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Residual zinc improves soil health, productivity and grain quality of rice in conventional and conservation tillage wheat-based systems

Faisal Nadeem[A], *Muhammad Farooq*[A,B,C,F], *Basit Mustafa*[A], *Abdul Rehman*[D] *and Ahmad Nawaz*[E]

[A]Department of Agronomy, University of Agriculture, Faisalabad 38040, Pakistan.

[B]Department of Crop Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud 123, Oman.

[C]The UWA Institute of Agriculture, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia.

[D]Department of Crop Science and Biotechnology, Dankook University, Chungnam, Republic of Korea.

[E]College of Agriculture, Bahauddin Zakariya University, Bahadur Sub-Campus Layyah, Punjab, Pakistan.

[F]Corresponding author. Email: farooqcp@gmail.com

Supplementary tables

Table S1. Analysis of the variance for the influence of Zn application in the wheat planted in conventional and conservation tillage on the soil health after rice harvest in wheat-based production systems

Sources of variation	DF	Total soil organic matter				Soil organic carbon			
		2017		2018		2017		2018	
		0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Replication	3	0.00075	0.00114	0.00095	0.00003	0.024	0.089	0.00422	0.00351
Wheat tillage-Zn (WT-Zn)	7	0.00699**	0.00039ns	0.00258**	0.00353**	2.122**	0.057ns	0.20057**	0.00214ns
Error	21	0.00030	0.00072	0.00041	0.00027	0.070	0.081	0.00078	0.00135
Rice production systems (RPs)	1	0.00766**	0.00031ns	0.00226**	0.00701**	0.146ns	0.034ns	0.17851**	0.04463**
WT-Zn × RPs	7	0.00040ns	0.00026ns	0.00041ns	0.00035ns	0.024ns	0.055ns	0.00715**	0.00249ns
Error	24	0.00038	0.00060	0.00026	0.00029	0.106	0.140	0.00069	0.00143
Total	63								

DF = Degree of freedom; ns = non-significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$

Table S2. Analysis of the variance for the influence of Zn application in the wheat planted in conventional and conservation tillage on the soil health after rice harvest in wheat-based production systems

Sources of variation	DF	Soil microbial biomass nitrogen				Soil microbial biomass carbon			
		2017		2018		2017		2018	
		0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Replication	3	7.42	7.22	16.62	31.30	272.83	98.85	6.06	205.31
Wheat tillage-Zn (WT-Zn)	7	8.96ns	17.26**	59.17**	284.30*	2423.93**	58.17ns	300.42**	434.66**
Error	21	7.00	2.20	8.04	104.37	365.81	75.06	5.68	66.59
Rice production systems (RPs)	1	1089.00**	511.89**	612.56**	791.01**	45.56ns	1406.25**	576.00**	1147.52**
WT-Zn × RPs	7	1.68ns	4.10ns	68.24**	22.37ns	115.42ns	19.36ns	189.78**	26.16ns
Error	24	6.14	7.78	5.78	107.82	596.56	108.34	4.56	59.58
Total	63								

DF = Degree of freedom; ns = non-significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$

Table S3. Analysis of the variance for the influence of Zn application in the wheat planted in conventional and conservation tillage on the soil nutrient concentration after rice harvest in wheat-based production systems

Sources of variation	DF	Total nitrogen		Available phosphorus		Exchangeable potassium		Zinc	
		2017	2018	2017	2018	2017	2018	2017	2018
Replication	3	0.00016	0.00152	0.725	0.411	23.65	162.29	0.00063	0.00911
Wheat tillage-Zn (WT-Zn)	7	0.00135**	0.00328ns	0.143ns	0.292ns	8.52ns	16.46ns	0.00789**	0.00589**
Error	21	0.00035	0.00167	0.435	0.186	6.86	25.83	0.00066	0.00111
Rice production systems (RPs)	1	0.00879**	0.01381**	0.523ns	0.589*	16.69ns	30.25ns	0.00083ns	0.00090ns
WT-Zn × RPs	7	0.00085ns	0.00066ns	0.173ns	0.056ns	11.58ns	9.46ns	0.00039ns	0.00046ns
Error	24	0.00042	0.00124	0.525	0.135	11.98	40.60	0.00043	0.00150
Total	63								

DF = Degree of freedom; ns = non-significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$

Table S4. Analysis of the variance for the influence of Zn application in the wheat planted in conventional and conservation tillage on the chlorophyll content index and grain/straw Zn concentration of rice harvest in wheat-based production systems

