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Integrating Effects of Applied Zn with Organic Amendments for Enhanced Maize and Wheat Yields at Two Diverse Calcareous Soils

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Abstract

Organic amendments need different management strategies and integration with chemical fertilizers for maximum benefits. The influence of various organic amendments in Zn nutrition was evaluated in two diverse calcareous soils. Amendments including FYM, PM and BC were applied at 20 t ha^{-1} with 0, 3 and 6 kg Zn ha^{-1} to maize-wheat cropping system in low limed Charsadda (6.6 % $CaCO_3$) and high limed Peshawar (16.6% $CaCO_3$) soils. Growth and grain yields of first season maize and succeeding wheat crop increased with increase in Zn levels and amendments with relatively higher response in Peshawar than in Charsadda soil that may be attributed to initially lower fertility status of Peshawar soil. The application of Zn with amendments also significantly increased the grain Zn and postharvest soil [Zn] in both soils. Among amendments, PM showed better performance in increasing crop growth and yields in both locations followed by FYM in maize but in succeeding wheat the biochar became more effective withstanding statistically at par to both PM and FYM. This increasing promising effect of BC with time reveals its slower but long lasting effects in crop production. FYM and BC required relatively higher amounts of Zn than PM and as such integration of 3 kg Zn ha^{-1} with PM, and 6 kg Zn ha^{-1} with FYM and BC is recommended for enhanced crop production. Furthermore more, the application of BC is recommended for long lasting results but its initial higher cost may hinder its application at large scale.

Key words: Organic amendments, zinc, plant growth, calcareous soil

Introduction

Zn, one of the essential elements involved in metabolic and enzymatic functions of plants, animals and human beings (Singh *et al*., 2005; Hotz and Brown, 2004) has been reported deficient and causing one of a major risk factors in disease susceptibility both at global and regional level (Ezzati *et al*., 2002). Zinc content in soil ranges from 10 to 300 mg kg^{-1} with an average value of 50 mg kg^{-1} (Kiekens, 1995). The occurrence of widespread Zn deficiency in plants and ultimately in human beings is due to a number of soil factors; low Zn content of soils, high pH, low organic matter, calcareousness, salt affected soils, highly weathered and coarse textured soils (Singh *et al*., 2005) and environmental factors including arid, semiarid (Cakmak *et al*., 2001) and tropical climatic condition of the world (Lopes, 1980). Modern crop species/ varieties have low levels of micronutrients and Zn as compared to indigenous (Khush, 2001; Cakmak, 2002). Because for their full yield potential new varieties require more nutrients due to their fast growing and high yielding qualities. As a result, these new varieties depleted the soil for these essential micronutrients like Zn which are already less available in soil. Organic amendments due to their variable mineralization, immobilization and adsorption capabilities need different management strategies and integration with chemical fertilizers for maximum benefits. In addition to nutrient release upon decomposition, organic materials solubilize the metals through chelation (Lindsay, 1974) and increase Zn availability to plants (Moraghan and Mascagni, 1991). As such the amount of Zn application varies with amendment type and soil properties. This research was conducted to evaluate Zn availability to maize and wheat crops in two diverse calcareous soils amended with Farm Yard Manure (FYM), Poultry Manure (PM) and Biochar (BC) and levels of $ZnSO_4$.

Materials and Methods

Characteristics of the Selected Soils and Organic Amendments

Before the establishment of the experiment, composite soil samples from both soil sites i.e. high limed Peshawar and low limed Charsadda were collected, air dried, passed through a 2 mm sieve and analyzed for important soil characteristics such as soil texture, pH, ECe, total nitrogen mineral nitrogen, available P,K, organic matter, and available zinc. Soil pH was determined in soil water suspensions (1:5) using a pH meter (Thomas, 1996). The same solutions prepared for pH were used for the determination of electrical conductivity. It was determined in soil water suspensions (1:5) using the Electrical Conductivity meter WTW Germmany (Rhoades, 1996). Soil organic matter content was determined according to Walkley-Black method (Nelson and Sommers, 1982). The AB DTPA-Zn in soil was determined in 1:2 soil solution suspensions (Soltanpour**,** 1985) by atomic absorption Perkin Elmer 2380 as described by Baker and Shur (1982).

