quality changes because of different crop growth characteristics, soil management practices or land uses; examples include the use of SMAF under poorly and well developed corn (*Zea mays* L.; Stott et al., 2011), native pasture, pastures converted from cropland, and continuously cropped fields (Stott et al., 2013), and different annual cropping and perennial vegetation systems (Veum et al., 2015; Hammac et al., 2016). To date, however, soil quality evaluations using the SMAF have focused no attention on irrigation practices. We hypothesized that shifting from furrow to sprinkler irrigation would cause changes in physical, chemical, nutrient, and biological indicators, and thus a change in overall soil quality. This hypothesis is supported by Karlen et al. (1997) who alluded to the fact that overland flow associated with furrow irrigation can carry sediment into receiving waters, causing both on- and off-site consequences, and further supported by Trout (1996) who showed that furrow irrigation erodes soil on the field inflow end and deposits soil on the lower field end. Most topsoil has been eroded from the upper ends of many furrow irrigated fields in the USR watershed. Sprinkler irrigation, on the other hand, uniformly applies water to soil without overland flow and ends the continual erosion/deposition process. Thus, the objective for this study was to quantify changes in soil quality indicators and various indices calculated using these data for a western US CEAP watershed following the transition from furrow to sprinkler irrigation methods.

MATERIALS AND METHODS

Study Sites

Four paired producer fields were identified within the USR watershed, where each producer was growing irrigated barley (*Hordecum vulgare* L.) under both furrow and sprinkler irrigation using similar agronomic practices. Sites had been historically furrow irrigated since the early 1900s, with the conversion to sprinkler irrigation 5 to 8 yr prior to this study. All crop land is irrigated because average annual precipitation within the watershed is approximately 270 mm yr^{-1} (Bjorneberg et al., 2008). The four producers had varied rotations of the following crops: alfalfa (*Medicago sativa* L.), silage corn, dry bean (*Phaseolus vulgaris* L.), sugarbeet (*Beta vulgaris* L.), and barley. Site management between irrigation practices and between locations was similar; each producer typically utilized disking/ripping in the fall followed by roller harrowing, and grain drilling in the spring. Additional site details are presented in Table 1. Finally, it should be noted that irrigation frequency is quite different between furrow and sprinkler irrigation. For furrow irrigation, water flows in furrows for 12 or 24 h during an irrigation. Furrow irrigation

Table 1. General field characteristics of four paired producer fields within the Conservation Effects Assessment Project-Twin Falls irrigation tract, where each producer was raising irrigated barley when soil quality indicator comparisons were made.

Descriptor	Producer 1	Producer 2	Producer 3	Producer 4
Furrow irrigation				
Latitude	42° 33′44″	42° 34′43″	42° 27′56″	42° 31′7″
Longitude	114° 40′42″	114° 39′35″	114° 17′49″	114° 21′17″
Soil series and texture	Sluka silt loam	Bahem silt loam	Portneuf silt loam	Portneuf silt loam
Elevation, m	1004	1147	1252	1214
Dominant parent material	Alluvium	Alluvium and loess	Alluvium and loess	Alluvium and loess
Sprinkler irrigation				
Latitude	42° 31′14″	42° 37′23″	42° 28′6″	42° 30′52″
Longitude	114° 42′49″	114° 38′46″	114° 17′47″	114° 20′43″
Soil series and texture	Minidoka silt loam	Portneuf silt loam	Portneuf silt loam	Portneuf silt loam
Elevation, m	1232	1091	1252	1213
Dominant parent material	Alluvium and loess	Alluvium and loess	Alluvium and loess	Alluvium and loess

interval is 7 to 14 d from late May to early July. Center-pivot sprinkler irrigation applies about 20 mm of water every 3 to 7 d depending on crop water requirements.

Soil Sampling and Analyses

All sprinkler irrigated fields were historically furrow irrigated, and thus had some slope (~1%) across the terrain. Within each field, three random sampling points across the upper and lower landscape positions were identified using a global positioning system (GPS). Then, 20 soil cores were collected within a 3-m radius of each sampling site and separated into 0- to 5- and 5- to 15-cm depth increments. The same protocol was used for all furrow irrigated locations except that within the 3-m radius of the GPS location, soil samples were further separated by bed, shoulder, or furrow position. All soil samples were placed in sealed plastic bags, transported back to the laboratory, thoroughly mixed, and then separated into separate plastic bags for subsequent analyses as indicated by Karlen et al. (2014). Samples were analyzed for ρ_b, pH, EC, clay content, WSA, SOC, PMN, MBC, BG, and extractable K (K_{ext}) as outlined in Karlen et al. (2014). Soils were also analyzed for Olsen-extractable P (Olsen et al., 1954).

Soil Management Assessment Framework

The SMAF was used to calculate soil physical, chemical, biological, nutrient, and overall SQI scores based on the 11 measured soil indicators above. Briefly, SMAF runs using an Excel spreadsheet to calculate unitless scores (from 0 to 1) for each of the 11 soil indicators. The unitless scores are based on scoring curves developed for each indicator, with scoring curves based on soil taxonomy, texture, area temperature and rainfall regimes, mineralogy, slope, current crop, and method of P and EC determination (Karlen et al., 2014). The unitless scores are added together for each index and then divided by the number of indicators used to calculate a particular index. Final physical, chemical, biological, nutrient, and overall SQI are based on a scale of 0 to 1, with 0 being the worst and 1 being the best index score. A more detailed explanation of SMAF creation can be found in Andrews et al. (2004). Additional indicators can be found in Stott et al. (2010) and Wienhold et al. (2009). The current version of SMAF is available from D.E. Stott (diane.stott@in.usda.gov) or D.L. Karlen (doug.karlen@ars.usda.gov).

