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Response of scheduled application of zn and fym on yield and micronutrient uptake under rice wheat rotation

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Abstract
Background: Application of Zn, FYM and their conjoint applications increased grain and straw yields of both rice and subsequent wheat crop however; no significant effect of treatment application schedule was recorded on yields of any crop. A proper nutrient management in rice-wheat system is warranted, so as to achieve high and sustainable productivity of the system present investigation was executed.
Methods: Field experiments were conducted at Modipuram, District Meerut (U.P.) to evaluate the effects of zinc, farmyard manure and their combined application at two different schedules of application i.e. after two crop cycles or once in three years on yields and micronutrient uptake of third year rice and subsequent wheat crops.
Result: Combined application of 2.5 kg Zn + 5 t FYM/ha increased the grain and straw yield of rice and wheat crops by 39.3, 34.2, 29.5 and 15.0 per cent over control, respectively. Application of treatments after two crop cycles resulted higher Zn uptake in rice grain as compared to treatment application limited to first year rice crop. Combined application of Zn and FYM was more effective in increasing total Zn uptake of rice and rice + wheat than individual application of FYM or Zn. The interaction effect of treatments and their application schedule significantly influenced uptake of Cu, Fe and Mn in crops. Application of 2.5 kg Zn + 5 t FYM/ha to rice crop can be recommended for rice-wheat rotation on Zn-deficient Ustochrept soils of western Uttar Pradesh.

Keywords: micronutrient, zinc, fym, rice-wheat rotation, straw yield, ustochrept soils

Introduction

Rice-wheat system is one of the most widely practiced cropping systems of *Tarai* as well as North India. With the development of suitable varieties, the area under rice-wheat is expanding even in many non-traditional areas. Both rice and wheat are exhaustive feeders of nutrients (700 kg NPK/ha/year for 15 tonnes of grain/ha) (Narang *et al.*, 1990) [5]. The cultivation of two cereals year after year has led to declining soil fertility and poor crop yields. With the use of high analysis NPK fertilizers, generally devoid of micronutrients, has no doubt remarkably increased food production but simultaneously put forth a host of problems relating micronutrient deficiencies, particularly of Zn in soil (Singh and Saxena, 2019) [13, 15]. A proper nutrient management in rice-wheat system is warranted, so as to achieve high and sustainable productivity of the system. Among all micronutrients, zinc is one of the most important micronutrient, for the healthy growth of plant; as it performs several physiological functions in the plant. Zinc is indispensable for normal plant growth and maintains oxidation-reduction potential with in the cell (Sommers and Lipman; 1926) [16]. "*Khaira*" diseases an expression of Zn deficiency which has become a widespread disorder in lowland rice (Nene; 1966) [6]. Zinc deficiency in soil is widespread throughout the world, especially in rice cropland of Asia (Tisdale *et al.*, 1997) [20]. and in soil order of *Entisol*, *Asidisol*, *Alfisol*, *Mollisol* and *Vertisol* (Srivastava and Gupta, 1996) [17]. As Zinc deficiency has been noticed from several parts of India, Zinc application in rice-wheat system has become inevitable. The integrated use of organic and inorganic fertilizers has been found promising not only in maintaining higher productivity, but also in providing maximum stability in terms of crop yield (Nambiar and Abrol, 1989) [4]. Though, FYM is bulky organic manure containing low concentration most of the essential plant nutrients and its application in rice-wheat cropping system tend to build up the organic matter in wet tropics and improve nutrient contents in soil and improve crop yields (Meelu and Morris, 1988; Saxena and Singh, 2019) [13, 15]. Organic manure acts as storehouse of micronutrients (Stevenson, 1982) [18]. The use of application which of even reduced application of zinc to about 50 per cent (Sakal *et al.*, 1985) [11].

Material and Methods

To ascertain the effects of frequency of treatment application and of individual and conjoint application of zinc and farmyard manure previously applied to first crop of rice, on yields and nutrient uptake of rice third year and in the following wheat crop, field experiments were conducted at Modipuram (Distt. Meerut). District lies between longitudes 77°7' to 78°14' east and latitudes 28°32' to 29°18' north, which is situated in the upper Ganga-Yamuna *Doab* (alluvium). On the north, it is bounded by Muzaffarnagar district and on the southwest by Delhi. The climate of Meerut district is influenced largely by the prevalence of dry air of the continental type, the summer being intensely hot followed by cold winter. It is only during the monsoon months when air of oceanic origin reaches the district, bringing humidity, cloudiness and rain. In Meerut district, the mean annual rainfall is 837.8 mm and increases from southwest to northeast. About 87.7 per cent of that total annual rainfall is received during months of June, July, August, September and October (8.4, 29.4, 27.4, 19.1 and 4.1 per cent, respectively). Remaining is 1.3 per cent is received in November-December, 9 per cent in January to March and 2 per cent in April-May. July and August witness the maximum rainfall followed by September, June and October.