The Research Farm of The University of Agriculture, Peshawar had strongly calcareous soil (16.6 % lime) and belonged to Peshawar soil series [Piedmont alluvium, silty clay loam, Ustochrept] having 0-5 % slope. Charsadda site, was a farmer's field in village Gulabad, district Charsadda. The soil in the area was moderately calcareous (6.6 % lime) and belonged to Guliana soil series having 0-1% slope (Table 3). Soils in both areas had semiarid condition and were irrigated by canal surface water. The Peshawar received water from uplift canal from Kabul River whereas the Charasadda soils received water from lower Swat Canal system. Initial Zn levels in Peshawar (0.8 mg kg^{-1}) was deficient and lower than Charsadda soils (1.12 mg kg^{-1}). However, AB-DTPA Extractable soil Zn from 0.9 to 1.5mgkg^{-1} (Soltanpour, 1985) falls in the medium range and the plant still expected to highly respond to Zn application.

Prior to experiment the manure used i.e. FYM, (BC), and (PM) were analyzed for nutrients concentration. Biochar is a name for charcoal when it is used for particular purposes, especially as a soil amendment and easily available in market. Farmyard manure was collect from Agricultural University Research Farm. Poultry manure was collected from poultry farm of the university. Chemical composition of these organic sources was determined in laboratory as given it each respective section. Soil total nitrogen was determined by the method of Bremner (1996). AB-DTPA extractable Phosphorus was determined in soil as described by Soltonpour and Schawab (1977). AB-DTPA extractable K was determined with the help of Perken-Elmer flame photometer. Micronutrients i.e. Zn, Cu and Fe of these organic sources were analyzed on atomic absorption spectrophotometer Perkin Elmer 2380 (Baker and Amacher 1982) in 1:2 soil solution suspensions (Soltanpour**,** 1985) after digestion with HNO_3: $HClO_4$ (3:1) (Benton *et al*., 1991) and filtration of digested solution. Biochar had comparatively lower NPK (Nitrogen-Phosphorus-Kalium) and micronutrients Zn, Cu and Fe than poultry manure and farmyard manure (Table 2). FYM had higher N and K than PM but was inferior to PM in term of P and micronutrient concentration. As such the PM could be regarded rich source of P and micronutrients whereas the FYM could be good sources of N and K.

Table 1. Pre sowing soil properties of experimental sites

Soils	EC_e (dSm^{-1})	pH_e	SOM (%)	$CaCO_3$ (%)	soil Zn (mg kg^{-1})	Sand (%)	Silt (%)	Clay (%)	Texture
Peshawar	0.86	8.36	0.68	16.6	0.8	11	53	36	Silty clay loam
Charsadda	0.65	7.87	0.86	6.6	1.12	12	61	27	Silty clay loam

Table 2. Total NPK and micronutrients (Zn, Cu, Fe) concentrations of organic amendments

Amendment	N	P	K	Zn	Cu	Fe
	(%)	(%)	(%)	(mg kg^{-1})	(mg kg^{-1})	(mg kg^{-1})
FYM	2.13	1.23	2.86	72.4	26.0	296
PM	1.83	1.54	1.69	154	49	557
BC	0.63	0.35	2.37	21.36	15.0	218