Statistical Analysis

Analysis of variance (ANOVA), using the Proc GLM model and a Bonferroni test significance level of $p \leq 0.05$ in SAS version 9.4 (SAS Institute, 2012), was performed on all indicator raw data (e.g., % clay content, % SOC, etc.), all indicator scores, and for the physical, chemical, biological, nutrient, and overall SQI for the 0- to 5- and 5- to 15-cm depths. The following six comparisons were made: bed vs. shoulder vs. furrow position within the top or the bottom of the furrow irrigated fields; bed or shoulder or furrow position in the top vs. bottom in the furrow irrigated fields; all positions (i.e., bed, shoulder, and furrow), top vs. bottom in furrow irrigated fields; sprinkler irrigation top vs. bottom of fields; furrow irrigated bed or shoulder or furrow position or all positions combined vs. sprinkler irrigation in the top or bottom of fields; and furrow vs. sprinkler irrigation with all data combined.

In addition, to determine whether all 11 indicators were necessary in the SMAF SQI, all indicator scores (from all furrow and sprinkler positions/locations in all producer fields) from the 0- to 5- or 5- to 15-cm depth increments were regressed against all of the overall SQI scores using multiple linear regression with forward selection, backward elimination, stepwise regression, and Akaike's Information Criteria; more detail on selection criteria can be found in Beal (2005). All statistical analyses were performed using the Proc REG model and an α of 0.05 in SAS version 9.4 (SAS Institute, 2012).

RESULTS

Soil Indicator Values

Mean indicator values for the 0- to 5- and 5- to 15-cm soil depth increments, for all site comparisons, are presented in Tables 2 and 3, respectively. In general, when significance was present in furrow irrigated fields, indicator values tended to follow furrow < shoulder < bed position in either top or bottom of the furrow irrigated fields (e.g., Olsen P top of field 0 to 5

Table 2. Soil Management Assessment Framework mean soil indicator characteristics (0- to 5-cm depth increment), analysis of variance (ANOVA), and Bonferroni test significance level at $p \leq 0.05$ (BMSD) for furrow and sprinkler irrigated soils within a western irrigated cropland Conservation Effects Assessment Project watershed.‡

Factor (0- to 5-cm depth)	Clay	SOC	WSA	MBC	pH	P	K$_{ext}$	ρ_b	EC	BG	PMN
	—%—		g kg^{-1}	mg g^{-1}		—mg kg^{-1}—		g cm^{-3}	dS m^{-1}	mg pnp§ kg^{-1} soil h^{-1}	mg g^{-1}
Furrow irrig. top of field											
Bed	16.0	0.87	34.1	336	8.12	45.8	304	1.65	0.68	110	16.0
Shoulder	15.6	0.86	31.0	283	8.26	42.6	322	1.67	0.38	94	24.3
Furrow	15.6	0.84	33.8	266	8.23	30.1	285	1.73	0.32	81	19.0
ANOVA	NS†	NS	NS	**	**	**	NS	NS	**	**	NS
BMSD				20	0.10	4.8			0.12	9	
Furrow irrig. bottom of field											
Bed	16.4	0.99	34.5	301	8.18	41.2	389	1.62	0.43	147	16.2
Shoulder	17.2	0.97	32.7	282	8.16	40.2	350	1.61	0.37	139	19.3
Furrow	17.6	0.98	27.6	249	8.21	29.9	329	1.62	0.34	126	24.4
ANOVA	*	NS	NS	*	NS	**	*	NS	**	**	*
BMSD	1.2			47		5.8	50		0.05	14	8.2
Bed top vs. bottom ANOVA	NS	**	NS	NS	NS	NS	**	NS	**	**	NS
Bed Top v bottom BMSD		0.07					35		0.16	12	
Shoulder top v Bottom ANOVA	NS	**	NS	NS	NS	NS	NS	*	NS	**	NS
Shoulder top v bottom BMSD		0.06						0.05		15	
Furrow top vs. bottom ANOVA	**	**	NS	NS	NS	NS	**	*	NS	**	NS
Furrow top vs. bottom BMSD	1.2	0.07					25	0.09		11	
All furrow irrig. locations top vs. bottom of field											
All locations top of field	15.7	0.86	33.0	294	8.20	39.5	304	1.68	0.46	95	17.8
All locations bottom of field	17.1	0.98	31.6	277	8.18	37.1	356	1.61	0.38	137	20.0
ANOVA	**	**	NS	NS	NS	NS	**	**	NS	**	NS
BMSD	0.6	0.03					31	0.04		10	
Sprinkler irrigation											
Top of field	15.9	0.81	37.7	291	8.18	20.4	249	1.67	0.35	102	16.9
Bottom of field	15.3	0.73	38.3	303	8.27	19.7	275	1.64	0.28	99	9.9
ANOVA	NS	**	NS	NS	*	NS	NS	NS	**	NS	*
BMSD		0.04			0.06				0.02		5.3
Furrow vs. sprinkler top of field											
Bed vs. sprinkler ANOVA	NS	NS	NS	NS	*	**	**	NS	**	NS	NS
Bed v sprinkler BMSD					0.06	6.4	32		0.15		
Shoulder vs. sprinkler ANOVA	NS	NS	NS	NS	*	**	NS	NS	NS	*	NS
Shoulder vs. sprinkler BMSD					0.06	2.9				7	
Furrow vs. sprinkler ANOVA	NS	NS	NS	NS	NS	**	*	**	NS	**	NS
Furrow vs. sprinkler BMSD						3.4	25	0.04		5	
All furrow vs. sprinkler ANOVA	NS	*	*	NS	NS	**	*	NS	NS	NS	NS
All furrow vs. sprinkler BMSD		0.04	4.4			6.30	50				
Furrow vs. sprinkler bottom of field											
Bed vs. sprinkler ANOVA	NS	**	NS	NS	**	**	**	NS	**	**	NS
Bed vs. sprinkler BMSD		0.02			0.04	3.1	37		0.04	6	
Shoulder vs. sprinkler ANOVA	*	**	*	NS	*	**	**	NS	**	**	**
Shoulder vs. sprinkler BMSD	1.4	0.06	4.5		0.09	7.2	42		0.04	9	4.0
Furrow vs. sprinkler ANOVA	*	**	**	**	*	**	**	NS	**	**	*
Furrow vs. sprinkler BMSD	1.9	0.06	4.4	20	0.05	4.1	25		0.03	9	9.9
All furrow vs. sprinkler ANOVA	**	**	*	NS	**	**	**	NS	**	**	*
All furrow vs. sprinkler BMSD	0.9	0.04	5.3		0.06	5.2	34		0.05	122	8.9
All top & bottom combined, furrow vs. sprinkler											
Furrow	16.4	0.92	32.3	285	8.19	38.3	330	1.65	0.42	116	19.9
Sprinkler	15.6	0.77	38.0	297	8.23	20.1	262	1.66	0.32	101	13.4
ANOVA	NS	**	**	NS	NS	**	**	NS	*	*	*
BMSD		0.04	3.7			4.22	34		0.10	14	6.3

