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Long-term (16 years) Influence of Surface Crop Residue Application on Soil Chemical Zn Fractions and Zn Uptake by Sorghum {*Sorghum bicolor* (L.) Moench} and Cowpea {*Vigna unguiculata* (L.) Walp} Crops Under Minimum Tillage in Rainfed Alfisol Soil

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Abstract

A study was conducted to evaluate the long-term (16 years) influence of different levels of surface crop residue applications on chemical Zn fractions in soil and their relationship with uptake and crop yields in sorghum and cowpea crops, grown under minimum tillage in rainfed Alfisol soil at Hayathnagar Research Farm of ICAR- Central Research Institute for Dryland Agriculture, Hyderabad, India. Results revealed an influence of long- term crop residue application under minimum tillage on soil chemical Zn fractions viz., water soluble + exchangeable zinc (Zn-CA), zinc specifically sorbed by inorganic sites (Zn-ACC), zinc specifically sorbed by organic sites (Zn-PYR), zinc occluded by free oxides (Zn-OX), residual zinc (Zn-RES), available zinc (Zn-DTPA) and total zinc (Zn-TOT) and also on Zn-uptake and grain yields of both sorghum and cowpea crops. Multiple regression studies indicated a positive influence of the Zn-ACC, Zn-DTPA and Zn-TOT on Zn-uptake by sorghum, while the sorghum grain yield was positively influenced by Zn-ACC, Zn-PYR, Zn-DTPA and Zn-TOT fractions. The Zn-uptake by cowpea was positively influenced by Zn-PYR, Zn-OX, Zn-RES, Zn-DTPA and Zn-TOT, while the cowpea yield was positively influenced by Zn-CA, Zn-ACC, Zn-RES, Zn-DTPA and Zn-TOT. The Common Fractions of Zn (ZnCF) which showed crop specificity towards both uptake of Zn by sorghum and its grain yield were: Zn-ACC, Zn-DTPA and Zn-TOT. Whereas the ZnCF for cowpea were: Zn-RES, Zn-DTPA and Zn-TOT. Thus, these results have significance and importance in managing the zinc (Zn) nutrition in soils.

Keywords: Crop residue; Zinc Chemical Fractions; Zn-uptake; Crop yields; Sorghum-cowpea system; Alfisol

Introduction

Among several other soil types, Alfisol soils represent about 42M ha area in India which are mainly located in dryland regions [1]. Semi-arid regions with low and highly variable rainfall, high evapo-transpiration rates, shallow soils with low water retention, problems of crusting and surface sealing, low soil fertility, low soil organic carbon (SOC) coupled with imbalanced nutrient use, low or virtually no crop residue recycling constrain the productivity of rainfed crops in Alfisols. Specifically, besides being thirsty due to low and erratic rainfall and frequent droughts, these soils are critically low in organic matter status, and consequently severely low in soil fertility, which in-turn result in low crop yields. In order to enhance organic matter and restore back the fertility of these soils, conservation agricultural practices such as minimum tillage, crop residue cover and crop rotation need to be put into practice. Earlier, several authors [2,3] have reported that application of crop residue on soil surface is a proven technology to protect soil from nutrients losses, enhance soil fertility, improve agronomic sustainability and maintain the overall soil quality in the tropics. CA is comprised of three important interlinked components viz., minimum or no tillage, permanent residue cover and crop diversification (*http://www.fao.org/ag/ca/1a.html*). Sharma et al.

[4,5], based on their earlier studies, have reported that maintaining of crop residues on soil surface along with minimum tillage have proved very effective in enhancing soil fertility, improving soil hydrology, and biological properties of soil. Lal [6] has also emphasized the importance of maintaining adequate amount of crop residue on soil surface as land cover, to get the benefit of minimum or reduced tillage in the Semi-Arid Tropical (SAT) regions. The importance of crop residue application lies when it is maintained on the soil surface instead of its incorporation into the soil. Sharma & Prasad [7] have reported that surface application of crop residues was found superior to increase the nutrient use efficiency compared to its incorporation into the soil. These authors further reported the surface application of crop residue to be promising in improving in- situ soil water conservation and suppressing the weeds.

Majumder et al. [8] and Mandal et al. [9] have brought out that the optimum levels of SOC can be maintained by way of adopting appropriate crop rotations and soil fertility management practices comprising of inorganic fertilizers and organic amendments. According to Food and Agriculture Organization [10], the crop husbandry practices such as minimum tillage, use of cover crops and application of crop residues on the soil surface help in increasing the restorative activity in the soil leading to the accumulation of SOM.