Organic amendments (FYM, PM, BC) at the rate of 20 t ha^{-1} each in different combinations with Zinc levels (0, 3 and 6 kg ha^{-1}) were applied to maize crop at two diverse calcareous soils i.e. high limed Peshawar (16.675%) and low limed Charsadda soils (6.65%) after proper seed bed preparation and keeping suitable row to row and plant distance. The objective of the study was to assess the influence of organic amendments in enhancing the Zn nutrition in both type of the soil prevailing in the local environment. NPK was also applied with adjusted values at the rate of 150, 90 and 60 kg N, P_2O_5 and K_2O ha^{-1} respectively at both locations. Data on plant growth and yield were recorded. After the maize, the same plots were sown with wheat crop for succeeding studies. This time the wheat crop was applied only with NPK at 120:90:60 kg N, P_2O_5, K_2O ha^{-1}. Data on wheat growth and yield were recorded. Plant height of 10 plants from each treatment plot was noted with measuring rod in centimeter. Grains of both crops were weight after drying up to 12% moisture and converted to kg ha^{-1}. Zn concentration in grain was determined by digestion with HNO_3: $HClO_4$ (3:1) (Benton *et al*., 1991) and analysis of filtrate on atomic absorption spectrophotometer Perkin Elmer 2380 (Baker and Amacher 1982). The AB DTPA-Zn in soil was determined in 1:2 soil solution suspensions after filtration (Soltanpour**,** 1985). All the data were subjected to split plot analysis where the organic amendments were kept in main plots (Factor A) and Zn levels in sub-plot (Factor B) for each recorded parameter, site and season independently. Two factorial split plot RCB design was used separately for both locations and all the field and laboratory data were analyzed through ANOVA whereas LSD test was used for mean comparison (Steel and Torrie, 1984).

Result and Discussion

Plant height of maize and succeeding wheat

Plant height of maize and succeeding wheat crop increased with increase in Zn levels averaged across the amendments levels (Table 3). Highest plant height was recorded with the application of 6 kg Zn ha^{-1} over 0 kg Zn ha^{-1} in Peshawar as compared to low limed Charsadda soil. The higher response in Peshawar could be attributed to potential adsorption of Zn on lime (Karimian, and Moafpouryan, 1999). It is a fact that fertilizers response in poor soils is more than equivalent fertile soils revealing that lower the initial nutrient concentration the higher would be the expected response of added nutrient. When averaged across the Zn levels, PM produced significantly taller maize and wheat plants in both soils followed by FYM. Several researchers (Dixit and Gupta, 2000; Selvakumari *et al*., 2000; Khoshgoftarmanesh and Kalbasi, 2002) have concluded improvement of crop tallness with the use of organic materials that could be attributed to improvement in soil characteristics, vigorous root growth and optimum nutrient uptake including Zn. The comparatively higher responses of BC in wheat than first season maize indicating its slower but long lasting effect (Table 3). It may be due to biochar resistant to decomposition and its slower nutrients release as compared to PM and FYM (Lehmann et al., 2008). The long-lasting effects of BC have also been reported by Swift (2001), Lehmann (2007). The response of both Zn and amendments application was comparatively more in high limed Peshawar as compared to low limed Charsadda soil that could be associated to increase in Zn, P and other nutrients adsorption with increase in pH and $CaCO_3$ contents (Karimian, and Moafpouryan, 1999). However, on overall average basis the Peshawar had taller maize while Charsadda had taller wheat plants.

Table 3. Plant heights of maize and succeeding wheat as influenced by Zn application and organic amendments at two diverse calcareous soils

Type of Amendments	Zn levels (kg ha^{-1})	Maize plant height (cm)		Wheat plant height (cm)	
		Peshawar	Charsadda	Peshawar	Charsadda
Control	0	153 f	152 h	73 f	84 g
Control	3	163 e	156 h	85 f	88 e
Control	6	174 d	164 fg	87 be	95 d
FYM	0	176 d	171 de	88 be	86 f
FYM	3	177 d	175 cd	90 bd	94 d
FYM	6	187 c	184 ab	96 a	99 b
PM	0	186 c	179 bc	86 de	95 d
PM	3	196 a	184 a	91 b	98 bc
PM	6	196 ab	183 ab	99 a	101 a
BC	0	168 e	163 g	87 be	94 d
BC	3	177 d	168 ef	88 be	95 d
BC	6	189 bc	175 cd	90 bc	97 c