* $p < 0.05$.

** $p < 0.01$.

† NS, not significant.

‡ SOC, soil organic C; WSA, water-stable aggregates; MBC, microbial biomass C; P, phosphorous; K$_{ext}$, extractable K; ρ_b, bulk density; EC, electrical conductivity; BG, β-glucosidase; PMN, potentially mineralizable N.

§ pnp = *p*-nitrophenol.

Table 3. Soil Management Assessment Framework mean soil indicator characteristics (5- to 15-cm depth increment), analysis of variance (ANOVA), and Bonferroni test significance level at $p \leq 0.05$ (BMSD) for furrow and sprinkler irrigated soils within a western irrigated cropland Conservation Effects Assessment Project watershed.‡

Factor (5- to 15-cm depth)	Clay	SOC	WSA	MBC	pH	P	K_{ext}	ρ_b	EC	BG	PMN
	——%——		g kg^{-1}	μg g^{-1}		——mg kg^{-1}——		g cm^{-3}	dS m^{-1}	mg pnp§ kg^{-1} soil h^{-1}	mg g^{-1}
Furrow irrig. top of field											
Bed	14.8	0.87	33.2	266	8.38	21.1	231	1.60	0.41	82	40.8
Shoulder	13.2	0.84	34.8	262	8.41	21.8	239	1.59	0.29	84	30.0
Furrow	14.3	0.79	38.4	238	8.44	18.3	244	1.63	0.28	69	39.0
ANOVA	NS†	NS	NS	NS	NS	*	NS	NS	**	*	NS
BMSD						3.1			0.07	14	
Furrow irrig. bottom of field											
Bed	17.0	0.99	33.2	261	8.28	23.4	328	1.59	0.31	129	19.4
Shoulder	15.7	0.99	32.6	258	8.24	21.2	333	1.57	0.29	127	24.9
Furrow	16.5	0.95	36.4	244	8.22	19.3	321	1.59	0.30	120	38.8
ANOVA	NS	NS	NS	NS	*	*	NS	NS	NS	NS	NS
BMSD					0.06	3.2					
Bed top vs. bottom ANOVA	*	NS	NS	NS	*	NS	**	NS	*	**	NS
Bed top vs. bottom BMSD	1.5				0.07		39		0.09	13	
Shoulder top vs. bottom ANOVA	*	**	NS	NS	**	NS	**	NS	NS	**	NS
Shoulder top vs. bottom BMSD	2.2	0.07			0.05		48			14	
Furrow top vs. bottom ANOVA	*	**	NS	NS	**	NS	**	NS	*	**	NS
Furrow top vs. bottom BMSD	1.4	0.06			0.04		40		0.02	15	
All furrow irrig. locations top vs. bottom of field											
All locations top of gield	14.1	0.83	35.5	255	8.41	20.4	238	1.61	0.33	78	36.6
All locations bottom of field	16.4	0.97	34.1	254	8.24	21.3	327	1.58	0.30	125	27.7
ANOVA	**	**	NS	NS	**	NS	**	NS	NS	**	NS
BMSD	0.9	0.04			0.03		17			7	
Sprinkler irrigation											
Top of field	16.9	0.77	34.6	265	8.22	12.2	181	1.64	0.32	89	25.5
Bottom of field	15.9	0.71	33.3	253	8.29	11.9	200	1.61	0.31	84	24.6
ANOVA	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS
BMSD					0.03						
Furrow vs. sprinkler top of field											
Bed vs. sprinkler ANOVA	NS	NS	NS	NS	**	**	NS	NS	NS	NS	NS
Bed vs. sprinkler BMSD					0.06	4.4					
Shoulder vs. sprinkler ANOVA	**	NS	NS	NS	**	**	**	NS	NS	NS	NS
Shoulder vs. sprinkler BMSD	1.9				0.08	3.6	35				
Furrow vs. sprinkler ANOVA	*	NS	NS	NS	**	**	**	NS	*	**	NS
Furrow vs. sprinkler BMSD	1.8				0.06	3.2	22		0.03	6	
All furrow vs. sprinkler ANOVA	**	*	NS	NS	**	**	**	NS	NS	*	NS
All furrow vs. sprinkler BMSD	1.4	0.06			0.05	2.4	27			10	
Furrow vs. sprinkler bottom of field											
Bed vs. sprinkler ANOVA	NS	**	NS	NS	NS	**	**	NS	NS	**	NS
Bed vs. sprinkler BMSD		0.10				5.6	23			9	
Shoulder vs. sprinkler ANOVA	NS	**	NS	NS	NS	*	**	NS	NS	**	NS
Shoulder vs. sprinkler BMSD		0.07				6.0	35			16	
Furrow vs. sprinkler ANOVA	NS	**	NS	NS	**	*	**	NS	NS	**	NS
Furrow vs. sprinkler BMSD		0.08			0.03	4.8	20			13	
All furrow vs. sprinkler ANOVA	NS	**	NS	NS	*	**	**	NS	NS	**	NS
All furrow vs. sprinkler BMSD		0.05			0.04	2.9	21			10	
All top & bottom combined, furrow vs. sprinkler											
Furrow	15.2	0.90	34.8	255	8.33	20.9	283	1.60	0.31	102	32.1
Sprinkler	16.4	0.74	34.0	259	8.25	12.0	190	1.63	0.32	86	25.0
ANOVA	NS	**	NS	NS	*	**	**	NS	NS	NS	NS
BMSD		0.06			0.06	2.3	31				

* $p < 0.05$.