The mean annual maximum temperature in Meerut district is 31.2°C and mean annual minimum temperature is 18.3°C. The mean monthly maximum temperature is lowest in January (20.6°C) and highest in May (40.0°C). The mean monthly minimum temperature is the lowest in January (7.9°C) and the highest in June (27.4°C). The mean monthly temperature remains low during December and January (16.65°C and 14.45°C, respectively) and high during May and June (32.4°C and 33.45°C, respectively).

The air remains dry for most part of the year. The relative humidity is the highest in July-August (average 81.0 per cent) and lowest in April-May (average 38.5 per cent) with an average of about 64 per cent.

Collection of Soil Samples after Wheat Harvest

Post-harvest surface (0-15 cm) soil samples of experimental area were collected with the help of a spade. The soil was air dried in shade and ground with a wooden roller and then passed through a 2 min sieve.

Table 1

Treatments*:		
Main Plots:	M_1	Application on alternate years
	M_2	Application once in three years
Sub-plot:		
	T_1	Control (No zinc application)
	T_2	FYM @ 5t/ha
	T_3	2.5 kg Zn as $ZnSO_4$/ha
	T_4	3.75 kg Zn as $ZnSO_4$/ha
	T_5	5.00 kg Zn as $ZnSO_4$/ha
	T_6	2.5 kg Zn as $ZnSO_4$/ha + FYM @ 5 t/ha
	T_7	3.75 kg Zn as $ZnSO_4$/ha + FYM@ 5 t/ha
* Treatments limited to rice crop only		
Experimental Design:	Split plot RBD	

Results and Discussion

Grain and Straw Yields of Rice and Wheat

It is evident from the data contained in Table 1 that the grain and straw yields of rice and grain yield of subsequent wheat crop were not significantly affected by main plots i.e. frequency of treatment application however, the straw yield of wheat was significantly higher where treatment application was made in the first year alone as compared to case where treatment application was repeated after two crop cycle.

Table 1: Effect of different Zn treatments and frequency of their application on grain and straw yield of rice and wheat in third year.

Main Plot	**Sub-plot Treatments**	**Yield (Q/ha)**			
		Rice		**Wheat**	
		Grain	**Straw**	**Grain**	**Straw**
After 2 crop cycles	Control	31.53	44.03	31.61	76.16
	5 t FYM/ha	36.96	52.36	35.89	83.30
	2.5 kg Zn/ha	41.65	54.50	37.37	82.24
	3.75 kg Zn/ha	41.29	53.31	41.17	90.44
	5.00 kg Zn/ha	44.98	57.12	41.65	87.47
	2.5 kg Zn + 5 t FYM/ha	45.22	59.50	42.06	85.09
	3.75 kg Zn + 5 t FYM/ha	45.03	60.69	42.57	83.97
	Mean	40.95	54.50	38.90	84.09
After 3 crop cycles	Control	32.13	46.41	32.92	77.35
	5 t FYM/ha	36.22	51.17	36.34	83.30
	2.5 kg Zn/ha	39.86	55.93	38.27	84.73
	3.75 kg Zn/ha	39.58	54.69	40.82	89.25
	5.00 kg Zn/ha	43.62	57.72	40.91	91.63
	2.5 kg Zn + 5 t FYM/ha	43.43	59.50	41.51	91.39
	3.75 kg Zn + 5 t FYM/ha	43.27	60.69	41.98	92.01
	Mean	39.73	55.16	38.97	87.09
Mean Sub-plot	Control	31.83	45.22	32.26	76.76
	5 t FYM/ha	36.59	51.77	36.12	83.30
	2.5 kg Zn/ha	40.76	55.22	37.82	83.49
	3.75 kg Zn/ha	40.44	54.00	41.00	89.85
	5.00 kg Zn/ha	44.30	57.42	41.28	89.55