Sources of variation	DF	Chlorophyll content index		Grain Zn concentration		Straw Zn concentration	
		2017	2018	2017	2018	2017	2018
Replication	3	0.81	0.39	3.15	12.53	0.264	0.734
Wheat tillage-Zn (WT-Zn)	7	11.31ns	11.63ns	32.20**	22.56**	21.949**	1.354ns
Error	21	5.38	18.90	1.08	5.22	0.313	1.074
Rice production systems (RPs)	1	0.49ns	7.28ns	0.96ns	2.39ns	0.008ns	0.024ns
WT-Zn × RPs	7	6.78ns	14.14ns	1.24ns	0.88ns	0.160ns	0.232ns
Error	24	5.08	14.35	1.12	10.62	0.464	0.856
Total	63						

DF = Degree of freedom; ns = non-significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$

Table S5. Analysis of the variance for the influence of Zn application in the wheat planted in conventional and conservation tillage on the grain quality of rice harvest in wheat-based production systems

Sources of variation	DF	Grain protein		Amylose		Carbohydrate		Chalkiness	
		2017	2018	2017	2018	2017	2018	2017	2018
Replication	3	0.552	0.294	5.34	28.74	9.39	1.63	0.0039	0.0039
Wheat tillage-Zn (WT-Zn)	7	0.794**	1.197*	14.08**	18.91*	5.63ns	9.52ns	0.0037**	0.0050ns
Error	21	0.223	0.469	4.48	7.02	5.50	9.23	0.0004	0.0024
Rice production systems (RPs)	1	0.985*	3.124*	8.79ns	1.69ns	2.50ns	3.62ns	0.1650**	0.1387**
WT-Zn × RPs	7	0.025ns	0.049ns	1.85ns	1.60ns	5.40ns	3.82ns	0.0002ns	0.0005ns
Error	24	0.170	0.621	3.24	8.62	5.30	16.71	0.0011	0.0020
Total	63								

DF = Degree of freedom; ns = non-significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$

Table S6. Analysis of the variance for the influence of Zn application in the wheat planted in conventional and conservation tillage on the yield related attributes of rice harvest in wheat-based production systems

Sources of variation	DF	Total tillers		Productive tillers		Spikelets per panicle		Kernels per panicle	
		2017	2018	2017	2018	2017	2018	2017	2018
Replication	3	315.10	349.52	1314.71	352.64	1.00	19.87	16.37	4.87
Wheat tillage-Zn (WT-Zn)	7	184.60*	129.02ns	2148.36**	814.17**	3.48ns	9.32ns	19.63**	58.03**
Error	21	72.09	84.39	509.05	99.73	2.44	8.23	5.72	2.57
Rice production systems (RPs)	1	5402.25**	264.06*	7140.25**	40.64ns	8.48*	0.06ns	196.35**	162.56**
WT-Zn × RPs	7	66.79	15.95ns	1113.50ns	35.21ns	4.49ns	5.99ns	9.72ns	8.38*
Error	24	257.76	57.34	525.09	51.55	1.90	20.66	6.95	3.15
Total	63								

DF = Degree of freedom; ns = non-significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$

Table S7. Analysis of the variance for the influence of Zn application in the wheat planted in conventional and conservation tillage on the grain yield and related attributes of rice harvest in wheat-based production systems

Sources of variation	DF	Panicle sterility		1000-grain weight		Grain yield		Biological yield		Harvest index	
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Replication	3	2.25	2.25	0.81	3.12	0.017	0.021	1.04	0.08	23.60	5.40
Wheat tillage-Zn (WT-Zn)	7	17.00**	11.35**	2.61ns	2.17ns	1.232**	0.380**	1.94ns	2.43**	7.61ns	82.85**
Error	21	2.33	3.35	1.18	1.13	0.121	0.008	0.99	0.55	6.34	5.14
Rice production systems (RPs)	1	540.56**	484.00**	10.49**	0.02ns	2.037**	0.088*	149.78**	0.44ns	49.46**	0.82ns
WT-Zn × RPs	7	6.09ns	8.17ns	1.39ns	0.33ns	0.041ns	0.041*	1.08ns	0.32ns	8.42	5.58ns
Error	24	3.65	5.40	0.66	1.18	0.131	0.014	0.89	0.29	4.46	
Total	63										

DF = Degree of freedom; ns = non-significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$

Table S8. Influence of Zn application in the wheat planted in conventional and conservation tillage on the yield related attributes of rice harvest in wheat-based production systems