Among the micronutrients, Zn is one of the important elements which is severely deficient in rainfed soils. The predominant reasons of deficiency of micronutrients in soils in India could be (i) use of high yielding cultivars coupled with use of high analysis fertilizers, and no or low use of organic manures. Further, high soil temperature, frequent deep and inversion tillage, burning of crop residues and their poor recycling in the SAT regions have taken a big toll on soil organic matter, which is very essential for ensuring the availability of micronutrients. Chakraborty et al. (2021) have reported that Indian soils are severely poor in zinc, iron, manganese, copper, boron and molybdenum as these nutrients have continuously been depleted due to repeated cultivation for a longer period without their balanced replenishment. Further, Singh [11], based on a comprehensive review, reported that crops grown in most soils in India suffer from deficiencies of one or more micronutrients, even though the soils often contain apparently adequate total amounts of the respective nutrients, and he further emphasized that the nature and extent of deficiencies varies with soil type, crop genotype, management and agro-ecological situations. Therefore, the management of zinc in soil and ensuring it availability either by way of its supplementation through zinc fertilizer or use of organics such as Farmyard manure (FYM), green manuring, recycling of crop residues is of paramount importance. Organic matter plays a vital role in improving availability of zinc by two ways: (i) direct contribution and (ii) indirect contribution by way of chemical transformation and microbial activity [12]. Mishra et al. [13] reported that zinc exists in soil in different forms viz., primary and secondary minerals; insoluble inorganic and organic precipitates; soluble organic complexes; exchangeable and adsorbed forms; and soil solution zinc. These forms are in a state of dynamic equilibrium. The quantum and rate of transformation of these forms influences the size of the labile zinc pool. Shuman [14] have reported that beside several other aspects, the behavior of zinc in soil and its readily availability to crop plants depend on the concentration and the percentage of each zinc fraction to soil total zinc. He further added that besides existing as free Zn or chelate complex in the soil solution, zinc in soil may be adsorbed on surfaces of solid particles such as carbonate, metal oxides of iron, aluminum, manganese, and organic matter. In order to better understand zinc forms and their behavior in soils in relation to its easy access (availability) and removal by crops, the exploration, development and use of sequences of different chemical extractants have proved very effective [15,16]. Considering these aspects, we hypothesized that long term use of low to heavy doses of crop residues under minimum tillage will help in positively influencing the Chemical zinc fractions or forms in soil and this in-turn will enhance the zinc availability in soil and its uptake by crop plants.

Sorghum-cowpea system is one of the important cropping systems found suitable for the rainfed regions of semiarid tropics (SATs) of India. But as mentioned above, due to several climate and soil fertility related constraints, the productivity of these crops is very low, especially in coarse textured Alfisol soils. Among the micronutrients, the Zn nutrition is very important in crops like sorghum which is being considered as an important nutritional cereal in India, and in cowpea, an important legume crop raised in rotation with cereals like sorghum.

In view of the above, the present study was conducted with the specific objectives: (i) to assess the long-term effect of varying levels of surface residue application under minimum tillage on the performance of both sorghum and cowpea crops, (ii) to quantify the Zn availability pool and Zn chemical fractions in soils as influenced by varying residue levels under minimum tillage, and (iii) to establish a dynamic relationship of chemical Zn fractions with crop uptake and yields.

Materials and Methods

Experimental details

A long-term field experiment was conducted during 2005-2020 with sorghum (CSH-9) and cowpea (C-152) as the test crops at Hayathnagar Research Farm of Indian Council of Agricultural Research (ICAR)-Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India. The experimental soils belong to Typic Haplustalf group, locally termed as Red Chalka soils. The experimental soils are mildly acidic to neutral in soil reaction (pH 6.5) with sandy loam texture in the surface layer and increasing clay content in the sub soil layers. The soils, in general were low in available N, medium in P and K. The experiment was conducted using sorghum and cowpea as the test crops, alternately grown in a yearly rotation. The test crops were grown in the kharif season with minimum tillage employing

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tractor drawn seed planter or using a non-inversion type plough, depending upon the situation. The four experimental treatments were comprised of different (graded) levels of sorghum residue application as given below: T1 - Control (No surface residue application), T2 - Surface application of dry sorghum residue @ 2 t ha^{-1}, T3 - Surface application of dry sorghum residue @ 4 t ha^{-1}, T4 -Surface application of dry sorghum residue @ 6 t ha^{-1}.

The experiment was conducted in a randomized block design (RBD) with three replications of each treatment. Different levels of residue were uniformly applied on the surface 25-30 Days After Sowing (DAS). Sorghum and cowpea crops received N every year as per the recommended doses of 60 and 30kg N ha^{-1}, respectively, in the form of urea. Phosphorus was applied every year uniformly to all the plots and to both the crops @ 30kg P_2O_5 ha^{-1} through single super phosphate. In case of sorghum, half of the recommended dose of N was applied as basal application and remaining half as top dressing, while for cowpea, whole of the recommended dose of N was applied as basal.