	2.5 kg Zn + 5 t FYM/ha	44.33	59.50	41.78	88.24
	3.75 kg Zn + 5 t FYM/ha	44.15	60.69	42.28	87.99
C.D.(p=0.05)	Main plot	NS	NS	NS	2.87
	Subplot	3.17	3.42	1.6	5.98
	Subplots within main plot	NS	NS	NS	NS
	Subplots across the main plot	NS	NS	NS	NS

The effect of subplots on yields of both grain and straw of rice and subsequent wheat crop was significant. Application of 2.5, 3.75 and 5 kg Zn/ha significantly increased the grain yield of rice crop by 28.1, 27.1 and 39.2 per cent and rice straw yield by 22.1, 19.4 and 27.0 over control, respectively. Application of 5 t FYM/ha also significantly increased rice grain yield by 14.9 per cent and straw yield by 14.5 per cent over control. Kumar *et al.*, (2010) [3]. reported similar to these findings. Application of 5 t/FYM together with 2.5 or 3.75 kg Zn/ha significantly increased rice grain yield by 39.3 and 38.7 per cent and rice straw yield by 31.6 and 34.2 per cent over control, respectively. Singh (1999) [14]. also reported that application of Zn to first crop rice had significantly increased grain yields of rice. A favorable effect of FYM application on yields of third crop of rice has been recorded earlier. Sakal *et al.* (1995) [9]. also reported that application of Zn and compost to first crop rice significantly increased yields of third crop of rice. Zinc application @ 2.5, 3.75 and 5.0 kg Zn/ha to rice crop had a significant residual effect on yields of subsequent third year wheat crop and the recorded increase in grain yield and straw yield was 17.2, 27.1 and 28.0 per cent and 8.8, 17.1 and 16.7 per cent over control, respectively. Application of farmyard manure alone or in combination with 2.5 and 3.75 kg Zn/ha to rice crop also had significant residual effect on grain and straw yields of wheat and wheat grain and straw yields were increased by 12.0, 29.5 and 31.1 per cent and 8.52, 15.0 and 14.6 over control, respectively. Patidar and Mali (2002) [7]. reported that higher yield of wheat under FYM treatment was owing to better plant growth and higher yield attributes of wheat as a result of improvement in soil physical and chemical properties with FYM application. Sakal (2001) [12]. have reported that application of Zn at the rate of 10 kg/ha brought a significant yield increase for the next three crops of rice-wheat system. Prasad *et al.* (1989) [8]. also observed that the residual effect of Zn applied through organic sources persisted even after the harvest of the fourth crop of wheat and rice.

Nutrient Uptake in Grain and Straw Parts and Total Uptake by Crops

The effect of different treatments and frequency of their application on micronutrient uptake by grain and straw parts and total zinc uptake of rice and wheat crop are presented in Table 2, 3, 4 and 5.

Zinc

As shown in Table 2 Zn uptake by the grain of rice was significantly higher where treatment application was repeated after two crop cycle as compared to case where treatment application was done in the first year alone; the magnitude of increase was 40.8 per cent.

The effect of subplots was only significant on Zn uptake by grains of rice and subsequent wheat crop. Application of 2.5 kg Zn/ha increased Zn uptake of wheat grain significantly by 17.1 per cent over control. Application of 3.75 and 5 kg Zn/ha increased Zn uptake of rice and wheat grains significantly by 38.0 and 40.9 and by 20.5 and 35.5 per cent over control, respectively.

Application of 3.75 and 5 kg Zn/ha increased total Zn uptake of rice and rice + wheat significantly by 32.2 and 25.3 and by 25.7 and 21.5 per cent over control, respectively. Application of 5 t FYM/ha increased total Zn uptake of rice significantly by 19.8 per cent over control.

Application of 5 t/FYM together with 2.5 and 3.75 kg Zn/ha increased Zn uptake of rice and wheat grain by 47.3 and 68.3 and by 28.0 and 26.2 per cent over control, respectively.

Application of 5 t FYM/ha together with 2.5 and 3.75 kg Zn/ha increased total Zn uptake of rice and rice + wheat by 35.7 and 35.4 and by 24.9 and 23.1 per cent over control, respectively. Sakal *et al.* (1981) [10].

Khamparia *et al.* (1994) [2].observed that an increase in the rate of zinc application increased the zinc uptake of wheat. Prasad *et al.* (1981) also observed that application of zinc increased uptake considerably in wheat grain.

Table 2: Effect of different Zn treatments and frequency of their application on Zn uptake by grain and straw of rice and wheat and total Zn uptake in third year.