Combining effect of Zn with organic amendments on plant height of maize and wheat was more pronounced over sole Zn and respective amendments (Table 3). However, the optimum level of Zn to be applied varied with amendment type and season of the crop. FYM and BC having lower levels of Zn contents had higher maize and wheat plant heights at 6 kg Zn ha^{-1} at both locations whereas the PM had higher maize plant heights at 3 kg Zn ha^{-1} and wheat at 6 kg Zn ha^{-1} in the following season at both locations. Such differential increases with Zn and amendments applications over location and crop season has been depicted in Fig.1b. It may be due to the fact of higher nutrient in PM than another organic source (Nahm, 2003). In the first season, at both locations the combine application of 3 kg Zn ha^{-1} with PM induced the higher increases in maize plant heights and its corresponding response was superior to FYM and BC especially in the high limed Peshawar soil. While the residual response of PM declined in the following season indicating taller plants with 6 kg Zn ha^{-1} rather than 3 kg Zn ha^{-1}in all treated plots. The data further revealed that BC and FYM had longer lasting effect than PM as observed in the succeeding wheat plant height at both locations.

The combine application of amendments (AM) with zinc (Zn) had superior maize and wheat plant heights at both locations followed by soil amendments (Table 3). These findings are in a close analogy with Hadi *et al*., (1997), Jain and Dhama (2007) and Ranjbar and Bahmaniar (2007), who harvested increased yield with the application of Zn.

Grain yield of maize and succeeding wheat

The maize grain yield both in low limed Charsadda and high limed Peshawar significantly increased with organic amendments and Zn applications as compared to control (Table 4). When averaged across the organic amendments, the grain yield in high limed Peshawar soil increased with increase in Zn levels from 7632 kg ha^{-1} at 0 kg Zn ha^{-1} to 8368 kg ha^{-1} at 6 kg Zn ha^{-1} but in low limed Charsadda non-significant result was found over control suggesting its lower Zn requirements (Table 4). In succeeding wheat crop, the higher levels of Zn induced significantly higher grain yields over lower Zn levels suggesting mining of soil Zn with crop harvest at both locations and as such regular or intermittently higher Zn application would be required for sustainable crop production under both soil systems. The results are in close conformity with findings of Goswami (2007), Tahir et al. (2009) and Singh et al. (2012) who reported that increasing levels of Zn increased wheat and maize yields. Similar results were reported by Butt et al. (1995) and Ali et al. (1983) that Zn fertilizer increased the crop yields and Zn concentration in crop tissues.

When values for grains yields of maize were averaged across the Zn levels, PM and FYM showed more pronounce results than BC in both locations. The application of PM at Peshawar, when averaged across the Zn levels, increased the grain yield from 6932 to 8800 kg ha^{-1} equivalent to 26.94 % increase over control and 15.22 % and 0.59 % over BC and FYM, respectively (Table 4). In low limed Charsadda soil, the PM increased maize grain yields from 6632 to 8225 kg ha^{-1} showing 24.01 % increase over control which was slightly lower than high limed Peshawar soils. These observations suggested that high limed Peshawar soil was more responsive to both organic amendments and Zn applications as compared to low limed Charsadda soils. However, Peshawar produced more maize grain yield than Charsadda soils. In succeeding wheat experiments, the biochar became more effective withstanding statistically at par to both PM and FYM. The gradual improvement in succeeding wheat with BC suggests its slower decomposing and long lasting effects.