During the experimental period of 16 years i.e. 2005 to 2020, sorghum (2005, 2007, 2009, 2011, 2013, 2015, 2017 and 2019) and cowpea crops (2006, 2008, 2010, 2012, 2014, 2016, 2018 and 2020) could be grown for eight years each. Besides the scheduled treatments as mentioned above, in order to leave the anchored residue in the field, at the time of the harvest of the crop, the stubbles were also retained at 30 cm height in case of sorghum crop and full biomass was retained after the harvest of the pods in case of cowpea. The remaining upper part (above 30cm height) of the sorghum stover was removed out of the field and stored for field application during the next kharif season. The weeds were controlled by use of pre-emergence herbicides such as Atrazine (for sorghum), Pendimethalin (for cowpea), and mechanical methods of weed control as and when required.

Soil samples from the experimental field were collected from 0 to 20cm soil depth. The air-dried soil samples were sieved through 2mm sieve and were subjected to zinc Fractionation study as per the procedure given by McLaren & Crawford [17] which was later modified by Elsokkary [18]. The data were analyzed using the analysis of variance technique. Regression functions were worked out to study the relationship between zinc fractions and other dependent variables.

Zinc uptake by plants

The zinc nutrient uptake by economical plant part (grains/ seeds) was determined by using the standard procedure of digestion of plant samples. The zinc uptake by grains was calculated by multiplying the Zn concentration in grains with the dry grain yield.

Results and Discussion

Influence of varying levels of crop residue on Zn fractions (mg kg^{-1}) under minimum tillage.

The results pertaining to the influence of residue application under minimum tillage on different Zn fractions in soils are presented in Table 1 and depicted in Figure 1 & 2.

Water soluble + exchangeable zinc (Zn-CA)

The Zn-CA in these soils varied from 0.84 to 1.32mg kg^{-1} across the residue treatments. Significantly higher Zn-CA (1.32mg kg^{-1}) was observed with the surface application of sorghum residue @ 6 t ha^{-1} and @ 4 t ha^{-1} (1.12mg kg^{-1}), followed by 2 t ha^{-1} (0.97mg kg^{-1}) compared to control (0.84mg kg^{-1}). The increase in Zn-CA due to application of sorghum residue @ 2, 4 and 6 t ha^{-1} was to the extent of 15.47, 33.33 and 40.32%, respectively over no residue application.

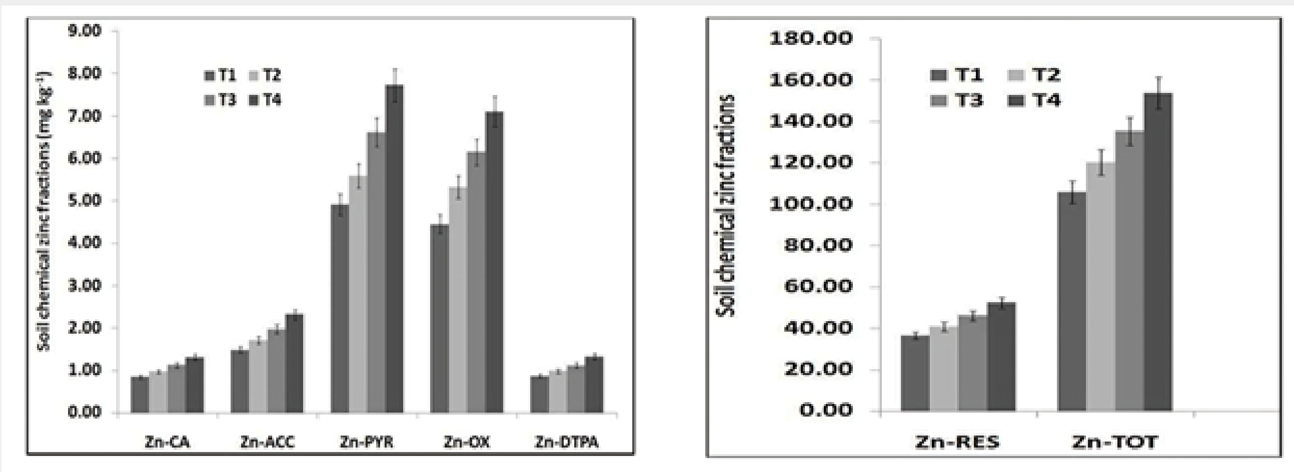

Figure 1 & 2: Effect of varying levels of residue application on Zn fractions (mg kg^{-1}) (Figure 1 - Zn-CA, Zn- ACC, Zn-PYR, Zn-OX, Zn-DTPA & Figure 2 - Zn-RES and Zn-TOT) in minimum tillage.