Main Plot	Sub-plot Treatments	Zn uptake (gm/ha)				Total Zn uptake (gm/ha)		
		Rice		Wheat				
		Grain	Straw	Grain	Straw	Rice	Wheat	Rice + Wheat
After 2 crop cycles	Control	68.61	97.53	103.72	85.47	166.14	189.18	355.32
	5 t FYM/ha	77.21	128.54	111.21	88.13	205.75	199.34	405.09
	2.5 kg Zn/ha	73.93	98.11	117.25	97.97	172.03	215.23	387.26
	3.75 kg Zn/ha	103.27	126.89	128.58	127.48	230.16	256.07	486.22
	5.00 kg Zn/ha	114.70	119.30	153.99	83.64	234.00	237.64	471.64
	2.5 kg Zn + 5 t FYM/ha	109.43	145.92	133.28	105.01	255.36	238.28	493.64
	3.75 kg Zn + 5 t FYM/ha	129.33	108.06	137.44	83.32	237.38	220.77	458.15
	Mean	96.64	117.76	126.50	95.86	214.40	222.36	436.76
After 3 crop cycles	Control	57.71	110.51	110.56	110.96	168.22	221.52	389.74
	5 t FYM/ha	67.35	127.46	106.13	85.89	194.80	192.03	386.83
	2.5 kg Zn/ha	60.88	131.85	133.66	75.17	192.73	208.83	401.56
	3.75 kg Zn/ha	71.09	140.84	129.54	108.96	211.92	238.50	450.42
	5.00 kg Zn/ha	63.35	121.70	136.45	112.01	185.04	248.46	433.50

	2.5 kg Zn + 5 t FYM/ha	76.68	121.59	141.05	97.51	198.27	238.56	436.83
	3.75 kg Zn + 5 t FYM/ha	83.25	131.95	133.06	110.76	215.20	243.82	459.03
	Mean	68.62	126.55	127.21	100.18	195.17	227.39	422.56
Mean Sub-plot	Control	63.16	104.02	107.14	98.21	167.18	205.35	372.53
	5 t FYM/ha	72.28	128.00	108.67	87.01	200.28	195.68	395.96
	2.5 kg Zn/ha	67.41	114.98	125.46	86.57	182.38	212.03	394.41
	3.75 kg Zn/ha	87.18	133.86	129.06	118.22	221.04	247.28	468.32
	5.00 kg Zn/ha	89.02	120.50	145.22	97.83	209.52	243.05	452.57
	2.5 kg Zn + 5 t FYM/ha	93.06	133.76	137.16	101.26	226.81	238.42	465.23
	3.75 kg Zn + 5 t FYM/ha	106.29	120.00	135.25	97.04	226.29	232.29	458.59
C.D.(p=0.05)	Main plot	20.21	NS	NS	NS	NS	NS	NS
	Subplot	21.34	NS	16.71	NS	26.14	NS	46.02
	Subplots within main plot	NS	NS	NS	NS	NS	NS	NS
	Subplots across the main plot	NS	NS	NS	NS	NS	NS	NS

Copper

As data depicted in Table 3, the values of Cu uptake by the straw of rice and by grain of subsequent wheat crop or total uptake by rice, wheat and rice + wheat in the third year were not significantly affected by main plots i.e. frequency of treatment application, however, Cu uptake by grain of rice was significantly higher and by straw of wheat was significantly lower when treatment application was repeated after two crop cycle as compared to case where treatment application was done in the first year alone; the magnitude of change was 19.6 and 18.5 per cent, respectively.

The effect of subplots was significant on Cu uptake by grains and straw of rice and subsequent wheat crop. Application of 2.5 kg Zn/ha significantly increased Cu uptake of wheat gain by 19.8 per cent over control. Application of 3.75 and 5 kg Zn/ha significantly increased copper uptake of grain and straw of wheat by 25.1 and 19.6 and by 24.8 and 24.3 per cent over control, respectively. These doses also increased total copper uptake of wheat and rice + wheat by 24.9 and 22.6 and by 12.7 and 16.2 per cent over control, respectively. Application of 5 t FYM/ha significantly increased copper uptake of grain and straw of rice by 8.3 and 33.6 per cent over control respectively, it also increased total copper uptake by rice and rice + wheat by 21.8 and 12.6 per cent over control respectively. Swarup (1985) [19]. reported an increase in copper uptake of rice in FYM treated soil. Dosani *et al.* (1999) [1]. also reported significantly rice + wheat increased copper uptake with increasing levels of fertilizers along with poultry manure which could be due to formation of organic complexes by chelation. Application of 5 t FYM together with 2.5 and 3.75 kg Zn/ha increased copper uptake by straw of rice and grain of subsequent wheat crop by 19.6 and 18.3 and by 35.0 and 32.2 per cent, respectively. These treatments also increased total copper uptake of rice + wheat by 9.1 and 6.6 per cent over control. The interaction effect of main plot × subplots significantly influenced Cu uptake by wheat straw. Application of 3.75 kg and 5 kg Zn/ha to rice crop after two crop cycles increased Cu uptake by wheat straw significantly over control. In general, Cu uptake values by wheat straw under two crop cycle frequency were lower than those under three crop cycle frequency.