Combined effect of Zn and organic amendments was more prominent as compared to their sole application and control (Table 4). The grain yields of maize, for example in high limed Peshawar soil, increased from 6359 kg ha^{-1} to 7219 kg ha^{-1} with sole Zn which further increased to 8056 and 8564 kg ha^{-1} with AM and AM+Zn application when values were averaged across the Zn and AM levels. Similarly, the AM+Zn application increased the maize grain yield by 26.80 % at Charsadda and wheat yields by 35.27 and 38.02 % over control at high and lower limed soils, respectively. Regarding the individual amendment effect, the response of combining Zn with BC was more prominent where it increased the maize grain yields from 7200 to 8063 kg ha^{-1} (11.99 %) at Peshawar and from 6799 to 7624 kg ha^{-1} (12.13 %) in Charsadda as compared to FYM and PM that showed increases of 5.15 and 8.79 % in high limed Peshawar and 12.24 and 4.95 % in low limed Charsadda over sole application of respective amendments. Furthermore, increasing levels of Zn with BC and FYM increased the maize grain yields but with PM the higher 6 kg Zn ha^{-1} rather reduced the maize grain yields as compared to its respective values at 3 kg Zn +PM at both locations. Dilshad et al. (2010); Osman et al. (2010) and Ahmad et al. (2002) also obtained more maize grain yield with combined use of organic and inorganic fertilizers.

The overall better performance of Zn addition with biochar in maize crop could be attributed to its slow decomposition especially in the first season with slower release of nutrients to meet the crop requirements. And as such the response of maize crop was high to applied Zn levels in these treatments. In the succeeding wheat succeeding crop, the similar pattern was observed but comparatively higher in Peshawar than Charsadda and the higher response of BC over FYM as averaged over Zn levels indicating improvement in BC effect with time. The sole application of Zn at 3 and 6 kg ha^{-1} increased the succeeding wheat grain yields by 12 and 24 % and over control in Peshawar and 7 and 15 % over control in low limed Charsadda soils. The continuous improvement with combined application of Zn and amendments corroborate the integrating effects of organic amendments in Zn nutrition. However, the integrating effect of Zn and amendments were comparable at both locations in contrast to sole Zn which was comparatively higher in high limed Peshawar as compared to low limed Charsadda soils.

Sharma and Subehia (2003) observed that the Integration of mineral fertilizers and FYM significantly enhanced the grain yields of maize and wheat as compared to that with chemical fertilizers alone. Sial *et al*., (2007) also observed the same trends of increasing maize grain yield from 83.9 to 108.7 % with the integration of organic and inorganic fertilizers. Likewise, Adhikari *et al*. (200) reported that integrated use of FYM and inorganic fertilizers (NPK+Zn) significantly increased maize grain yield by 89 % over NPK fertilizer alone. Long-term use of biochar enhances availability of plant nutrient and soil productivity (Steiner *et al*., 2007).

Table 4. Grain yield of maize and succeeding wheat as influenced by Zn application and organic amendments at two diverse calcareous soils

Amendments Type	Zn levels (kg ha^{-1})	Maize grain yield (kg ha^{-1})		Wheat grain yield (kg ha^{-1})	
		Peshawar	Charsadda	Peshawar	Charsadda
FYM	0	8576	7381 cd	4968 ef	4823
FYM	3	8649	7975 ac	5321 cd	5127
FYM	6	9018	8285 ab	5950 a	5508
PM	0	8394	8024 ac	5569 bc	5435
PM	3	9132	8421 a	5733 ab	5712
PM	6	8876	8231 ab	5707 ab	5594
BC	0	7200	6799 ef	5551 bd	5071
BC	3	7648	7210 de	5662 ac	5328
BC	6	8063	7624 bd	5748 ab	5644
Control	0	6359	6276 e	4204 g	3974
Control	3	6925	6892 ef	4710 e	4251
Control	6	7513	6729 ef	5199 de	4566
	LSD at $p < 0.05$	NS	664	356	NS
Average across zinc levels					
FYM	-	8748 a	7880 ab	5413 a	5153 b
PM	-	8800 a	8225 a	5669 a	5580 a
BC	-	7637 b	7211 bc	5654 a	5348 ab
Control	-	6932 c	6632 c	4704 b	4264 c
LSD at $p < 0.05$		677	834	264	301
Average across OM Sources					
Zn	0	7632 c	7120 b	5073 c	4826 c
Zn	3	8089 b	7624 a	5357 b	5104 b
Zn	6	8368 a	7717 a	5651 a	5328 a
	LSD at $p < 0.05$	258	207	147	200

