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Kinetics of decomposition of wheat straw and mineralisation of micronutrients in zinc-treated rice field

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Abstract : The decomposition of wheat straw in a rice field was investigated by nylon mesh bag technique and mineralization of micronutrients was estimated. In general, the rate of decomposition of wheat straw was rapid in the beginning and it slows down after two weeks probably when the assimilable products such as carbohydrate and proteins of decomposition of crop residues were exhausted. By the end of 23rd week, 86.2, 85.5, 87.0, 86.2, 82.3 and 79.4 per cent of wheat straw had decomposed under the treatments of CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively. The first order kinetic model showed better fitness than zero or second order kinetic models for wheat straw decomposition. The rate constant for wheat straw decomposition was computed and it ranged from 0.0075 to 0.0109 day^{-1} in various treatments and the range of half life of the wheat straw was found to vary from 63.6 to 92.4 days. The patterns of Zn, Fe, Cu and Mn mineralization were very much similar in quantity. Considerable amounts of Zn, Fe, Cu and Mn were mineralized which could be sufficient to meet the need of rice crop in Zn-deficient calcareous soil.

Additional key words : *Rice-Wheat cropping system, calcareous soil*

Introduction

Incidences of micronutrients deficiency in soils and crops in India, in general, and in Bihar, in particular, have increased since the adoption of modern agricultural technology with increased use of NPK fertilizers generally free from micronutrients (Ganeshamurthy *et al.* 1997). The long term fertilizer experiments provide a good illustration of the beneficial role of crop residue and organic manures in mitigating the pronounced deficiency of micronutrients which becomes more evident after a few years of continuous cropping by applying only NPK fertilizers without any micronutrient fertilizer or crop residues. The application of mineral fertilizer alone might supply one or two nutrients only but conjoint use of macro, micronutrient and crop residues could provide all macro and micronutrients to plant and soils and resist the emergence of multiple micronutrient deficiency. If sufficient quantity of organic and crop residue are added along with mineral fertilizer, then perhaps there might be no need of adding micronutrient fertilizers (Prasad and Sinha 1995).

There is meager information related to the effect of conjoint use of wheat straw, NPK fertilizers and zinc on the kinetics of decomposition of wheat straw and mineralization of micronutrients in rice fields.

Materials and Methods

A field experiment was conducted during 2003-04 in a light textured highly calcareous soil (sandy loam) deficient in available zinc (0.56 mg kg^{-1}) at RAU Research Farm, Pusa. The experimental soil (0-15 cm) had pH (1:2) 8.6, EC 0.36 dSm^{-1}, organic carbon 0.62 g kg^{-1}, Olsen's P 17.3 kg ha^{-1}, NH_4OAC-K 162 kg ha^{-1}, DTPA-Zn 0.56 mg kg^{-1}. Four levels of crop residues viz. no crop residue (CR_0), 25% of wheat straw produced (CR_1), 50% of straw produced (CR_2), 100% straw produced (CR_3) were applied as treatments in main plots. The treatments were imposed on each crop in each year. The main plot was divided into 4 sub-plots in which treatment nos Zn (Zn_0), 2.5 kg Zn ha^{-1} (Zn_1), 5.0 kg Zn ha^{-1} (Zn_2) and 10 kg Zn ha^{-1} (Zn_3) were superimposed on crop residue levels. These four levels of Zn were applied only to the first crop as a starter dose. The experiment was laid out in a split plot design with three replications. Plot size was 5.0 m x 2.0 m. Rice and wheat crops were grown continuously under rice-wheat cropping system during kharif and rabi season, since kharif 1994. Wheat cv H.D. 2733 and rice cv Rajshree were grown as 20^{th} and 21^{st} test crop, respectively during the reported period.