Table 3: Effect of different Zn treatments and frequency of their application on Cu uptake by grain and straw of rice and wheat and total Cu uptake in third year.

Main Plot	Sub-plot Treatments	Cu uptake (gm/ha)				Total Cu uptake (gm/ha)		
		Rice		Wheat				
		Grain	Straw	Grain	Straw	Rice	Wheat	Rice + Wheat
After 2 crop cycles	Control	32.02	30.75	17.31	28.00	62.77	45.31	108.08
	5 t FYM/ha	33.96	42.10	20.24	27.47	76.06	47.71	123.77
	2.5 kg Zn/ha	21.65	29.72	21.00	33.53	51.37	54.53	105.90
	3.75 kg Zn/ha	24.38	38.79	22.41	41.17	63.17	63.58	126.75
	5.00 kg Zn/ha	27.64	33.60	25.53	39.53	61.24	65.06	126.30
	2.5 kg Zn + 5 t FYM/ha	25.86	38.46	23.77	33.13	64.32	56.90	121.22
	3.75 kg Zn + 5 t FYM/ha	28.13	36.39	25.58	26.24	64.52	51.82	116.34
	Mean	27.66	35.68	22.26	32.72	63.34	54.98	118.32
After 3 crop cycles	Control	25.34	34.59	21.33	38.66	59.93	59.99	119.92
	5 t FYM/ha	28.18	45.22	20.10	39.39	73.40	59.44	132.89
	2.5 kg Zn/ha	20.16	31.91	25.30	35.30	52.07	60.60	112.67
	3.75 kg Zn/ha	22.04	40.23	25.94	42.02	62.27	67.96	130.23
	5.00 kg Zn/ha	19.06	35.67	20.69	43.31	54.73	64.00	118.73
	2.5 kg Zn + 5 t FYM/ha	22.22	39.67	28.41	37.25	61.89	65.66	127.55
	3.75 kg Zn + 5 t FYM/ha	24.89	40.92	25.53	35.47	65.81	61.00	126.81
	Mean	23.12	38.31	23.90	38.77	61.43	62.67	124.40
Mean Sub-plot	Control	28.68	32.67	19.32	33.33	61.35	52.65	114.00
	5 t FYM/ha	31.07	43.66	20.17	33.43	74.73	53.60	128.33
	2.5 kg Zn/ha	20.91	30.81	23.15	34.41	51.72	57.56	109.28
	3.75 kg Zn/ha	23.21	39.51	24.17	41.59	62.72	65.76	128.48
	5.00 kg Zn/ha	23.35	34.63	23.11	41.42	57.98	64.53	132.51

	2.5 kg Zn + 5 t FYM/ha	24.04	39.06	26.09	35.19	63.10	61.28	124.38
	3.75 kg Zn + 5 t FYM/ha	26.51	38.66	25.55	30.85	65.17	56.40	121.57
C.D.(p=0.05)	Main plot	2.97	NS	NS	3.52	NS	NS	NS
	Subplot	2.88	4.14	3.50	3.93	5.18	7.3	9.8
	Subplots within main plot	NS	NS	NS	5.55	NS	NS	NS
	Subplots across the main plot	NS	NS	NS	5.99	NS	NS	NS