** $p < 0.01$.

† NS, not significant.

‡ SOC, soil organic C; WSA, water-stable aggregates; MBC, microbial biomass C; P, phosphorous; K_{ext}, extractable K; P_b, bulk density; EC, electrical conductivity; BG, β-glucosidase; PMN, potentially mineralizable N.

§ pnp = *p*-nitrophenol.

cm: furrow = 30.1 mg kg^{-1}, shoulder = 42.6 mg kg^{-1}, and bed = 45.8 mg kg^{-1}). The bed or shoulder or furrow position in the bottom of furrow irrigated fields tended to have greater indicator values as compared with the tops of fields (only pH and ρ_b were opposite; e.g., Extractable K, 0 to 5-cm, top versus bottom of field in bed = 304 versus 389 mg kg^{-1}, respectively). Indicator values in furrow irrigated field top < field bottom when all field positions (i.e., bed, shoulder, furrow) were combined (e.g., Extractable K, 0 to 5cm, top versus bottom of field = 304 vs. 356 mg kg^{-1}, respectively).

Sprinkler irrigation did not follow the same pattern as furrow irrigation. For sprinkler irrigation, within the 0- to 5-cm depth, top of field indicator values tended to be greater than field bottom (e.g., SOC = 0.81% vs. 0.73%, respectively). Within the 5- to 15-cm depth, soil pH was the only indicator slightly greater in the bottom (8.29) compared with top (8.22) of field. Comparisons between furrow irrigation field position (bed, shoulder, or furrow) and sprinkler irrigation for either the field tops or bottoms indicated that furrow irrigation typically contained greater indicator values (e.g., 0 to 5 cm, furrow irrigated bed position top of field Olsen P = 45.8 mg kg^{-1} versus sprinkler top of field = 20.4 mg kg^{-1}). Comparisons between furrow and sprinkler irrigation, when all data per irrigation type was combined, showed that SOC, Olsen P, K_{ext}, EC, BG activity, and PMN were greater, and WSA was lower under furrow as compared with sprinkler irrigation in the 0- to 5-cm depth, and SOC, pH, Olsen P, and K_{ext} were greater under furrow irrigation as compared with sprinkler irrigation in the 5- to 15-cm depth.

Soil Indicator Scores

Indicator scores for the 0- to 5- and 5- to 15-cm soil depth increments, for all site comparisons, are presented in Tables 4 and 5, respectively. Note that clay content is not directly presented in Tables 4 and 5, as it was an indicator used for SOC score determination. In general, greater SOC, WSA, MBC, Olsen P, and K_{ext} concentrations, greater BG activity, and lower pH, ρ_b, and EC led to greater indicator scores.

When significance was present in furrow irrigated fields, the bed and shoulder positions tended to have greater indicator scores as compared with the furrow position (e.g., BG top of field 0 to 5 cm: bed = 0.24, shoulder = 0.18, furrow = 0.13). The bed or shoulder or furrow position in the bottom of furrow irrigated fields tended to have greater indicator concentrations as compared with the tops of fields (e.g., 0 to 5 cm, BG bed top = 0.24 vs. bottom = 0.41). When all field positions (bed, shoulder, and furrow) were combined, bottom of furrow irrigated fields had greater indicator scores as compared with the top end of furrow irrigated fields (e.g., 0 to 5 cm, BG top = 0.18 vs. bottom = 0.37).

When significance was present in the sprinkler irrigated fields, field tops had greater SOC (0 to 5 cm) and pH indicator scores (0–5 and 5–15 cm), and a lower K_{ext} indicator score (5 to 15 cm) than field bottoms (e.g., 0 to 5 cm, SOC top = 0.30 vs. bottom = 0.25).

Comparisons between furrow irrigation field position (bed, shoulder, or furrow) and sprinkler irrigation for the field tops indicated that sprinkler irrigation had greater indicator scores (e.g., 0 to 5-cm, furrow irrigated bed position top of field BG = 0.24 versus sprinkler top of field = 0.19), and field bottoms indicated that furrow irrigation had greater indicator scores (e.g., 0 to 5-cm, furrow irrigated bed position bottom of field BG = 0.41 versus sprinkler bottom of field = 0.19). Comparisons between furrow and sprinkler irrigation, when all data per irrigation type was combined, showed that furrow irrigated fields had greater SOC and BG indicator scores (0 to 5 and 5 to 15 cm) and lower WSA (0 to 5 cm) and pH (5 to 15 cm) indicator scores as compared with sprinkler irrigation.

Soil Quality Indices

The SQIs for the 0- to 5- and 5- to 15-cm soil depths, for the all site comparisons, are presented in Table 6. When significance was present in the furrow irrigated fields, the bed position had greater physical (top of field 0 to 5 cm) and nutrient (top and bottom of field 0 to 5 and 5 to 15 cm) SQIs as compared with the furrow position, while the furrow position had a greater soil chemical quality index score as compared with the shoulder positions (top of field 0 to 5 and bottom of field 5 to 15 cm). The bed or shoulder or furrow position in furrow irrigated field bottoms tended to have greater overall SQIs as compared with the field tops (e.g., 0 to 5-cm, bed field top = 0.65, bed field bottom = 0.71). When all field positions (bed, shoulder, and furrow) were combined, the bottom of furrow irrigated fields had greater biological, nutrient, and overall SQIs as compared with furrow irrigated field tops (e.g., 0 to 5 cm, top overall SQI = 0.65, field bottom = 0.70).