For studying the decomposition of wheat straw and micronutrients mineralization in rice field, nylon mesh bag technique (Schinner 1996) was followed. Sample of wheat straw applied in this investigation contained 41.9%, 0.49% and 85.5 carbon, nitrogen and C/N ratio, respectively. Zn, Fe, Cu and Mn contents of wheat straw were 20.5 mg kg^{-1} 242.2 mg kg^{-1}, 8.15 mg kg^{-1} and 78.9 mg kg^{-1}, respectively. Before transferring to nylon mesh bag, straw samples were cut into pieces of 2-3 cm size and 15 g straw sample was filled in nylon mesh (1x1 mm) bag of 15 cm x 20 cm size. Bag dimension permits all straw to be spread in a thin layer within the bag thereby ensuring good contact between straw and soil. The bags were placed in the soil vertically (15 cm deep), one day after rice transplanting in each plot receiving treatments like $R_2CR_0Zn_5$, $R_3CR_0Zn_5$, $R_2CR_{25}Zn_5$, $R_3CR_{25}Zn_5$, $R_2CR_{50}Zn_5$, $R_3CR_{50}Zn_5$, $R_2CR_{100}Zn_5$, $R_3CR_{100}Zn_5$, $R_2CR_{100}Zn_0$, $R_3CR_{100}Zn_0$, $R_2CR_0Zn_0$, $R_3CR_0Zn_0$, where R_2 and R_3 are replications. CR_0, CR_{25}, CR_{50} and CR_{100} are crop residue @ 0, 25, 50 and 100% of crop residue produced. Zn_0 and Zn_5 are 0 and 5 mg kg^{-1} soil. All the plots were kept submerged (5-7 cm) from 15^{th} day after transplanting until flowering stage of rice crop. At the end of 2, 4, 7, 11, 15, 19 and 23^{rd} weeks, one nylon mesh bag from each plot of above mentioned treatments was pulled out of the soil, washed with water for removing adhering soil particles and dried in oven at 70±1°C. The remaining straw samples were removed from the bags and weighed and finally ground before subjecting to chemical analysis for micronutrients by Atomic absorption spectrophotometer. The straw sample was digested in tri-acid mixture (H_2SO_4:H_2ClO_4:HNO_3 = 10:3:1).

The loss of mass and micronutrients from straw buried in the nylon mesh bag represented the extent of decomposition and micronutrients mineralization. Three kinetics models viz. zero, first and second order were evaluated to describe the kinetics of straw decomposition and was tested by the least square method (Croxton and Cowden 1966).

Results and Discussion

Kinetics of wheat straw decomposition

The quantity of wheat straw remaining in nylon mesh bag at various sampling intervals during investigation is presented in table 1. In general, the wheat straw decomposed rapidly for two weeks and then rate of decomposition decreased. This could be probably because of the exhaustion of the assimilable products, such as carbohydrates and proteins as a result of decomposition of crop residues. Mishra *et al.* (2001) and Sridevi *et.al.* (2003) reported similar trend of decomposition of crop residues. They further reported that decomposition rate of crop residues in flooded soil was lower than well aerated upland soils. The warm temperature (minimum 19-27°C and maximum 25-33°C) of rice field in this investigation was, however, a favourable environment for straw decomposition. Within 2 weeks, 36.4, 38.2, 39.9, 42.2, 38.6 and 32.6 per cent of wheat straw kept in the nylon bag had decomposed under treatments of CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively. At the end of 23^{rd} week, 86.2, 85.5, 87.0, 86.2, 82.3 and 79.4 per cent of wheat straw had

Table 1. Decomposition of wheat straw in rice fields and wheat straw remaining (gm)

Treatments	Time interval (weeks)						
	2	4	7	11	15	19	23
CR_0Zn_5	9.54	7.43	5.53	4.49	3.09	2.33	2.07
	(63.6)	(49.5)	(36.8)	(29.9)	(20.6)	(15.5)	(13.8)
$CR_{25}Zn_5$	9.27	8.07	5.44	4.60	3.59	2.63	2.18
	(61.8)	(53.8)	(36.2)	(30.6)	(23.9)	(17.5)	(14.5)
$CR_{50}Zn_5$	9.02	7.80	5.07	4.20	3.27	2.11	1.95
	(60.1)	(52.0)	(33.8)	(28.0)	(21.8)	(14.0)	(13.0)
$CR_{100}Zn_5$	8.68	7.28	5.02	4.24	3.42	2.48	2.08
	(57.8)	(48.5)	(33.4)	(28.2)	(22.6)	(16.5)	(13.8)
$CR_{100}Zn_0$	9.21	7.57	5.46	4.42	3.91	2.89	2.21
	(61.4)	(50.4)	(36.4)	(29.4)	(26.0)	(19.2)	(17.7)
CR_0Zn_0	10.12	8.58	7.10	6.11	5.40	4.12	3.10
	(67.4)	(57.2)	(47.3)	(40.7)	(36.0)	(27.4)	(20.6)