Iron

It is evident from Table 4, iron uptake by the grain of rice and total uptake by rice and rice + wheat was significantly higher and uptake by grain of wheat was significantly lower when treatment application was repeated after two crop cycle as compare to case where treatment application was made in the first year alone. The effect of subplots on iron uptake by grain and straw of rice and subsequent wheat crop was significant, total uptake by rice, wheat and rice + wheat rotation was also significant. Application of 2.5 kg Zn and 5.0 kg Zn/ha significantly decreased iron uptake of grain of rice by 32.4 and 17.2 per cent over control. Application of 2.5 kg Zn decreased iron uptake by rice straw but that of 3.75 kg Zn/ha increased iron uptake by rice straw significantly over control. Application of 5 t FYM with 3.75 kg Zn/ha significantly increased uptake in grain of rice 32.3 per cent control. Application of 2.5 kg Zn + 5 t FYM/ha significantly increased iron uptake in straw of rice by 26.4 per cent over control. In case of subsequent wheat crop, iron uptake by grain was significantly increased due to application of 2.5 kg Zn/ha, with application of 5 t FYM/ha there was a significant decrease in iron uptake by grain of wheat. Application of 3.75 kg Zn and 5.0 kg Zn/ha significantly increased iron uptake by straw of wheat by 48.8 and 13.2 per cent over control respectively. Application of 2.5 kg Zn + 5 t FYM/ha also significantly increased iron uptake in straw of subsequent wheat crop by 18.7 per cent over control. Total iron uptake by rice crop significantly increased by 11.8 and 20.3 per cent over control due to application of 3.75 kg Zn/ha and 2.5 kg Zn + 5 t FYM/ha. Application of 3.75 kg Zn/ha and 2.5 kg Zn with 5 t FYM/ha significantly increased total iron uptake of wheat crop by 38.4 and 13.6 per cent and total uptake of rice-wheat rotation by 21.5 and 17.8 per cent over control, respectively. The interaction effect of main plot × subplots significantly influenced Fe uptake by grain and straw of both rice and wheat crop.

Application of 2.5 kg and 5.0 kg Zn/ha to rice crop after two crop cycles decreased Fe uptake by rice grain significantly over control but application of 3.75 kg Zn + 5 t FYM/ha after two crop cycles significantly increased it. Similarly, application of 3.75 kg Zn or 3.75 kg Zn + 5 t FYM/ha to first year rice crop increased Fe uptake by rice grain over control. Application of 3.75 kg Zn and 2.5 kg Zn + 5 t FYM/ha to rice crop after two crop cycles increased Fe uptake by rice straw significantly over control, while application of 2.5 kg Zn/ha to rice crop after two crop cycles decreased it in comparison to control.

Table 4: Effect of different Zn treatments and frequency of their application on Fe uptake by grain and straw of rice and wheat and total Fe uptake in third year.

Main Plot	Sub-plot Treatments	Fe uptake (gm/ha)				Total Fe uptake (gm/ha)		
		Rice		Wheat				
		Grain	Straw	Grain	Straw	Rice	Wheat	Rice + Wheat
After 2 crop cycles	Control	464.43	1399.92	80.50	804.51	1864.35	885.01	2749.36
	5 t FYM/ha	448.65	1353.01	88.17	991.56	1801.66	1079.73	2881.39
	2.5 kg Zn/ha	305.57	840.19	105.29	945.56	1145.39	1050.85	2196.61
	3.75 kg Zn/ha	439.17	1657.51	167.80	1188.61	2096.68	1356.41	3453.17
	5.00 kg Zn/ha	351.66	1374.18	122.14	977.28	1725.44	1099.42	2825.26
	2.5 kg Zn + 5 t FYM/ha	422.34	2132.40	147.18	947.70	2554.74	1094.88	3649.62
	3.75 kg Zn + 5 t FYM/ha	630.34	1210.56	132.22	970.78	1840.90	1103.00	2943.90
	Mean	437.45	1423.98	120.36	975.14	1861.30	1095.50	2957.04
After 3 crop cycles	Control	313.41	1173.68	230.89	821.85	1487.09	1052.84	2539.93
	5 t FYM/ha	359.66	1068.19	73.21	772.68	1427.45	885.89	2273.74
	2.5 kg Zn/ha	282.03	1160.10	256.90	557.46	1442.13	814.36	2256.49
	3.75 kg Zn/ha	421.53	1227.43	93.94	1231.50	1648.96	1325.44	2974.40
	5.00 kg Zn/ha	311.99	1219.74	88.21	863.30	1531.73	951.51	2483.24
	2.5 kg Zn + 5 t FYM/ha	356.58	1120.31	123.65	982.75	1476.89	1106.98	2583.29
	3.75 kg Zn + 5 t FYM/ha	398.43	1376.37	109.41	734.43	1774.80	843.84	2618.64
	Mean	349.09	1192.26	139.47	851.99	1541.35	991.46	2532.81
Mean Sub-plot	Control	388.92	1286.80	155.74	813.18	1675.72	968.92	2644.65
	5 t FYM/ha	404.15	1210.60	80.69	882.12	1614.76	962.81	2577.57
	2.5 kg Zn/ha	293.80	1000.14	181.09	751.50	1293.94	932.59	2226.53
	3.75 kg Zn/ha	430.35	1442.24	130.51	1210.05	1872.82	1340.56	3213.79
	5.00 kg Zn/ha	331.82	1296.96	105.17	920.29	1628.78	1025.46	2654.24
	2.5 kg Zn + 5 t FYM/ha	389.46	1626.35	135.41	965.22	2015.81	1100.63	3116.44
	3.75 kg Zn + 5 t FYM/ha	514.39	1293.46	120.82	852.60	1807.85	973.42	2781.27
C.D.(p=0.05)	Main plot	49.30	NS	18.28	NS	179.30	NS	205.30
	Subplot	45.78	181.07	18.45	90.80	175.40	90.60	201.70
	Subplots within main plot	64.74	256.00	26.09	128.41	NS	NS	NS
	Subplots across the main plot	87.64	320.38	29.02	164.21	NS	NS	NS