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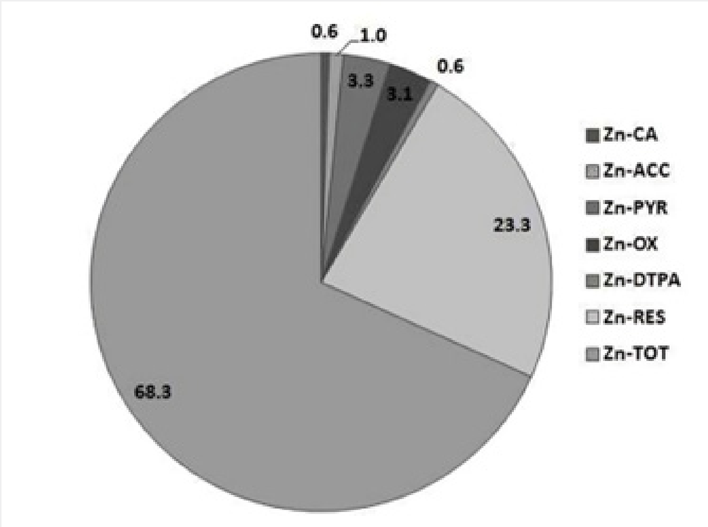

Figure 3: Percent contribution of different Zn fractions toward the sum total of extracted Zn fractions (averaged over residue levels).

Zinc specifically sorbed by inorganic sites (Zn-ACC)

The soil Zn-ACC fraction varied from 1.48 to 2.32mg kg^{-1} across the treatments. Zn-ACC (2.32mg kg^{-1}) was observed to be significantly higher with the surface application of sorghum residue @ 6 t ha^{-1} and 4 t ha^{-1} (1.98mg kg^{-1}), followed by the application @ 2 t ha^{-1} (1.71mg kg^{-1}) compared to control (1.48 mg kg^{-1}). The increase in Zn-ACC with surface application of sorghum residue @ 2, 4 and 6 t ha^{-1} was 15.54, 33.78 and 56.75%, respectively over the control.

Zinc specifically sorbed by organic sites (Zn-PYR)

The fraction of Zn-PYR significantly varied from 4.92 to 7.73mg kg^{-1} across the levels of residue treatments. Significantly higher Zn-PYR was observed with the surface application treatments of sorghum residue viz., 6 tha^{-1} (7.73mg kg^{-1}), 4 t ha^{-1} (6.62mg kg^{-1}) and 2 t ha^{-1} (5.59mg kg^{-1}) compared to control (4.92mg kg^{-1}). Thus, the application of sorghum residue @ 2, 4 and 6 t ha^{-1} significantly influenced the Zn-PYR content which was 13.61, 34.55 and 57.11% higher compared to no residue application.

Zinc occluded by free oxides (Zn-OX)

Varying levels of residue application significantly increased the Zn-OX fraction in soil which varied from 4.46 to 7.11mg kg^{-1}. A significantly higher Zn-OX was observed with the surface application of sorghum residue @ 6 t ha^{-1} (7.11 mg kg^{-1}), followed by @ 4 t ha^{-1} (6.16mg kg^{-1}) and 2 t ha^{-1} (5.34mg $k^{g-}1$) compared to control (4.46mg kg^{-1}). Thus, the application of sorghum residue @ 2, 4 and 6 t ha^{-1} significantly influenced the Zn-OX content which was 19.73, 38.11 and 59.41% higher, respectively, compared to the control.

Residual zinc (Zn-RES)

The soil Zn-RES fraction in these soils varied from 36.42 to 52.32mg kg^{-1} across the treatments. Significantly higher Zn-RES was observed with the surface application of sorghum residue t @ 6 t ha^{-1} (52.32mg kg^{-1}) and @ 4 t ha^{-1} (46.25mg kg^{-1}) followed by 2 t ha^{-1} (40.85mg kg^{-1}) compared to control (36.42mg kg^{-1}). The increase in Zn-RES due to application of sorghum residue @ 2, 4 and 6 t ha^{-1} was to the extent of 12.16, 26.99 and 43.65%, respectively, over no residue treatment.

Total Zinc (Zn-TOT)

The application of sorghum residue @ 2, 4 and 6 t ha^{-1} increased the soil Zn-TOT by 13.68, 27.85 and 45.31%, respectively over control treatment. The soil Zn-TOT varied from 105.92 to 153.92mg kg^{-1} across the residue treatments. Significantly higher Zn-TOT was observed with the surface application of sorghum residue @ 6 tha^{-1} (153.92mg kg^{-1}) and @ 4t ha^{-1} (135.42mg kg^{-1}) followed by 2 t ha^{-1} (120.42mg kg^{-1}) compared to control (105.92mg kg^{-1}).

Available Zinc (Zn-DTPA)

The application of sorghum residue @ 2, 4 and 6 t ha^{-1} increased the Zn-DTPA in soil to the extent of 13.79, 28.73 and 54.02%, respectively compared to no residue application.