Data in parentheses indicates un-decomposed wheat straw (%)

Table 2. Rate constants and half life time of decomposition of wheat straw in rice field

Treatments	Rate constants (day^{-1})	Half life time ($t^{1/2}$ days)	R^2
CR_0Zn_5	0.0105	66.0	0.981**
$CR_{25}Zn_5$	0.0098	70.7	0.987**
$CR_{50}Zn_5$	0.0109	63.6	0.985**
$CR_{100}Zn_5$	0.0097	71.4	0.979**
$CR_{100}Zn_0$	0.0088	78.8	0.987**
CR_0Zn_0	0.0075	92.4	0.985**

decomposed in CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively. This indicated that zinc had accelerated the decomposition of wheat straw from 32.6 to 36.4 per cent at 2 weeks whereas it increased decomposition of wheat straw with increasing doses of crop residues. The stimulating effect of zinc on the decomposition of wheat straw may be attributed to utilization of zinc by microbes and so it facilitated multiplication of microorganisms to carry out decomposition process. The microorganisms perhaps utilized wheat straw as a source of energy, nutrients and nourishment.

The first order kinetic model showed the best fit for the wheat straw decomposition data in this investigation (R^2 = 0.979 to 0.987 for various treatments). The decay constants (K) for wheat straw as computed from first order equation were 0.0105, 0.0098, 0.0109, 0.0097, 0.0088 and 0.0075 d^{-1} for CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively (Table 2). The corresponding half-life (t ½) of the wheat straw was worked out to be 66.0, 70.7, 63.6, 71.4, 78.8 and 92.4 day^{-1}. The rate of decomposition of the wheat straw estimated under field condition appears to be greater than that reported by Prasad and Sinha (1996) from incubation study. These results suggest the limitations of incubation studies for extrapolation to field conditions.

Micro nutrients mineralization

Zinc mineralization

The results on the effect of wheat straw and zinc on zinc mineralization are presented in table 3. The

Table 3. Zinc mineralized (%) from wheat straw during decomposition in rice field

Treatments	Zn mineralization (%)							
	Time (weeks)							
	2	4	7	11	15	19	23	Mean
CR_0Zn_5	35.0	43.0	53.5	55.8	68.3	76.2	77.3	58.4
$CR_{25}Zn_5$	36.9	38.6	54.4	54.7	63.3	73.2	76.3	56.8
$CR_{50}Zn_5$	38.7	41.0	57.6	58.3	66.4	78.5	78.8	59.9
$CR_{100}Zn_5$	41.1	44.7	57.9	58.2	65.1	74.7	77.4	59.9
$CR_{100}Zn_0$	37.4	42.8	58.7	62.8	66.7	70.4	75.8	59.2
CR_0Zn_0	31.2	35.1	40.4	41.9	44.6	58.0	66.4	45.4
Mean	36.7	40.8	53.7	55.3	62.4	71.8	75.3	

	SEm±	CD (P=0.05)
Treatments (T)	0.33	0.94
Time (I)	0.31	0.87
T x I	0.82	2.30

zinc content of wheat straw remaining after decomposition increased with increasing time interval. During the first four weeks, 43.0, 38.6, 41.0, 44.7, 42.8 and 35.1% of the initial zinc in the wheat straw had mineralized as against 43.8, 38.3, 41.3, 44.7, 42.7 and 34.2 per cent of straw nitrogen in the treatments of CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively. These results suggest that the pattern of zinc mineralization was very much similar and more or less equal to nitrogen mineralization of wheat straw. During 7^{th} to 11^{th} week and 19^{th} to 23^{rd} week, little zinc mineralization occurred probably because of low temperature effect. Zinc mineralization enhanced attaining 77.3, 76.3, 78.8, 77.4, 75.8 and 66.4% of initial zinc content of wheat straw in the treatments of CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively by the end of the 23^{rd} week of field study.

The increase in Zn content of wheat straw observed in this study may be the direct effect of rapid carbon loss during the decomposition. The quantity of wheat straw mineralized during the growth period of rice would however be of much significance for crop growth in zinc deficient soil.