Zinc application methods in wheat tillage systems	2017			2018		
	PuTR	DSAR	Mean (WT-Zn)	PuTR	DSAR	Mean (WT-Zn)
	Total tillers (m^{-2})					
PTW-C	308	319	314D	307	313	310
PTW-SA	306	326	316CD	311	318	314
PTW-FA	309	327	318BCD	315	321	318
PTW-SP	307	331	319A-D	309	309	309
NTW-C	315	332	324ABC	316	319	317
NTW-SA	319	333	326AB	320	322	321
NTW-FA	313	341	327A	312	314	313
NTW-SP	313	330	321A-D	310	317	314
Mean (RPs)	311B	330A		313B	317A	
LSD (p 0.05)	WT-Zn = 8.82; RPs = 8.28			RPs = 3.90		
	Productive tillers (m^{-2})					
PTW-C	255	274	264C	260	257	258DE
PTW-SA	312	309	310A	279	282	280AB
PTW-FA	310	293	301AB	264	262	263CDE
PTW-SP	295	305	300AB	258	256	257E
NTW-C	257	303	280BC	266	270	268CD
NTW-SA	301	328	315A	284	287	285A
NTW-FA	281	320	301AB	273	274	273BC
NTW-SP	269	317	293AB	268	277	273BC
Mean (RPs)	285B	306A		269	270	
LSD (p 0.05)	RPs = 11.82; WT-Zn = 23.46			WT-Zn = 10.38		
	Kernels per panicle					
PTW-C	87	89	88C	80i	84efg	82E
PTW-SA	89	94	92A	87cd	90ab	88B
PTW-FA	86	91	89C	82gh	87cde	84CD
PTW-SP	88	92	90ABC	81hi	87cd	84CD
NTW-C	89	89	89C	84fg	83gh	83DE
NTW-SA	88	95	92A	89bc	92a	90A
NTW-FA	91	93	92AB	83gh	86de	85CD
NTW-SP	88	90	89BC	84efg	86def	85C
Mean (RPs)	88	92		84B	87A	
LSD (p 0.05)	WT-Zn = 2.48			RPs = 0.91; WT-Zn = 1.66; RPs × WT-Zn = 2.59		

Interaction and main effect sharing the same letter for a parameter during an experimental year do not differ significantly at $p \leq 0.05$; WT-Zn = Zn application in wheat tillage systems; RPs = Rice production systems; PuTR = Puddled transplanted rice; DSAR = Direct seeded aerobic rice; PTW-C = Plough till wheat without Zn application; PTW-SA = Plough tillage wheat with soil applied Zn; PTW-FA; Plough tillage wheat with foliage applied Zn; PTW-SP = Plough tillage wheat with Zn seed priming; NTW-C = No till wheat without Zn application; NTW-SA = No tillage wheat with soil applied Zn; NTW-FA; No tillage wheat with foliage applied Zn; NTW-SP = No tillage wheat with Zn seed priming; *NS* = non-significant

Table S9. Influence of Zn application in the wheat planted in conventional and conservation tillage on the harvest index and chlorophyll content index of rice harvest in wheat-based production systems

Zinc application methods in wheat tillage systems	2017			2018			2017			2018		
	PuTR	DSAR	Mean (WT-Zn)	PuTR	DSAR	Mean (WT-Zn)	PuTR	DSAR	Mean (WT-Zn)	PuTR	DSAR	Mean (WT-Zn)
	Harvest index (%)						Chlorophyll content index					
PTW-C	29.20	28.55	28.87	31.03	30.42	30.72D	30.97	28.45	29.71	34.09	32.06	33.07
PTW-SA	28.68	30.27	29.48	37.35	35.39	36.37AB	33.46	31.28	32.37	36.18	35.79	35.99
PTW-FA	29.25	32.49	30.87	30.54	28.44	29.49D	27.87	29.45	28.66	31.46	34.34	32.90
PTW-SP	27.63	32.30	29.97	30.32	30.64	30.48D	28.31	31.16	29.74	33.33	31.93	32.63
NTW-C	30.42	29.01	29.71	32.55	33.87	33.21C	29.03	28.53	28.78	32.96	33.87	33.41
NTW-SA	30.80	32.40	31.60	37.12	39.79	38.45A	30.26	31.09	30.67	31.86	36.92	34.39
NTW-FA	30.63	32.19	31.41	34.85	35.86	35.35BC	29.22	29.40	29.31	35.22	32.94	34.08
NTW-SP	29.09	32.55	30.82	34.80	35.96	35.38BC	29.16	30.33	29.75	30.90	33.55	32.23
Mean (RPs)	29.46B	31.22A		33.57	33.79		29.78	29.96		33.25	33.92	
LSD (p 0.05)	RPs = 1.09			WT-Zn = 2.35				*NS*			*NS*	

Interaction and main effect sharing the same letter for a parameter during an experimental year do not differ significantly at $p \leq 0.05$; WT-Zn = Zn application in wheat tillage systems; RPs = Rice production systems; PuTR = Puddled transplanted rice; DSAR = Direct seeded aerobic rice; PTW-C = Plough till wheat without Zn application; PTW-SA = Plough tillage wheat with soil applied Zn; PTW-FA; Plough tillage wheat with foliage applied Zn; PTW-SP = Plough tillage wheat with Zn seed priming; NTW-C = No till wheat without Zn application; NTW-SA = No tillage wheat with soil applied Zn; NTW-FA; No tillage wheat with foliage applied Zn; NTW-SP = No tillage wheat with Zn seed priming; *NS* = non-significant