The Zn-DTPA in soil varied from 0.87 to 1.34 mg kg^{-1} across the surface residue treatments. Significantly higher Zn-DTPA was observed with the surface application of sorghum residue @ 6 t ha^{-1} (1.34mg kg^{-1}) and also @ 4t ha^{-1} (1.12mg kg^{-1}) followed by 2 t ha^{-1} (0.99mg kg^{-1}) compared to control (0.87mg kg^{-1}).

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From the results obtained from this study, it was clearly understood that there was a gradual increase in all the zinc fractions viz. Zn-CA, Zn-ACC, Zn-PYR, Zn-OX, Zn-RES, Zn-DTPA and Zn-TOT with the increase in rate of residue application from 2 t to 6 t ha^{-1} compared to control. The increase in all the Zn fractions with the residue treatments was significant compared to the control, except only the Zn-CA, Zn-OX, Zn-RES, Zn-DTPA and Zn-TOT fractions under 2 t ha^{-1} treatments. This increase could be due to the increase in organic matter with the increasing levels of residue application, which could contribute to the Zn fractions from its decomposition. These results are in conformity with those earlier reported by Shahina Tabassum et al [19] who brought out that use of manures significantly enhanced the zinc content in different fractions. Earlier, Munna Lal et al. [20], also reported significant increase in zinc content in different zinc fractions in soil in castor-sorghum crop rotation with the application of crop residues. According to Kumari et al. (2015) [21], long-term crop residue application increased the water soluble + exchangeable, complexed, organically bound, carbonate and amorphous oxide, crystalline oxide, residual and total Zn in the soil. While highlighting the role of application of higher levels of an aerobically digested bio slurry in maize mustard sequence in Alluvial soils. Sharma et al. [22] have also reported significant increase in zinc content in different fractions over control. Walia et al. [23] reported a significant increase in DTPA-extractable Zn (along with Cu, Fe, and Mn) content in Typic Ustochrept soil with the long-term application of all organic nutrient sources viz., FYM, WCS (wheat cut straw), and GM (green manure with *Sesbania aculeata*).

When the average percent contribution of different Zn fractions towards the sum total of extracted Zn was computed (Figure 3), the order of fractions was found as: Zn-CA (0.6%) < Zn-ACC (1.0%) < Zn-OX (3.1%) < Zn- PYR (3.3%) < Zn-RES (23.3%) < Zn-TOT (68.3%). This data indicated that the quantum of labile fractions was substantially lower compared to that of non-labile or less labile fractions. The results of the present study have clearly established an increasing trend in the quantum of Zn in different fractions with increasing levels of crop residue. Our results are in conformity with the findings of several authors who have used one or the other kind of organics for their soil and nutrient management studies.

Crops yield

The grain yield of sorghum significantly increased with the increase in the level of residue application. It varied from 2000.0 to 2520.0kg ha^{-1} in different treatments. Significantly higher sorghum grain yield was observed with the surface application of crop residue @ 2 t ha^{-1} (2114.3kg ha^{-1}), 4t ha^{-1} (2284.2kg ha^{-1}) and 6 t ha^{-1} (2520.0 kg ha^{-1}) compared to no residue application (2000.0 kg ha^{-1}). The increase in grain yield of sorghum due to application of sorghum residue @ 2, 4 and 6 t ha^{-1} was to the extent of 6%, 14%, and 26%, respectively over no residue application (Table 2). While the cowpea seed yield under the four residue treatments varied from 371.3 to 545.9kg ha^{-1} in different treatments. The increase in seed yield of cowpea due to application of sorghum residue @ 2, 4 and 6 t ha-1 was to the extent of 11%, 30%, and 47%, respectively over the control no residue application (Table 2 & Figure1). Significantly higher cowpea seed yield was observed with the surface application of crop residue @ 2 t ha^{-1} (413.8 kg ha^{-1}), 4t ha^{-1} (483.7 kg ha^{-1}) and 6 t ha^{-1} (545.9 kg ha^{-1}) compared to no residue application (371.3 kg ha^{-1}).

Table 1: Influence of varying levels of crop residue application on Zn fractions (mg kg^{-1}) in minimum tillage.

Treatments	Zn-CA	Zn-ACC	Zn-PYR	Zn-OX	Zn-DTPA	Zn-RES	Zn-TOT
T1=No residue	0.84	1.48	4.92	4.46	0.87	36.42	105.92
T2=2ton ha^{-1} SS	0.97	1.71	5.59	5.34	0.99	40.85	120.42
T3=4ton ha^{-1} SS	1.12	1.98	6.62	6.16	1.12	46.25	135.42
T4=6ton ha^{-1} SS	1.32	2.32	7.73	7.11	1.34	52.32	153.92
CD at 0.05%	0.25	0.23	0.48	0.74	0.23	6.51	22.81

Table 2: Influence of varying levels of crop residue application on Zn uptake (g ha^{-1}) by sorghum and cowpea seed in minimum tillage.