There was not much effect of various treatments on zinc mineralization. However, the highest zinc mineralization was observed in the treatment of $CR_{50}Zn_5$ which was very much similar to the effect on crop yield. Prasad and Sinha (1995) also reported that wheat straw incorporation in soil also replenished 61 per cent zinc removal by rice crop (137 g Zn ha^{-1}).

Copper mineralization

Data on the changes in Cu content of wheat straw and per cent mineralized Cu are presented in table 4. The Cu content of remaining wheat straw after decomposition gradually increased with increasing time intervals. The pattern of Cu mineralization is very much similar to Zn mineralization of wheat straw both in quantity and quality. During 7^{th} and 11^{th} weeks and 19^{th} and 23^{rd} weeks, little Cu mineralization was observed. Copper mineralization attained 77.5, 76.4, 78.7., 77.1, 76.2 and 66.0 per cent of initial Cu content of wheat straw in the treatment of CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively by the end of 23^{rd} week of field study. There was little effect of various treatments on Cu mineralization. However, the highest Cu mineralized was 78.7 per cent in the treatment of $CR_{50}Zn_5$. Prasad and Sinha (1995) also reported that wheat straw incorporation recycled 73% of Cu removal by rice. The copper recycled by wheat straw is very much

Table 4. Cu mineralized (%) of wheat straw during decomposition in rice field

Treatments	Cu mineralization (%)							
	Time interval (weeks)							
	2	4	7	11	15	19	23	Mean
CR_0Zn_5	35.8	45.0	54.1	56.6	69.1	76.6	77.5	59.2
$CR_{25}Zn_5$	38.2	39.0	54.4	54.4	63.4	73.1	76.4	57.0
$CR_{50}Zn_5$	37.0	40.9	57.4	58.2	65.3	77.9	78.7	59.3
$CR_{100}Zn_5$	40.1	44.0	60.6	61.0	62.9	72.4	77.1	59.7
$CR_{100}Zn_0$	37.7	48.8	59.2	60.0	60.7	70.3	76.2	59.1
CR_0Zn_0	32.1	35.7	41.0	42.8	44.6	58.0	66.0	45.7
Mean	36.8	42.2	54.4	55.5	61.0	71.9	75.3	

	SEm±	CD (P=0.05)
Treatments (T)	0.28	0.78
Time (I)	0.26	0.72
T x I	0.68	1.90

important in maintaining and sustaining soil fertility and crop productivity.

Iron mineralization

The data on changes in Fe content and Fe mineralized of wheat straw during decomposition in rice field are presented in table 5. The Fe content of remaining wheat straw after decomposition at various time intervals increased gradually. The Fe content of decomposed wheat straw increased from 24.0 to 35.5 mg kg^{-1} with periodic changes from 0 to 23rd weeks. The pattern of Fe mineralization followed the trend of zinc mineralization. Iron mineralized (%) was very much similar to Zn and Cu mineralization. During the first four weeks, 43.8, 38.1, 39.6, 45.0, 41.3 and 39.1 per cent of the initial Fe content in wheat straw mineralized as against 43.0, 38.6, 41.0, 44.7, 42.8 and 35.1 per cent of initial Zn content of wheat straw in the treatments of CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively. These results

Table 5. Fe mineralized (%) of wheat straw during decomposition in rice field

Treatments	Fe mineralization (%)							
	Time interval (weeks)							
	2	4	7	11	15	19	23	Mean
CR_0Zn_5	35.2	43.8	53.5	55.8	68.4	77.3	76.2	58.6
$CR_{25}Zn_5$	37.0	38.1	53.8	67.2	67.5	76.0	72.9	58.9
$CR_{50}Zn_5$	38.5	39.6	56.4	57.8	66.2	78.4	77.9	59.2
$CR_{100}Zn_5$	41.1	45.0	57.5	58.3	65.1	77.3	74.4	59.8
$CR_{100}Zn_0$	39.0	41.3	54.1	56.5	59.9	75.9	70.4	56.7
CR_0Zn_0	31.5	39.1	40.4	41.9	50.5	66.3	57.7	46.8
Mean	37.0	41.1	52.6	56.2	62.9	71.6	75.2	

	SEm±	CD (P=0.05)
Treatments (T)	0.28	0.80
Time (I)	0.26	0.74
T x I	0.70	1.96

indicated that the modes of Zn, Cu and Fe mineralization are very much similar. During 7th and 11th weeks and 15th and 23rd weeks, little Fe mineralization process occurred. Iron mineralization increased with increasing time interval and by the end of 23rd week attained 77.3, 76.0, 78.4, 77.3, 75.9, 66.3 per cent of initial Fe in wheat straw in the treatments of CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively.

