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Long-term impact of organic and inorganic fertilization on physico-chemical properties of soil under wheat-maize cropping system in typic *Heplustepts*

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Abstract

A field study entitled "Long-term impact of organic and inorganic fertilization on physico-chemical properties of soil under wheat-maize cropping system in *Heplustepts*" was conducted during Kharif 2016-17 and 2017-18 in the Long Term Fertilizer Experiments initiated in Kharif, 1997 at the Instructional Farm of the Rajasthan College of Agriculture, Udaipur. The results of the present investigation revealed that different treatments have not shown any significant effect on soil pH. However, application of 20 t ha^{-1} FYM significantly increased CEC of soil followed by 100% NPK+ FYM 10 t ha^{-1} application. Application of FYM alone recorded highest soil organic carbon and total organic carbon content of soil. Application of FYM @ 20 t ha^{-1} gave lowest bulk density and significantly maximum total porosity, water holding capacity and hydraulic conductivity of soil followed by FYM 10 t ha^{-1} + 100% NPK treatment. Application of 100% NPK+ FYM 10 t ha^{-1} and 150% NPK increased availability of N, P and K as compared to other treatments. Significantly maximum available S was recorded with the application of 100% NPK + Zn + S. Application of FYM @ 20 t ha^{-1} recorded the highest availability of Fe, Cu and Mn in soil. Whereas, highest DTPA- Zn was observed with 100% NPK +Zn application.

Keywords: Farmyard manure, soil organic carbon, total organic carbon

Introduction

The present investigation was carried out at the Instructional Farm of the Rajasthan College of Agriculture, Udaipur during 2016-17 and 2017-18. The experimental site is a permanent manurial trial and its layout is on fixed site, at block B2, situated at 24°34N' latitude, 73°42E' longitude and 582.17 m about mean sea level. The area comes under sub-humid southern plain (Zone-IVa) of Rajasthan. The climate of the region is subtropical, characterized by mild winters and distinct summers associated with high relative humidity particularly during the months of July to September. The mean annual rainfall of the region varies from 650 to 750 mm, most of which is received in rainy season from July to September. The mean maximum and minimum temperature are 35.45 °C and 17.41 °C, respectively. At the inception of the experiment, the composite soil samples were drawn from 0-15 cm depth prior to treatment application in order to as certain initial fertility status and physico-chemical properties of the experimental soil. At the initiation of the experiment, soil of the experimental field was having pH 8.20, EC 0.48 dSm^{-1}, Organic carbon 6.80 g kg^{-1}, available Nitrogen 360 kg ha^{-1}, available phosphorus 22.4 kg ha^{-1}, available potassium 671 kg ha^{-1}, available Zn 3.76 mg kg^{-1}, available Fe 2.52 mg kg^{-1}. The 12 treatments with four replications in a randomized block design with 152 m^2 plot for each treatment were as follows: T_1-control; T_2-100% N; T_3-100% NP; T_4-100% NPK; T_5-100% NPK + Zn; T_6-100% NPK + S; T_7-100% NPK + Zn + S; T_8-100% NPK + *Azotobacter;* T_9-NPK 100% NPK + FYM 10 t ha^{-1}; T_{10}- FYM 10 t ha^{-1} + 100 % NPK (-NPK of FYM); T_{11}-150%; T_{12}-FYM 20 t ha^{-1}. Statistical analysis was done as outlined by Panse and Sukhatme (1985) [13].

Results and Discussion

Bulk Density

Data presented in the Table 1 revealed that the bulk density varies from 1.30 to1.45 Mg m^{-3} and 1.29 to 1.44 Mg m^{-3} during 2016-17 and 2017-18 under different treatments.