Treatments	Sorghum Grain Yield (kg ha^{-1})	Cowpea Seed Yield (kg ha^{-1})	Sorghum Zn Uptake (kg ha^{-1})	Cowpea Zn Uptake (g ha^{-1})
T1=No residue	2000	371.3	44.21	24.3
T2= 2ton ha^{-1} SS	2114.3	413.8	53.68	29.38
T3=4ton ha^{-1} SS	2284.2	483.7	66.62	37.07
T4=6ton ha^{-1} SS	2520	545.9	86.84	46.32
CD at 0.05%	186.66	43.59	18.49	3.74

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Grains/seeds zinc uptake

Plant zinc uptake by sorghum grain varied from 44.21 to 86.84g ha^{-1}. Significantly higher plant zinc uptake by sorghum grain (86.84g ha^{-1}) was observed with the two treatments of surface residue application viz.@ 6 t ha^{-1} and @ 4 t ha^{-1} (66.62g ha^{-1}) followed by 2 t ha^{-1} (53.68g ha^{-1}) compared to control (44.21g ha^{-1}) (Table 2). The increase in zinc uptake by sorghum grain due to the application of sorghum residue @ 2, 4 and 6 t ha^{-1} was to the extent of 21.42, 50.68 and 96.42%, respectively over no residue application. Plant zinc uptake by cowpea seed varied from 24.30 to 46.32g ha^{-1}. Significantly higher plant zinc uptake by cowpea seed was observed with the surface application treatments of sorghum residue @ 6 t ha^{-1} (46.32g ha^{-1}), @ 4 t ha^{-1} (37.07g ha^{-1}) and @ 2 t ha^{-1} (29.38g ha^{-1}) compared to the control (24.30g ha^{-1}) (Table 2). The increase in zinc uptake by cowpea seed due to the application of sorghum residue @ 2, 4 and 6 t ha^{-1} was 20.9, 52.55 and 90.61%, respectively over no residue application treatment.

Earlier studies conducted by several researchers revealed that the application of surface crop residues (sorghum stover, glyricidia loppings, rice straw, wheat straw) have increased the uptake of Zn compared to no residue application treatment [20,21,24]. The relatively higher Zn uptake by sorghum and cowpea crops under residue application treatments in the present study could be due to the increase in microbial exudates which have been reported to enhance micro-nutrient availability to plants, including Zn. Further, in this study, the heavy loadings of organics like crop residue for a period as long as 16 years also might have released the Zn in soil by its decomposition. These findings are in conformity with the observations of Rathod et al. [12], who observed that organic manures contribute towards the Zn availability in soil not only directly by their decomposition but also indirectly by chemical transformation and microbial activity.

Thus, the observations of the present study in relation to Zn uptake by plants have clearly brought out that the increasing levels of crop residue added to the soil helped in increasing the Zn mobilization and availability in soil and its absorption and accumulation by both the crops.

Simple quantitative relationship of different zinc fractions with total zinc:

Simple linear regression equations were developed to predict the relationship of all the zinc fractions with total zinc content so as to understand the contribution of different fractions towards the total zinc content in the soil and to plan their best management for crop production. The simple regression equations between total zinc and all other fractions are presented in the Table 3 and their graphical representation is also given in the Figure 4 (A to F). Based on the linear regression equations developed, all the soil zinc fractions were found to contribute significantly (at p = 0.01 level) towards the total soil zinc (Zn-TOT).

Table 3: Regression equations between total and available zinc and zinc fractions.

Dependent Variable	Linear Regression Equation	R^2
Y total Zn in soil	23.107+99.589 (Zn-CA)	0.9982**
Y total Zn in soil	22.496+56.835 (Zn-ACC)	0.9989**
Y total Zn in soil	25.122+16.701 (Zn-PYR)	0.9954**
Y total Zn in soil	24.29+18.141 (Zn-OX)	0.9985**
Y total Zn in soil	2.5776+2.9913 (Zn-RES)	0.9992**
Y total Zn in soil	19.007+101.77 (Zn-DTPA)	0.9912**

**significant at p = 0.01.

Multiple quantitative predictive relationships of sorghum and cowpea yields and their zinc uptake with chemical zinc fractions:

Multiple quantitative predictive relationships of yield and zinc uptake of both sorghum and cowpea crops with chemical zinc fractions (Zn-CA, Zn-ACC, Zn-PYR, Zn-OX, Zn-RES, Zn-DTPA and Zn-TOT) in soils were worked out and are presented in Table 4. The coefficient of multiple determinations (R2) for yield and zinc uptake of sorghum with chemical zinc fractions were found to be 0.953 and 0.953, respectively which explained about 95.3% to 95.3% variation in the sorghum grain yield and zinc uptake by sorghum, respectively, due to simultaneous influence of chemical Zn fractions. This study also revealed that the Zn-ACC, Zn-DTPA and Zn- TOT played a positive role in contribution towards the sorghum zinc uptake, while sorghum grain yield was positively influenced by the Zn-ACC, Zn-PYR, Zn-DTPA and Zn-TOT. Some of the Zn fractions viz., Zn-ACC, Zn-DTPA and Zn-TOT were found to be common Zn fractions (ZnCF) in positively influencing the sorghum Zn uptake and sorghum gain yield, in-turn, these fractions indicate their specificity or preference by sorghum crop. The coefficient of multiple determinations (R^2) of yield and Zn uptake of cowpea with chemical zinc fractions were found to be 0.950 and 0.938, respectively, which means that the coefficients explained about 95% and 93.8% variation in the cowpea zinc uptake and seed yield, respectively as a result of simultaneous influence of chemical zinc fractions. The fractions Zn-PYR, Zn-OX,