When significance was present in the sprinkler irrigated fields, field tops only had a greater chemical SQI (0 to 5 cm) as compared with sprinkler irrigated field bottoms.

Comparisons between furrow irrigation field position (bed, shoulder, or furrow) and sprinkler irrigation for the field tops indicated that sprinkler irrigation had greater overall SQIs (e.g., furrow irrigation furrow position = 0.64, sprinkler = 0.68), and field bottoms indicated that furrow irrigation had greater overall SQIs (e.g., furrow irrigation furrow position = 0.69, sprinkler = 0.64). Comparisons between furrow and sprinkler irrigation, when all data per irrigation type was combined, indicated no difference in overall SQIs in the 0- to 5-cm depth, a greater chemical quality index for sprinkler irrigated fields, and greater biological and overall SQIs in the 5- to 15-cm depth.

DISCUSSION

Due to the nature of soil quality, it has been suggested that only variations of soil parameters with regard to soil or land management should be compared to identify which soil parameters could be suggested as indicators of soil quality (Letey et al., 2003). This argument is supported by the contention that assessing soil quality between sites is likely influenced by many factors, including climate, soil type, crop, and management practice

Table 4. Mean Soil Management Assessment Framework scores (0.00 to 1.00; greater is better) for soil quality indicators (0- to 5-cm depth increment), analysis of variance (ANOVA), and Bonferroni test significance level at $p \leq 0.05$ (BMSD) for furrow and sprinkler irrigated soils within a western irrigated cropland Conservation Effects Assessment Project watershed.‡

Factor (0- to 5-cm depth)	SOC score	WSA score	MBC score	pH score	P score	K score	ρ_b score	EC score	BG score	PMN score
Furrow irrig. top of field										
Bed	0.35	0.94	0.90	0.05	1.00	1.00	0.36	0.91	0.24	0.75
Shoulder	0.34	0.91	0.94	0.03	1.00	1.00	0.31	1.00	0.18	0.75
Furrow	0.33	0.92	0.97	0.04	0.96	1.00	0.28	1.00	0.13	0.79
ANOVA	NS †	NS	NS	**	**	NS	NS	**	**	NS
BMSD				0.01	0.01			0.04	0.04	
Furrow irrig. bottom of field										
Bed	0.46	0.93	0.98	0.04	1.00	1.00	0.37	1.00	0.41	0.89
Shoulder	0.44	0.93	0.97	0.04	1.00	1.00	0.39	1.00	0.37	0.84
Furrow	0.45	0.86	0.98	0.04	0.96	1.00	0.38	1.00	0.33	0.91
ANOVA	NS	NS	NS	NS	**	NS	NS	NS	**	NS
BMSD					0.01				0.06	
Bed top vs. bottom ANOVA	**	NS	NS	*	NS	NS	NS	**	**	NS
Bed top vs. bottom BMSD	0.06			0.01				0.05	0.06	
Shoulder top vs. bottom ANOVA	**	NS	NS	NS	NS	NS	*	NS	**	NS
Shoulder top vs. bottom BMSD	0.06						0.06		0.08	
Furrow top vs. bottom ANOVA	**	NS	NS	NS	NS	NS	**	NS	**	NS
Furrow top vs. ottom BMSD	0.06						0.03		0.03	
All furrow irrig. locations top vs. bottom of field										
All locations top of field	0.34	0.92	0.94	0.04	0.99	1.00	0.32	0.97	0.18	0.76
All locations Bottom of field	0.45	0.91	0.98	0.04	0.99	1.00	0.38	1.00	0.37	0.88
ANOVA	**	NS	NS	NS	NS	NS	**	NS	**	NS
BMSD	0.03						0.05		0.04	
Sprinkler irrigation										
Top of field	0.30	0.97	1.00	0.04	0.99	1.00	0.35	1.00	0.19	0.92
Bottom of field	0.25	0.97	1.00	0.03	0.97	1.00	0.35	1.00	0.19	0.67
ANOVA	**	NS	NS	*	NS	NS	NS	NS	NS	NS
BMSD	0.03			0.01						
Furrow vs. sprinkler top of field										
Bed vs. sprinkler ANOVA	NS	NS	NS	NS	NS	NS	NS	**	*	NS
Bed vs. sprinkler BMSD								0.05	0.04	
Shoulder vs. sprinkler ANOVA	NS	NS	NS	*	NS	NS	*	NS	NS	NS
Shoulder vs. sprinkler BMSD				0.01			0.03			
Furrow vs. sprinkler ANOVA	NS	NS	NS	NS	*	NS	**	NS	**	NS
Furrow vs. sprinkler BMSD					0.03		0.03		0.01	
All furrow vs. sprinkler ANOVA	*	*	NS	NS	NS	NS	NS	NS	NS	NS
All furrow vs. sprinkler BMSD	0.03	0.04								
Furrow vs. sprinkler bottom of field										
Bed vs. sprinkler ANOVA	**	NS	NS	**	**	NS	NS	NS	**	NS
Bed vs. sprinkler BMSD	0.02			0.01	0.01				0.03	
Shoulder vs. sprinkler ANOVA	**	NS	NS	*	**	NS	*	NS	**	NS
Shoulder vs. sprinkler BMSD	0.05			0.01	0.01		0.03		0.05	
Furrow vs. sprinkler ANOVA	**	**	NS	*	NS	NS	NS	NS	**	NS
Furrow vs. sprinkler BMSD	0.04	0.05		0.01					0.03	
All furrow vs. sprinkler ANOVA	**	*	NS	*	NS	NS	NS	NS	**	NS
All furrow vs. sprinkler BMSD	0.04	0.06		0.01					0.06	
All top & bottom combined, furrow vs. sprinkler										
Furrow	0.39	0.92	0.96	0.04	0.99	1.00	0.35	0.99	0.28	0.82
Sprinkler	0.28	0.97	1.00	0.03	0.98	1.00	0.35	1.00	0.19	0.80
ANOVA	**	**	NS	NS	NS	NS	NS	NS	**	NS
BMSD	0.04	0.04							0.07	

* $p < 0.05$.