Means following the same letter (s) in column or group do not change at $p < 0.05$

Zn concentration (Zn) in maize and succeeding wheat grains

Statistical analysis of the data showed that maize and succeeding wheat grain [Zn] significantly increased over control with Zn and amendment application both in low limed Charsadda and high limed Peshawar soil. However combined application of Zn and organic amendments indicated better response in high limed Peshawar soils for maize crop. As concerned to Zn levels, grain [Zn] of both maize and wheat crop increased with each increment. At both tested sites (Table 5). In high limed Peshawar, the increase of maize grain Zn from 27.5 to 32 mg kg^{-1} with 6 kg Zn ha^{-1}

was comparatively higher than observed in low limed Charsadda for the same crop. The higher response in Peshawar could be attributed to initially lower grain [Zn] associated to high lime contents as also indicated by higher maize and grain [Zn] at 6 kg Zn ha^{-1} as well as when averaged across all Zn and amendments levels. This suggested the application of Zn in high limed soils to fulfill their need and gives better response. Regarding amendment effect, PM being nutritionally concentrated resulted in significantly higher maize grain Zn in high limed Peshawar during first season maize while it remained at par with FYM and BC in low limed Charsadda soil for the same crop. In succeeding wheat, though PM was significantly higher in both low and high limed soils but the grain Zn in higher limed Peshawar was substantially lower than low limed Charsadda. When averaged across the Zn level, PM application induced increases in wheat grain Zn from 18.4 to 21.5 mg kg^{-1} but in low limed Charsadda such values were 27.0 and 33.1 mg kg^{-1} revealing that low limed Charsadda maintained higher grain [Zn] especially in the succeeding crop.

Combining Zn with amendments further improved the maize and succeeding grain [Zn] over their sole application. When averaged across the Zn and AM levels, AM+Zn application increased the maize grain [Zn] in high limed Peshawar from 24 in control to 32 mg Zn kg^{-1} which was 14.28 % higher than sole Zn and AM. Math and Trivedi, (2001) also observed the better yield of wheat and maize, and increased Zn concentration in both crops by the combined application of organic amendment and Zn fertilizers. Several other scientists also have reported the enhanced solubility of Zn with the addition of organic materials. (Sinha and Prasad, 1977; Arnesen and Singh 1998; Tarkalson *et al.*, 1998).

Table 5. Grain Zn content of maize and succeeding wheat as influenced by Zn application and organic amendments at two diverse calcareous soils

Amendments Type	Zn levels(kg ha^{-1})	Maize grain [Zn] (mg kg^{-1})		Wheat grain [Zn] (mg kg^{-1})	
		Peshawar	Charsadda	Peshawar	Charsadda
FYM	0	26.0 de	30.7	20.0	20.4
FYM	3	30.0 c	32.5	21.5	21.8
FYM	6	32.9 ab	33.9	22.9	23.7
PM	0	31.6 bc	32.7	21.7	21.7
PM	3	33.1 a	34.1	23.7	23.7
PM	6	34.7 a	34.6	25.7	25.7
BC	0	27.8 d	32.5	21.5	21.5
BC	3	30.0 c	32.9	21.9	22.6
BC	6	31.1 c	33.7	22.7	23.5
Control	0	24.4 e	26.6	16.9	19.4
Control	3	26.9 d	29.8	18.5	21.4
Control	6	29.9 c	31.7	19.9	24.0
	LSD at $p < 0.05$	1.75	NS	NS	NS
Average across zinc levels					
FYM	-	29.6 b	32.3 a	21.5 b	29.6 bc
PM	-	33.1 a	33.8 a	23.7 a	33.1 a
BC	-	29.6 b	33.0 a	22.0 b	29.6 b
Control	-	27.0 c	29.4 b	18.4 c	27.0 c
	LSD at $p < 0.05$	1.40	1.36	1.35	0.86
Average across OM Sources					
Zn	0	27.5 c	30.6 c	20.0 c	20.8 c
Zn	3	30.0 b	32.3 b	21.4 b	22.4 b
Zn	6	32.1 a	33.5 a	22.8 a	24.2 a
	LSD at $p < 0.05$	0.69	0.96	0.64	0.89