Manganese

The effect of subplots was significant on Mn uptake by grain and straw of rice and subsequent wheat crop (Table 5). Application of 3.75 and 5 kg Zn/ha significantly increased manganese uptake of grain and straw of rice by 29.8, 11.1 and by 27.4 and 24.3 per cent over control, respectively. Application of 3.75 kg Zn + 5 t FYM/ha significantly increased manganese uptake of grain and straw of rice crop by 38.8 and 17.5 over control respectively. Swarup (1985) [19]. also reported that the use of FYM increased the uptake of Mn by rice crop.

Total manganese uptake by rice (grain + straw) was increased significantly due to application of 5 t FYM/ha alone and combined application 5 t FYM + 3.75 kg Zn/ha; the magnitude of increase over control was 13.9 and 20.6 per cent, respectively. The residual effect of 5.0 kg Zn/ha to rice significantly increased manganese uptake in wheat grain and straw by 22.3 and 15.8 per cent over control respectively. The residual effect of combined application of 5 t FYM + 2.5 or 3.75 kg Zn/ha to rice significantly increased manganese uptake in wheat grain by 32.5 and 28.9 per cent, in wheat straw by 20.6 and 18.2 per cent and total manganese uptake of wheat by 24.7 and 22.0 per cent over control, respectively. Total manganese uptake of rice-wheat rotation was also significantly increased by 16.4 and 23.0 per cent over control due to application of 3.75 and 5 kg Zn/ha to rice, respectively. Application of 5 t FYM alone and combined application of 5 t FYM + 3.75 kg Zn/ha to rice also significantly increased total manganese uptake of rotation by 24.3 and 20.9 per cent over control, respectively. The interaction between main plot and subplots significantly influenced Mn uptake by rice straw, by grain and straw of wheat and total Mn uptake by rice and rice + wheat crops. Application of 5 t FYM/ha 3.75 and 5.0 kg Zn/ha, and 3.75 kg Zn + 5 t FYM after two crop cycles increased Mn uptake by third year rice straw significantly over control. Application of 5 t FYM/ha, 2.5 and 5.0 kg Zn/ha and 3.75 kg Zn + 5 t FYM/ha to first year rice crop increased Mn uptake by rice straw in the third year significantly over control. In general, combined application of Zn and FYM after two crop cycles decreased Mn uptake by rice straw in comparison to combined application of these treatments to first year rice crop alone.

Application of 5 kg Zn/ha and 2.5 or 3.75 kg Zn + 5 t FYM/ha after two crop cycles increased Mn uptake by wheat grains significantly over control. Application of 5 t FYM/ha, 2.5 kg Zn/ha, 2.5 or 3.75 kg Zn + 5 t FYM after two crop cycles increased Mn uptake by wheat straw in third year. Application of 5 t FYM/ha and 3.75 kg Zn/ha to first year rice crop also increased Mn uptake by wheat straw over control in the third year.