** $p < 0.01$.

† NS, not significant.

‡ SOC, soil organic C; WSA, water-stable aggregates; MBC, microbial biomass C; P, phosphorous; K_{ext}, extractable K; P_b, bulk density; EC, electrical conductivity; BG, β-glucosidase; PMN, potentially mineralizable N.

Table 5. Mean Soil Management Assessment Framework scores (0.00 to 1.00; greater is better) for soil quality indicators (5- to 15-cm depth increment), analysis of variance (ANOVA), and Bonferroni test significance level at $p \leq 0.05$ (BMSD) for furrow and sprinkler irrigated soils within a western irrigated cropland Conservation Effects Assessment Project watershed.‡

Factor (5- to 15-cm depth)	SOC score	WSA score	MBC score	pH score	P score	K score	ρ_b score	EC score	BG score	PMN score
Furrow irrig. top of field										
Bed	0.35	0.94	0.89	0.02	0.84	0.96	0.34	1.00	0.14	0.94
Shoulder	0.33	0.94	0.99	0.02	0.90	0.97	0.35	1.00	0.15	0.96
Furrow	0.30	0.96	0.98	0.02	0.74	0.95	0.32	1.00	0.10	1.00
ANOVA	NS †	NS	NS	NS	**	NS	NS	NS	NS	NS
BMSD					0.09					
Furrow irrig. bottom of field										
Bed	0.46	0.93	0.98	0.03	0.95	1.00	0.38	1.00	0.33	1.00
Shoulder	0.45	0.93	0.99	0.03	0.90	1.00	0.39	1.00	0.32	1.00
Furrow	0.42	0.96	0.98	0.03	0.81	1.00	0.41	1.00	0.31	1.00
ANOVA	NS	NS	NS	NS	**	NS	NS	NS	NS	NS
BMSD					0.04					
Bed top vs. bottom ANOVA	NS	NS	NS	*	*	**	NS	NS	**	NS
Bed top vs. bottom BMSD				0.01	0.07	0.02			0.04	
Shoulder top vs. bottom ANOVA	**	NS	NS	**	NS	NS	NS	NS	**	NS
Shoulder top vs. bottom BMSD	0.07			0.01					0.08	
Furrow top vs. bottom ANOVA	**	NS	NS	**	**	**	NS	NS	**	NS
Furrow top vs. bottom BMSD	0.04			0.01	0.02	0.01			0.06	
All furrow irrig. locations top vs. bottom of field										
All locations top of field	0.32	0.95	0.95	0.02	0.83	0.96	0.33	1.00	0.13	0.96
All locations bottom of field	0.44	0.94	0.99	0.03	0.89	1.00	0.39	1.00	0.32	1.00
ANOVA	**	NS	NS	NS	**	**	NS	NS	**	NS
BMSD	0.03				0.01	0.01			0.03	
Sprinkler Irrigation										
Top of field	0.25	0.96	0.99	0.03	0.78	0.95	0.30	1.00	0.13	1.00
Bottom of Field	0.23	0.96	0.99	0.02	0.82	0.97	0.32	1.00	0.13	1.00
ANOVA	NS	NS	NS	**	NS	**	NS	NS	NS	NS
BMSD				0.01		0.01				
Furrow vs. sprinkler top of field										
Bed vs. sprinkler ANOVA	NS	NS	NS	**	NS	NS	NS	NS	NS	NS
Bed vs. sprinkler BMSD				0.01						
Shoulder vs. sprinkler ANOVA	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
Shoulder vs. sprinkler BMSD				0.01						
Furrow vs. sprinkler ANOVA	NS	NS	*	**	NS	NS	NS	NS	**	NS
Furrow vs. sprinkler BMSD			0.02	0.01					0.02	
All furrow vs. sprinkler ANOVA	*	NS	NS	**	NS	NS	NS	NS	NS	NS
All furrow vs. sprinkler BMSD	0.05			0.01						
Furrow vs. sprinkler bottom of field										
Bed vs. sprinkler ANOVA	**	NS	NS	NS	NS	**	NS	NS	**	NS
Bed vs. sprinkler BMSD	0.07					0.01			0.03	
Shoulder vs. sprinkler ANOVA	**	NS	NS	NS	NS	**	NS	NS	**	NS
Shoulder vs. sprinkler BMSD	0.06					0.01			0.08	
Furrow vs. sprinkler ANOVA	**	NS	NS	**	NS	**	NS	NS	**	NS
Furrow vs. sprinkler BMSD	0.06			< 0.01		0.01			0.05	
All furrow vs. sprinkler ANOVA	**	NS	NS	*	NS	**	NS	NS	**	NS
All furrow vs. sprinkler BMSD	0.04			< 0.01		< 0.01			0.04	
All top & bottom combined, furrow vs. sprinkler										
Furrow	0.38	0.94	0.97	0.02	0.86	0.98	0.36	1.00	0.22	0.98
Sprinkler	0.24	0.96	0.99	0.03	0.80	0.96	0.31	1.00	0.13	1.00
ANOVA	**	NS	NS	*	NS	NS	NS	NS	**	NS
BMSD	0.04			< 0.01					0.06	

* $p < 0.05$.

** $p < 0.01$.

† NS, not significant.

‡ SOC, soil organic C; WSA, water-stable aggregates; MBC, microbial biomass C; P, phosphorous; K_{ext}, extractable K; ρ_b, bulk density; EC, electrical conductivity; BG, β-glucosidase; PMN, potentially mineralizable N.

Table 6. Mean Soil Management Assessment Framework physical, chemical, biological, nutrient, and overall soil quality index (SQI) scores (0.00 to 1.00; greater is better; 0- to 5- and 5- to 15-cm depth increments), analysis of variance (ANOVA), and Bonferroni test significance level at $p \leq 0.05$ (BMSD) for furrow and sprinkler irrigated soils within a western irrigated cropland Conservation Effects Assessment Project watershed.