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Zn-RES, Zn-DTPA and Zn-TOT were found to play a positive role in contributing toward the cowpea Zn uptake, while cowpea seed yield was positively influenced by the Zn-CA, Zn-ACC, Zn-RES, Zn-DTPA and Zn-TOT. Some of the Zn fractions (viz., Zn-RES, Zn-DTPA and Zn- TOT) were found to be common Zn fractions (ZnCF) to positively influence both the Zn uptake and cowpea seed yield thus indicate their specificity or preference by cowpea crop.

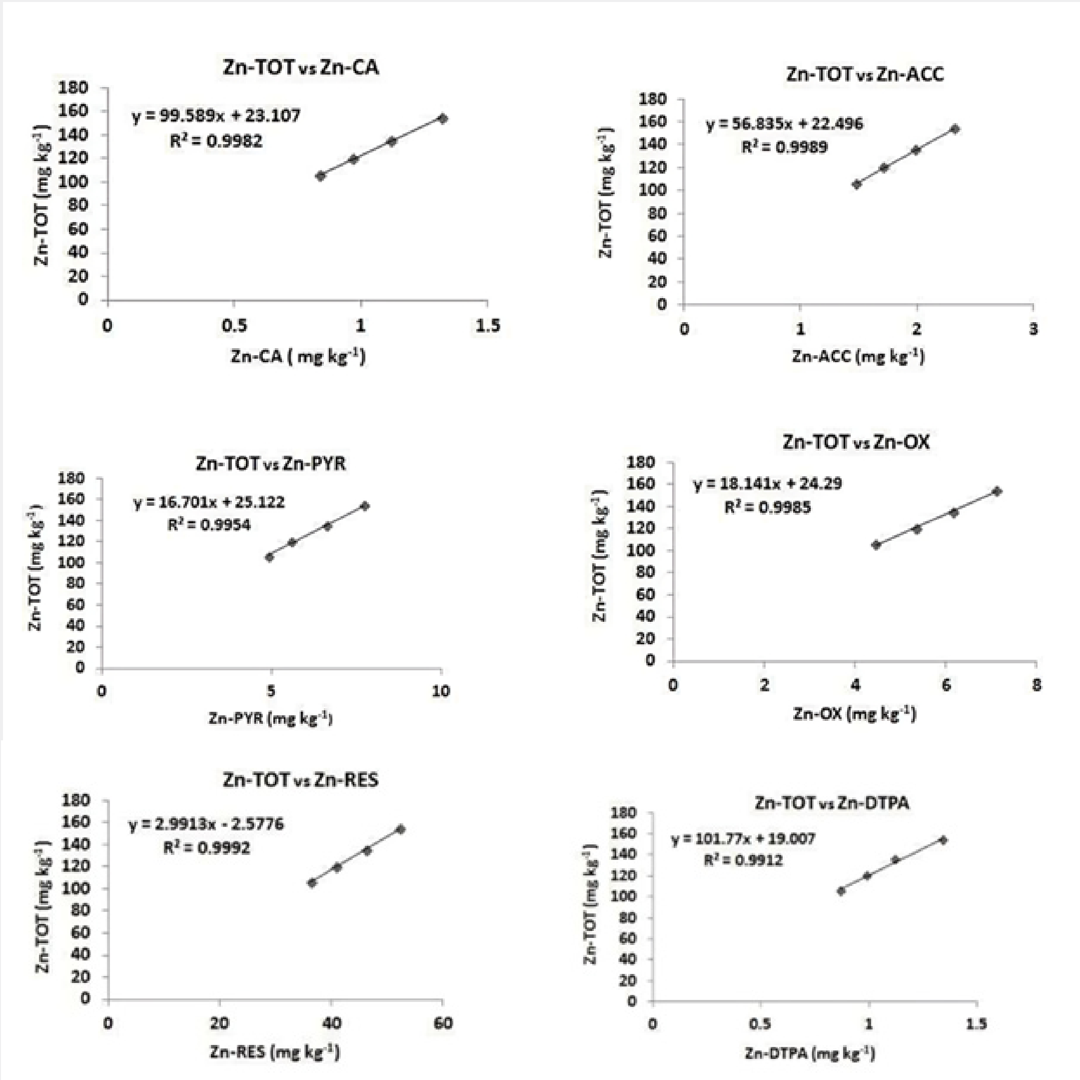

Figure 4: Linear relationships of different soil Zn fractions with total soil Zn.