The pooled data revealed that application of FYM 20 t ha^{-1} gave lowest bulk density *i.e.* 1.30 Mg m^{-3} and at par with 100% NPK + FYM 10 t ha^{-1} treatment. This treatment gave 11.53 and 7.69 per cent less bulk density as compare to control (1.45 Mg m^{-3}) and recommended dose of fertilizer (1.40 Mg m^{-3}). Application of balanced fertilizers alone or in combination with organics decreased bulk density of soil significantly over control and the extent of reduction was more when FYM were applied alone in both maize and wheat crops which may be due to the addition of organic matter that resulted in increase in pore space and good soil aggregation (Singh et al. 2014) [17]. Comparison of different fertilizer treatments with control revealed that there was a general decrease in the bulk density of soil.

Porosity

A deep insight into the data (Table 1) revealed that the porosity varies from 49.61 to 44.66 per cent and 50.00 to 45.04 per cent during 2016-17 and 2017-18 under different treatments. The porosity significantly decreased 49.61 and 50.00 per cent during 2016-17 and 2017-18, under FYM 20 t ha^{-1} application. The pooled data revealed that application of FYM 20 t ha^{-1} gave highest porosity *i.e.* 49.81 per cent and at par with T_9 and T_{10}. This treatment gave 9.95 and 7.34 per cent high porosity as compare to control (44.85%) and 100 per cent NPK treated plot (46.15%).

Water holding capacity

Data presented in the Table 1 revealed that the application of different treatments differed significantly with respect to water holding capacity of the experimental soil during both the years and pooled basis. The significantly maximum water holding capacity was recorded (49.00%) with the application of FYM 20 t ha^{-1} and at par with T9 and T_{10} during both the years 2016-17, 2017-18 and in pooled. Increasing SOM content characteristically leads to a decrease in bulk density and surface crusting and an increase in water holding capacity and macroporosity. The beneficial effect of soil organic matter in increasing the water holding capacity of the soil has been reported by several workers (Vennila and Muthuvel, 1998 and Choudhary *et al.* 2017) [21].

Hydraulic conductivity

Data presented in the Table 1 revealed that the hydraulic conductivity varies from 4.40 to 18.20 cm hr^{-1} and 4.50 to 18.80 cm hr^{-1} during 2016-17 and 2017-18 under different treatments. Application of FYM 20 t ha^{-1} recorded maximum hydraulic conductivity (18.20, 18.80 and 18.50 cm hr^{-1}) during both the years 2016-17, 2017-18 and in pooled, respectively and significantly higher as compared to all other treatments. The pooled data revealed that application of FYM 20 t ha^{-1} gave 75.94 and 43.78 percent higher hydraulic conductivity as compare to control (4.45 cm hr^{-1}) and 100 percent NPK treated plot (10.40 cm hr^{-1}). Increasing SOM content characteristically leads to a decrease in bulk density and surface crusting and an increase in macro porosity, and hydraulic conductivity. The beneficial effect of soil organic matter in increasing the hydraulic conductivity of the soil has been reported by several workers (Choudhary *et al.* 2017 and Meena *et al.* 2018) [12].

pH of soil

It is evident in data presented in Table 2 that application of different treatments significantly influences the pH among different treatments. pH values varies from 8.18 to 8.32 during 2016-17 and 8.17 to 8.35 during 2017-18. However the differences were found statistically not significant.

EC of soil

Data pertaining to the effect of different treatments on EC presented in Table 2. It is evident from the data, the application of 150% NPK in treatment T_{11} significantly increases to 0.92 as compared to 0.86 under control plot. Application of 20 t ha^{-1} FYM lowers the EC values significantly as compared to control plot. Same trend was observed during both years of experimentation.