Factor	Physical SQI score	Chemical SQI score	Biological SQI score	Nutrient SQI score	Overall SQI score	Physical SQI score	Chemical SQI score	Biological SQI score	Nutrient SQI score	Overall SQI score
	0- to 5-cm depth					5- to 15-cm depth				
Furrow irrig. top of field										
Bed	0.65	0.48	0.56	1.00	0.65	0.64	0.51	0.58	0.90	0.64
Shoulder	0.61	0.52	0.55	1.00	0.65	0.65	0.51	0.60	0.94	0.66
Furrow	0.60	0.52	0.56	0.98	0.64	0.64	0.51	0.59	0.84	0.63
ANOVA	*	**	NS †	**	NS	NS	NS	NS	**	NS
BMSD	0.05	0.02		0.01					0.07	
Furrow irrig. bottom of field										
Bed	0.65	0.52	0.68	1.00	0.71	0.66	0.51	0.69	0.97	0.70
Shoulder	0.66	0.52	0.66	1.00	0.70	0.66	0.51	0.69	0.95	0.70
Furrow	0.62	0.52	0.67	0.98	0.69	0.68	0.52	0.68	0.90	0.69
ANOVA	NS	NS	NS	**	NS	NS	*	NS	**	NS
BMSD				< 0.01			< 0.01		0.02	
Bed top vs. bottom ANOVA	NS	**	*	NS	*	NS	NS	*	*	*
Bed top vs. bottom BMSD		0.02	0.10		0.04			0.10	0.05	0.05
Shoulder top vs. bottom ANOVA	NS	NS	*	NS	**	NS	**	**	*	**
Should. Top vs. bottom BMSD			0.09		0.03		< 0.01	0.02	0.01	0.01
Furrow top vs. bottom ANOVA	NS	NS	**	NS	**	NS	**	**	**	**
Furrow top vs. bottom BMSD			0.04		0.01		< 0.01	0.01	0.01	0.02
All furrow irrig. locations top vs. bottom of field										
All locations top of field	0.62	0.50	0.56	0.99	0.65	0.64	0.51	0.59	0.89	0.65
All locations Bottom of field	0.65	0.52	0.67	0.99	0.70	0.67	0.51	0.69	0.94	0.70
ANOVA	NS	NS	**	NS	**	NS	**	**	*	**
BMSD			0.04		0.02		< 0.01	0.03	0.04	0.02
Sprinkler irrigation										
Top of field	0.66	0.52	0.60	0.99	0.68	0.63	0.52	0.60	0.91	0.65
Bottom of field	0.66	0.51	0.53	0.99	0.64	0.63	0.51	0.59	0.91	0.65
ANOVA	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
BMSD		0.01								
Furrow vs. sprinkler top of field										
Bed vs. sprinkler ANOVA	NS	**	NS	NS	NS	NS	**	NS	NS	NS
Bed vs. sprinkler BMSD		0.02					< 0.01			
Shoulder vs. sprinkler ANOVA	*	NS	NS	NS	NS	NS	**	NS	NS	NS
Shoulder vs. sprinkler BMSD	0.04						< 0.01			
Furrow vs. sprinkler ANOVA	*	NS	NS	*	*	NS	**	NS	*	*
Furrow vs. sprinkler BMSD	0.05			0.01	0.03		< 0.01		0.04	0.01
All furrow vs. sprinkler ANOVA	NS	NS	NS	NS	*	NS	**	NS	NS	NS
All furrow vs. sprinkler BMSD					0.03		< 0.01			
Furrow vs. sprinkler bottom of field										
Bed vs. sprinkler ANOVA	NS	**	*	**	*	NS	NS	**	*	**
Bed vs. sprinkler BMSD		< 0.01	0.11	0.01	0.05			0.03	0.06	0.02
Shoulder vs. sprinkler ANOVA	NS	NS	**	**	**	NS	NS	**	NS	*
Shoulder vs. sprinkler BMSD			0.08	0.01	0.03			0.04		0.04
Furrow vs. sprinkler ANOVA	NS	NS	**	NS	**	NS	NS	**	NS	*
Furrow vs. sprinkler BMSD			0.08		0.03			0.03		0.03
All furrow vs. sprinkler ANOVA	NS	*	**	NS	**	NS	NS	**	NS	**
All furrow vs. sprinkler BMSD		0.01	0.06		0.02			0.02		0.02
All top & bottom combined, furrow vs. sprinkler										
Furrow	0.67	0.63	0.51	0.61	0.99	0.65	0.51	0.64	0.92	0.67
Sprinkler	0.66	0.66	0.52	0.56	0.99	0.63	0.52	0.60	0.91	0.65
ANOVA	NS	NS	NS	NS	NS	NS	*	*	NS	*
BMSD							< 0.01	0.04		0.02

* $p < 0.05$.

** $p < 0.01$.

† NS, not significant.

(Stott et al., 2011). Fortunately, in the current study all soils were relatively similar in terms of climate, parent material, soil texture, crops, and management style, and thus should allow for soil quality comparisons between irrigation methods.

Soil Indicator Values and Scores

Letey et al. (2003) suggested that analyzing and indexing undifferentiated soil samples could lead to erroneous soil quality conclusions, and that soil management should be used as a basis for sustainable farming practices. With the soil management concept in mind and under the currently used soil quality framework, soil samples were obtained and compared between the bed, shoulder, and furrow positions within furrow irrigated fields (i.e., a form of soil management in the context of Letey et al. [2003]). Results showed that bed and/or shoulder indicator concentrations were typically greater when compared with the furrow position, which is the area that is saturated during each irrigation. These results, however, did not always translate to greater indicator scores. For example, furrow irrigation causes particle detachment and soil surface erosional losses, and in arid locations as in the current study, can lead to exposure of more calcareous (i.e., greater soil pH) B horizons in field tops and soil deposition in field bottoms (e.g., Trout, 1996; Carter et al., 1985). It has also long been known that furrow irrigation can cause soluble salts to accumulate in shoulder or bed positions because of capillary rise (Richards, 1954). Greater pH values, as observed in the 0- to 5-cm shoulder and furrow positions, and greater EC values as observed in the 0- to 5- and 5- to 15-cm bed position, led to lower indicator scores for both these constituents in the top and bottom of furrow irrigated fields. Obviously, understanding and proper sampling within soil management zones not only supports the contention of Letey et al. (2003), but will ensure that soil quality characterization is performed properly.