Table 4: Multiple regression equations between seed yield and zinc uptake of sorghum and cowpea with chemical zinc fractions.

Dependent Variable	Linear Regression Equation	R^2
$Y_{Sorghum\ Zn\ uptake}$	- 52.083 - 48.136 (Zn-CA) + 39.366 (Zn-ACC) - 4.251 (Zn-PYR) – 12.142 (Zn-OX) - 0.477 (Zn-RES) + 86.582 (Zn-DTPA) + 0.903 (Zn- TOT)	0.953
$Y_{Sorghum\ grain\ yield}$	921.028 - 503.718 (Zn-CA) + 197.088 (Zn-ACC) + 2.605 (Zn-PYR) - 75.797 (Zn-OX) - 12.611 (Zn-RES) + 1184.478 (Zn-DTPA) + 9.106 (Zn-TOT)	0.953
$Y_{Cowpea\ Zn\ uptake}$	- 22.017 - 3.424 (Zn-CA) - 0.469 (Zn-ACC) + 0.638 (Zn-PYR) +0.244 (Zn-OX) + 0.373 (Zn-RES) + 15.484 (Zn-DTPA) + 0.174 (Zn-TOT)	0.950
$Y_{Cowpea\ seed\ yield}$	8.703 + 15.760 (Zn-CA) + 76.081 (Zn-ACC) - 7.222 (Zn-PYR) - 15.420 (Zn-OX) + 1.811 (Zn-RES) + 171.065 (Zn-DTPA) + 1.206 (Zn- TOT)	0.938

**significant at p=0.05; * p=0.01

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Correlation among different soil Zn fractions (Inter correlations)

An attempt was made to understand the relation among different soil Zn fractions by deriving correlation

coefficients among all the fractions under study (Table 5). All the fractions have shown highly significant correlation among themselves (p =0.05) and also shown significant correlation (p= 0.01) only except among the Zn-DTPA and Zn-TOT. Similar results of correlation among Zn fractions were earlier reported by Munna Lal et al. [20] and Sharma et al. [22]. The significant magnitude of correlation coefficients exhibits a some short of dynamic relationship among the Zn fractions.

Table 5: Inter- correlation coefficients (r) between zinc fractions, available and total zinc.

	Zn-CA	Zn-ACC	Zn-PYR	Zn-OX	Zn-RES	Zn-DTPA	Zn-TOT
Zn-CA	1						
Zn-ACC	0.868**	1					
Zn-PYR	0.905**	0.933**	1				
Zn-OX	0.861**	0.919**	0.953**	1			
Zn-RES	0.945**	0.929**	0.933**	0.903**	1		
Zn-DTPA	0.829**	0.791**	0.879**	0.895**	0.809**	1	
Zn-TOT	0.845**	0.870**	0.910**	0.828**	0.887**	0.690*	1

**Correlation is significant at the p =0.01 levels (2-tailed); *Correlation is significant at the 0.05 levels (2-tailed).

Conclusion

The present study on the influence of varying levels of crop residues application on soil chemical Zn fractions was taken up as these fractions have great significance in understanding the Zn dynamics. From the present study of long-term crop residue application under minimum tillage, it was clearly understood that the soil management through the application of crop residues on a long-term basis significantly influenced the distribution of Zn in different chemical fractions in soil. Some of these fractions were found to play an important role in influencing the Zn availability in soil and thereby Zn uptake and grain yields. The multiple regression studies reflected that sorghum zinc uptake was positively influenced by the Zn-ACC, Zn-DTPA and Zn-TOT, and its grain yield was influenced by Zn-ACC, Zn-PYR, Zn-DTPA and Zn-TOT fractions. The zinc uptake by cowpea was found to be influenced by Zn-PYR, Zn-OX, Zn-RES, Zn-DTPA and Zn-TOT, while the fractions viz. Zn-CA, Zn- ACC, Zn-RES, Zn-DTPA and Zn-TOT were found to influence cowpea seed yield. Thus, the present study has established that the Zn availability can be significantly enhanced in soil by adopting the appropriate soil management practices like crop residue application on long-term basis using minimum tillage practices under semi-arid tropical Alfisol soils. Crop specificity or preference of both the crops towards some of the Zn fractions was also clearly understood. The results of the present study have great significance and importance in managing the Zn availability in soil through appropriate soil management practices on SAT Alfisol soils, which are marginal not only in primary nutrients fertility but also in micronutrients like Zn.

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Conflict of Interest

Authors declared that no economic interest or any conflict of interest exists in this manuscript.

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