* Means following the same letter (s) in column or group do not change at $p < 0.05$

Regarding different amendment, maize grain [Zn] increased with increasing Zn levels whereas with PM increasing levels of Zn indicated statistically similar and equal increase in the maize grain Zn (Table5). However, in succeeding study, the wheat grain linearly increased with increase in Zn levels irrespective of soil lime contents and amendment types. Such results lead to the conclusion that PM required less Zn (3 kg Zn ha^{-1}) whereas the BC and FYM required higher Zn (6 kg Zn ha^{-1}) for potential increases in grain Zn nutrition in both soils especially in the first season. This differential effect of various organic sources was in consistence with Gramss *et al*. (2003) who reported that trace elements bioavailability was influenced by type, source and form of the organic materials applied.

Postharvest soil [Zn] after maize and succeeding wheat

Zn and amendments application significantly increased the postharvest soil AB-DTPA extractable Zn both after 1st season maize and succeeding wheat as well as at both sites. However the interaction effect of Zn and AM application was non-significant at low limed soil during first season maize but was significant at high limed Peshawar and after succeeding wheat at both locations. The overall significance shows that response in high limed soils was comparatively more than low limed Charsadda soil to both Zn and AM application.

Postharvest soil AB-DTPA extractable Zn was increased with increase in Zn levels. When values were averaged across the AM, application of 6 kg Zn ha^{-1} increased the soil Zn from 0.82 to 1.02 mg Zn ha^{-1} after maize in high limed Peshawar and from 0.92 to 1.01 mg kg^{-1} in low limed Charsadda indicating increase in response with soil lime content (Table 6). Adiloglu and Saglam (2005) also observed the enhanced N and Zn contents by application of N and Zn fertilizers. Similar pattern but with relative lower values was observed in the succeeding wheat at both soils where the 6 kg Zn ha^{-1} showed increases of 16.5 % in high limed and 13.0% in low limed Charsadda soils. However, the overall values in high limed Peshawar after both crops were comparatively lower than low limed Charsadda soils that could be associated to Zn adsorption and complexation with increase in soil lime contents (Al-Kaysi, 2000; Al-Tamimi, 2006).

Table 6. Postharvest soil Zn of maize and succeeding wheat as influenced by Zn application and organic amendments at two diverse calcareous soils