CEC of soil

The values of cation exchange capacity in the present study (Table 2) varied from lowest value of 9.20 and 9.19 c mol (p^+) kg^{-1} in control to the highest value of 12.80 and 13.10 c mol (p^+) kg^{-1} in T_{12} treatment which received 20 t ha^{-1} FYM in 2016-17 and 2017-18, respectively. The pooled data revealed that application of FYM 20 t ha^{-1} gave highest CEC *i.e.* 12.95 cmol (p^+) kg^{-1} and at par with T_9. This treatment gave 40.76 and 23.33 per cent high CEC as compare to control {9.20 c mol (p^+) kg^{-1}} and recommended dose of fertilizer {10.50 c mol (p^+) kg^{-1} }. The value of CEC was higher in FYM 20 t ha^{-1} and followed by 100% NPK + FYM treated plots which might be attributed to higher organic colloids in these plots. Moreover, FYM additions increase the CEC of the soils due to increase in root biomass and crop residues production and their incorporation in the soil. Similar findings were reported by Prasad *et al.*, 1996, Jagdeshwari *et al.*, 2001.

Soil organic carbon

Soil organic carbon (SOC) contents after harvest of maize crop under wheat-maize cropping sequence influenced significantly during both years of experimentation (Table 2). The pooled data revealed that the SOC contents in 100% NPK treated plot was statistically at par with T_5, T_6, T_7, and T_8. A critical perusal of data indicates that the highest soil organic carbon 9.50 and 9.90 g kg^{-1} was obtained during 2016-17 and 2017-18, respectively with application of FYM 20 t ha^{-1}. Application of FYM alone or in combination with chemical fertilizers increased soil organic carbon content after harvest of maize crop. Reason attributed is the direct incorporation of organic matter, better root growth and more plant residues addition after harvest of crops. These findings are in agreement with the observations of Katyal *et al*., 2003 [9], Kannan *et al.*, 2013 [8] and Brar *et al*., 2015 [4].

Total organic carbon

The pooled data (Table 2) revealed that application of FYM 20 t ha^{-1} gave highest TOC *i.e.* 15.16 g kg^{-1} and significantly higher as compared to all other treatments. This treatment gave 97.39 and 33.21 per cent high TOC as compare to control plot (7.68 g kg^{-1}) and 100% NPK treated plot (11.38 g kg^{-1}). The marked increase in total carbon content with the application of FYM 20 t ha^{-1} and 100% NPK + FYM can be ascribed to direct addition of organic carbon through FYM and root biomass and root exudates during last twenty one years. Similar effects of FYM and inorganic fertilizer applications on soil organic carbon has also been reported by Singh *et al.*, 2017; Swati *et al.*, 2018 and Tripura *et al.*, 2018 [15, 18, 20].

Available nitrogen

Critical perusal of data (Table 3) revealed that the highest available nitrogen content 394 and 405 kg ha^{-1} was recorded under 150% NPK treatment during 2016-17 and 2017-18, respectively and significantly higher than other treatments except 100% NPK + FYM. The pooled analysis reveals that Application of 100% NPK +FYM and 150% NPK recorded about 10.14 and 14.20 per cent higher available N content as compared to 100% NPK. The available nitrogen in 100% NPK treated plot was statistically at par with T_6, T_7, and T_8. Application of recommended dose of fertilizer with FYM and super optimal dose of fertilizer registered maximum content of available N after the harvest of maize crop. The reason might be due to the additional supply of N through recommended dose of NPK and contribution of additional N through super optimal dose of fertilizer and contribution of additional N through FYM in above two treatments. These results are in agreement with those of Kundu *et al*., 2016 [11] and Thangasamy *et al.*, 2017 [19].

Available phosphorus

The highest available phosphorus 32.12 and 34.86 kg ha^{-1} was recorded under 150% NPK treatment during 2016-17 and 2017-18, respectively (Table 3). It was followed by 30.38 and 32.10 kg ha^{-1}, respectively by application of 100% NPK+ FYM 10 t ha^{-1} in both the year. The pooled analysis reveals that this treatment gave 111.56 and 32.0 per cent higher available phosphorus as compared to control (15.83 kg ha^{-1}) and recommended dose of fertilizer (25.37 kg ha^{-1}). Application of 100% NPK + FYM 10 t ha^{-1} and 150% NPK increased availability of phosphorus to other treatments. This increase in available phosphorus might be due to decomposition of organic matter accompanied by the release of appreciable quantities of carbon dioxide, organic acids, which play an important role in increasing the phosphate availability. These findings was in line with findings of Singh *et al.*, 2017 [15, 19], Thangasamy *et al.*, 2017 [19] and Khan *et al*., 2017 [10].