The increase in Cu and Fe contents of the wheat straw noted in this study might be the direct effect of rapid carbon loss during the decomposition. In a similar study, Zogal *et al.* (2003) reported that P content of wheat straw increased after 30 days since its application in the soil. The quantity of wheat straw Fe mineralized during the growth of rice would sufficiently meet the requirement of Fe by rice crop. Prasad and Sinha (1995) reported that wheat straw recycled 82% of Fe removal by rice crop in rice field (1023 g Fe ha^{-1}).

Manganese mineralization

Results on changes in Mn content of decomposed wheat straw at different time intervals are presented in table 6. Mn content of the decomposed wheat straw increased gradually with increasing time interval. The highest Mn content of decomposing wheat straw at 23rd weeks of interval was obtained in the treatment of $CR_{100}Zn_0$ and the lowest being in the treatment of CR_0Zn_0. The pattern of Mn mineralization was very much similar to that of N, Zn, Cu and Fe mineralization of wheat straw. During 7th and 11th weeks and 19th and 23rd weeks, little Mn mineralization occurred probably due to temperature effect. The increase in Mn content of wheat straw noticed in the present study might be the direct effect of rapid carbon loss during the decomposition. During 4th week, the extent of Mn mineralization was 44.7, 38.0, 40.0, 44.3, 42.1, and 34.7 per cent which enhanced to 69.2, 62.8, 66.0, 64.5, 57.8 and 40.8 per cent at 15th week time interval in the treatments of CR_0Zn_5, $CR_{25}Zn_5$, $CR_{50}Zn_5$, $CR_{100}Zn_5$, $CR_{100}Zn_0$ and CR_0Zn_0, respectively. In these treatments, respective values of Mn mineralization were, 78.0, 76.0, 78.2, 77.4, 74.3 and 63.5 per cent of initial Mn mineralized during growth period of rice which could be sufficient to meet the requirement of rice in the field. Prasad and Sinha (1995) reported that wheat straw recycled 83 per cent removal of Mn by rice in calcareous soil.

To sum up, the kinetics of decomposition of wheat straw in rice field followed first order. In general, the rate of decomposition of wheat straw was rapid in the beginning and it slowed down after two weeks in calcareous rice field perhaps when

Table 6. Mn mineralized (%) of wheat straw during decomposition in rice field

Treatments	Mn mineralization (%)							
	Time interval (weeks)							
	2	4	7	11	15	19	23	Mean
CR_0Zn_5	35.9	44.7	54.3	56.1	69.2	76.3	78.0	59.2
$CR_{25}Zn_5$	37.1	38.0	53.7	53.9	62.8	72.7	76.0	56.3
$CR_{50}Zn_5$	38.2	40.0	57.3	58.2	66.0	77.3	78.2	59.3
$CR_{100}Zn_5$	41.1	44.3	58.0	58.3	64.5	74.1	77.4	59.6
$CR_{100}Zn_0$	37.1	42.1	53.7	55.3	57.8	67.7	74.3	55.4
CR_0Zn_0	32.2	34.7	39.8	40.6	40.8	54.2	63.5	43.7
Mean	36.9	40.6	52.8	53.7	60.2	70.4	74.5	

	SEm±	CD (P=0.05)
Treatments (T)	0.26	0.73
Time (I)	0.24	0.68
T x I	0.64	1.79

assimilable products such as carbohydrates and proteins of decomposition of crop residues were exhausted. The pattern of Zn, Cu Fe and Mn mineralization was very much similar in quantity. Considerable quantities of Zn, Cu, Fe and Mn contents of wheat straw were mineralized which could meet the requirements of these micro-nutrients by rice crop in zinc deficient calcareous soil.

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