Amendments Type	Zn levels ($kg\ ha^{-1}$)	Soil [Zn] in maize ($mg\ kg^{-1}$)		Soil [Zn] in wheat ($mg\ kg^{-1}$)	
		Peshawar	Charsadda	Peshawar	Charsadda
FYM	0	0.83 df	0.87 de	0.86 bd	0.84 de
FYM	3	0.89 ce	0.89 de	0.78 de	0.88 cd
FYM	6	0.94 cd	0.93 ce	0.85 be	0.93 bc
PM	0	0.89 ce	1.04 bc	0.82 ce	0.89 cd
PM	3	1.17 b	1.09 ab	0.88 bc	0.97 b
PM	6	1.33 a	1.22 a	0.86 bd	0.93 bc
BC	0	0.86 ce	0.93 ce	0.76 e	0.85 ce
BC	3	0.78 ef	0.91 ce	0.94 ab	0.91 bd
BC	6	1.00 c	0.99 bd	1.02 a	1.06 a
Control	0	0.70 f	0.83 e	0.56 f	0.77 e
Control	3	0.83 df	0.84 e	0.64 f	0.87 cd
Control	6	0.82 df	0.92 ce	0.61 f	0.90 bd
	LSD at $p < 0.05$	0.15	0.15	0.09	0.08
Average across zinc levels					
FYM	-	0.89 b	0.89 b	0.83 b	0.88 ab
PM	-	1.13 a	1.11 a	0.85 ab	0.93 a
BC	-	0.88 b	0.94 b	0.91 a	0.94 a
Control	-	0.78 c	0.86 b	0.60 c	0.85 b
	LSD at $p < 0.05$	0.09	0.10	0.06	0.06
Average across OM Sources					
Zn	0	0.82 c	0.92 b	0.75 b	0.84 c
Zn	3	0.92 b	0.93 b	0.81 a	0.91 b
Zn	6	1.02 a	1.01 a	0.84 a	0.95 a
	LSD at $p < 0.05$	0.07	0.07	0.05	0.04

* Means following the same letter (s) in column or group do not change at $p < 0.05$

Among organic amendments, significantly higher postharvest AB-DTPA extractable Zn was produced by PM in the first season in both soils, whereas in succeeding wheat its was at par to BC indicating its increase in effectiveness with time and its long lasting role in maintaining soil fertility and crop productivity. When averaged across Zn level, significantly higher AB-DTPA ext. Zn 1.13 mg kg^{-1} was observed by PM in high limed Peshawar soil after maize which was followed by FYM and BC with almost similar values. In the low limed soil again the FYM and BC were at par to each other but lower by 18.9 % than 1.11 mg kg^{-1} recorded by PM after the same crop. These results are in agreement with the findings of Singh *et al.,* (1979) and Akinrinde *et al*., (2006) who observed that the combined application of poultry manure and $ZnSO_4$ increased plant Zn content. Prasad *et al*. (1984) also reported that addition of poultry manure alone or in combination with N, P, K, Zn and Fe increased the uptake of Zn and Fe by wheat and rice.

In succeeding wheat, the differences among the amendments were statistically at par in both soils but the magnitude of increases were more in high limed Peshawar than Charsadda soils indicating the more needed role of amendments in poor and degraded soils. The comparatively at par values of BC with FYM in first season maize and also to nutritionally enriched PM in the succeeding wheat at both sites indicates the potential and even long lasting role of BC in improving soil fertility and productivity in both type of soils. Uzoma *et al*., (2011) also observed the same pattern that nutrient uptake and crop growth was increased by the application of BC. Gondek and Mazur (2005) observed that the application of FYM also increased the concentration of N and Zn. The work of Khan *et al*., (2013) was also in great analogy that Application of organic waste can increase zinc content in soil.

The combined application of Zn and AM augmented their effectiveness as compared to their sole application at both soils and crops indicating synergistic effect (Table 6). When averaged across the tested AM and Zn level, combined application of AM+Zn increased the postharvest maize AB-DTPA ext. soil Zn from 0.703 to 1.017 mg kg^{-1} which was 23.27 higher than sole Zn and by 18.25 over AM in high lime Peshawar soil. Similar pattern was observed in the low limed Charsadda for maize and in both soils for succeeding wheat studies. However, the magnitude of increases with AM+Zn was higher in high limed than low limed where it increased the soil Zn by 44.66 and 20.84 %, respectively over control in maize and 59.60 and 22.85 in succeeding wheat.

The same trend was observed when individual AM was considered, where the given AM+Zn invariably produced higher soil AB-DTPA ext. Zn than sole Zn or AM in all seasons and soils. However, selecting the optimal dose of 3 or 6 kg Zn ha^{-1} with the given amendments changed with type of AM and crop. In maize, the soil Zn increased with increase in Zn application in all amendments but in succeeding wheat higher soil Zn at higher Zn application rate was recorded in BC only (Table 6).

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