Application of 5 t FYM/ha and 3.75 kg Zn + 5 t FYM/ha either to first year rice crop or after two crop cycles increased total Mn uptake by rice and rice + wheat in the third year significantly over control. Application of 5 kg Zn/ha after two crop cycles increased total Mn uptake by rice and rice + wheat in third year significantly over control however, application of similar dose of first year rice crop increased total Mn uptake by third year rice crop alone in comparison to control. Application of 3.75 kg Zn/ha after two crop cycles increased total Mn uptake by third year rice and rice + wheat crop significantly over control but this treatment application to first year rice crop increased only total Mn upake of rice + wheat in third year in comparison to control. Application of 2.5 kg Zn/ha to first year rice crop was effective in significantly increasing total Mn uptake by rice crop over control in the third year. In general, combined application of Zn and FYM together after two crop cycles decreased Mn uptake by rice and wheat crop as compared to application to first year rice crop alone.

Thus, based on the results of third year rice and wheat crop, it could be concluded that treatment application schedule had no significant effect on grain and straw yield of rice and grain yield of wheat. Application of 2.5 kg Zn + 5 t FYM/ha gave yields either at par with or slightly higher than those obtained with application of 5 kg Zn/ha. Both treatment application schedule and treatments influenced the uptake of micronutrients cations other than Zn. Application of 2.5 kg Zn + 5 t FYM/ha to rice crop can be recommended for rice-wheat rotation on Zn deficient Ustochrept soils of Western Uttar Pradesh.

Table 5: Effect of different Zn treatments and frequency of their application on Mn uptake by grain and straw of rice and wheat and total Mn uptake in third year.

Main Plot	Sub-plot Treatments	Mn uptake (gm/ha)				Total Mn uptake (gm/ha)		
		Rice		Wheat				
		Grain	Straw	Grain	Straw	Rice	Wheat	Rice + Wheat
After 2 crop cycles	Control	86.94	512.46	67.12	139.40	599.40	206.52	805.92
	5 t FYM/ha	123.95	639.85	87.00	208.71	763.80	295.71	1059.51
	2.5 kg Zn/ha	113.18	470.16	91.11	179.14	583.34	270.25	853.59
	3.75 kg Zn/ha	129.58	586.44	86.27	148.57	716.02	234.84	950.86
	5.00 kg Zn/ha	126.56	700.02	99.60	157.11	826.58	256.71	1083.29
	2.5 kg Zn + 5 t FYM/ha	134.03	417.93	106.53	186.18	551.96	292.71	844.67
	3.75 kg Zn + 5 t FYM/ha	122.42	561.94	106.81	191.46	684.36	298.27	982.63
	Mean	119.52	555.54	92.06	172.93	675.06	264.99	940.05
After 3 crop cycles	Control	93.44	516.81	85.81	143.52	610.25	229.33	839.58
	5 t FYM/ha	102.48	581.58	87.64	214.35	684.06	301.99	986.05
	2.5 kg Zn/ha	85.85	588.05	84.59	115.42	673.90	200.01	873.91
	3.75 kg Zn/ha	104.56	556.95	91.99	210.85	661.51	302.84	964.35
	5.00 kg Zn/ha	103.24	579.49	87.41	170.57	682.73	257.98	940.71
	2.5 kg Zn + 5 t FYM/ha	131.12	540.31	96.03	154.97	671.43	251.00	922.43
	3.75 kg Zn + 5 t FYM/ha	127.91	647.15	90.27	143.07	775.06	233.34	1008.40
	Mean	106.94	572.91	89.11	164.67	679.85	253.78	933.63
Mean Sub-plot	Control	90.19	514.64	76.46	141.46	604.83	217.92	822.75
	5 t FYM/ha	113.22	610.72	87.32	211.53	723.94	298.85	1022.79

	2.5 kg Zn/ha	99.51	529.11	87.85	147.28	628.62	235.13	863.75
	3.75 kg Zn/ha	117.07	571.70	89.13	179.71	688.77	268.84	957.61
	5.00 kg Zn/ha	114.90	639.76	93.51	163.84	754.66	257.35	1012.01
	2.5 kg Zn + 5 t FYM/ha	132.58	479.12	101.28	170.57	611.70	271.85	883.55
	3.75 kg Zn + 5 t FYM/ha	125.17	604.55	98.54	167.26	729.72	265.80	995.52
C.D.(p=0.05)	Main plot	NS	NS	NS	NS	NS	NS	NS
	Subplot	18.71	34.17	16.77	18.71	44.3	35.2	73.04
	Subplots within main plot	NS	48.32	25.71	30.45	62.6	NS	103.3
	Subplots across the main plot	NS	59.64	26.32	35.85	81.96	NS	130.14

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