Furrow irrigated field tops have eroded, depositing soils in field bottoms. Carter et al. (1985) estimated a top of field soil loss of 20 to 30 cm over an 80-yr period because of furrow irrigation within the USR watershed. In the current study, erosional deposition was evident via the observed increase in clay content, SOC, K_{ext}, and BG activity within either the 0- to 5- and/or 5- to 15-cm depth increments. Subsequently, greater indicator scores in furrow irrigated field bottoms versus tops was observed, regardless of position (i.e., bed, shoulder, or furrow, or all combined). Zobeck et al. (2015) observed a similar response in soil quality, with greater water erosional losses leading to reduced soil quality. However, others have not observed soil quality differences due to landscape position under differing practices such as agroforestry and agroforestry buffers (Weerasekara et al., 2016; Paudel et al., 2011).

Unlike furrow irrigated conditions, sprinkler irrigated field tops and bottoms showed only subtle differences between indicator concentrations in the 0- to 5- and 5- to 15-cm depths. Furthermore, indicator scores favored the top of the sprinkler irrigated fields as compared with position in the top of furrow irrigated fields (the opposite was observed for field bottoms regardless of soil depth). The effects of furrow irrigation erosion, along with the possible reduction in soil erosion under sprinkler irrigation, have likely caused these differences (e.g., greater clay content under top of field sprinkler as compared with furrow irrigated bed, shoulder, or furrow position). This suggests that, over time, changing to sprinkler irrigation may improve soil quality by reducing in-field differences induced by long-term furrow irrigation.

The above findings suggest that in addition to considering soil management as a response variable for soil quality, indirect effects of soil management need also to be considered. This is especially evident when combining and comparing between all sprinkler and all furrow field tops and bottoms. As compared with sprinkler irrigation, furrow irrigation overall tended to have greater 0- to 5- and 5- to 15-cm indicator values. This, however, did not translate to greater indicator scores under furrow irrigation, suggesting that disregarding within-field position or location comparisons could lead to erroneous assumptions regarding system soil health.

Soil Quality Indices

Only subtle index differences were present when comparing furrow irrigation bed, shoulder or furrow positions in the top or bottom of fields. However, when comparing position in the top versus bottom, it was apparent that furrow irrigation field bottoms always had greater index scores. Again, this was likely because of long-term soil erosional losses from field tops and soil deposition in field bottoms leading to greater indices. As shown by Carter et al. (1985), greater SQI scores at field bottoms can be correlated with greater crop yields than at field tops. The link between erosional losses, deposition gains, crop yield increases or decreases, and soil quality, is plausible.

Index differences were almost nonexistent between sprinkler irrigated field tops and bottoms. However, indices were always greater in top of the field sprinkler irrigation as compared with furrow irrigated bed, shoulder, or furrow positions, while the opposite was observed for field bottoms. These findings negated one another when all data were combined and compared between furrow and sprinkler irrigation; no index differences were present in the 0- to 5-cm depth, while furrow irrigation had greater biological and overall soil quality indices in the 5- to 15-cm depth. As previously stated, these findings suggest that direct and indirect effects of soil management need to be considered when quantifying soil quality under furrow or sprinkler irrigation. What may be considered a conservation practice leading to good soil quality may not always lead to desired outcomes (Andrews et al., 2002) as in the case when comparing all data combined from sprinkler- with furrow-irrigated fields.

Indicator Selection

To identify those indicators that best explain differences between furrow and sprinkler irrigation, all indicator scores were regressed against all of the overall soil quality index scores via multiple linear regression using forward selection, backward elimination, stepwise regression, and Akaike's Information

Criteria. Within the 0- to 5-cm depth, all four selection criteria suggested that all indicators, except test K, were necessary in the SQI determination (data not shown). Within the 5- to 15-cm depth, forward, backward, and stepwise analysis suggested that all indicators except soil pH and EC were needed for soil quality determination, while Akaike's Information Criteria suggested that only EC could be excluded. Dropping soil-test K, pH, or EC from the soil analysis regime could save laboratory time, but those three soil tests are not laborious relative to some other SMAF soil tests. Thus, the majority of indicators currently included in the SMAF should likely be used to make an accurate assessment of soil quality under irrigated management systems similar to those in the current study.

CONCLUSIONS

Effects of furrow or sprinkler irrigation were studied from a soil quality standpoint. Soil chemical, biological, nutrient, and overall soil quality were greater within the bottom as compared with the top of furrow irrigated fields, suggesting erosional effects, top of field soil degradation, and bottom of field soil deposition. Under sprinkler irrigation, soil quality was similar between field tops and bottoms, suggesting that previously long-term top-of-field furrow irrigation degradation may be beneficially altered after conversion to sprinkler irrigation. Soil quality comparisons between sprinkler and furrow irrigation suggested that sprinkler irrigation had greater soil physical, chemical, nutrient, and overall soil quality indices as compared with furrow irrigation within field tops, while soil chemical, biological, nutrient, and overall soil quality indices were greater under furrow irrigation within field bottoms. These findings support the above conclusions regarding soil erosion, deposition, and beneficial alterations based on irrigation type. Our findings suggest that soil quality can be improved after switching from furrow to sprinkler irrigation, yet understanding the direct and indirect effects of soil management and sampling location are paramount to enhanced understanding of soil quality changes under varying irrigation methods.

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