Available potassium

It was apparent from the data (Table 3) that the highest available potassium 595 and 602 kg ha^{-1} was recorded under 150% NPK treatment during 2016-17 and 2017-18, respectively. The pooled analysis reveals that this treatment gave 26.93 and 7.64 per cent higher available potassium as compare to control (471.5 kg ha^{-1}) and recommended dose of fertilizer (556 kg ha^{-1}). The higher levels of K in 150% NPK treatment was due to higher application rates of K in this treatment. The results are in conformity to the findings of Singh *et al.*, 2017 [15, 19], Thangasamy *et al.*, 2017 [19] and Gowda *et al.*, 2017 [6].

Available sulphur

Results showed (Table 3) that the content of available sulphur increased with addition of S over control and significantly maximum available sulphur was recorded with the application of 100% NPK + Zn + S and at par with100% NPK+ S treatments. Application of FYM alone or in combination with NPK fertilizers significantly increased available S content in soil. This could be due to the release of organic acids during the decomposition of organic matter ultimately causing resolution of applied as well as native S into available S compounds thereby it increases the activity and concentration of available S in soil. Similar result was observed by Thangasamy *et al.*, 2017 [19] and Bhatt *et al.*, 2019 [3].

Available zinc

It was apparent from the data (Table 4) that the highest DTPA extractable zinc 3.59 and 3.66 ppm was recorded in 100% NPK + Zn treatment during 2016-17 and 2017-18, respectively. This treatment is closely followed and statistically at par with 100% NPK + Zn +S, treatment during both the years and also in pooled analysis. The pooled analysis reveals that this treatment gave 88.08 and 57.14 per cent higher available zinc as compare to control (1.93 ppm) and recommended dose of fertilizer (2.31 ppm).

Available iron

Results showed (Table 4) that the highest DTPA extractable iron 4.15 and 4.35 ppm was recorded in FYM 20 t ha^{-1} treatment during 2016-17 and 2017-18, respectively. It was at par with 100% NPK+ FYM 10 t ha^{-1} treatments during both the years and also in pooled analysis. This both treatments were significantly superior to all other treatments during both years of experimentation and it was also observed in pooled analysis. The pooled analysis reveals that this treatment gave 64.72 and 45.54 per cent higher available iron as compare to control (2.58 ppm) and recommended dose of fertilizer (2.92 ppm).

Available copper

It was apparent from the data (Table 4) that the highest available copper 2.62, 2.75 and 2.69 ppm was recorded by application of FYM 20 t ha^{-1} treatments during 2016-17, 2017-18 and pooled analysis, respectively. This treatment (T_{12}) was at par with T_9 treatments during both the years and also in pooled analysis. The pooled analysis reveals that this treatment gave 70.25 and 55.49 per cent higher available copper as compare to control (1.58 ppm) and recommended dose of fertilizer (1.73 ppm).

Table 1: Effect of organic and inorganic fertilization on BD (Mg m^{-3}), porosity (%), WHC (%) and hydraulic conductivity (cm hr^{-1}) of soil after harvest of maize under wheat-maize cropping sequence

Treatments	BD			Porosity			WHC			Hydraulic conductivity		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
T_1 = Control	1.45	1.44	1.45	44.66	45.04	44.85	39.92	39.80	39.86	4.40	4.50	4.45
T2 = 100% N	1.41	1.40	1.41	45.98	46.56	46.27	44.86	44.88	44.87	4.80	5.00	4.90
T3 = 100% NP	1.39	1.37	1.38	46.95	47.51	47.23	45.96	46.26	46.11	6.90	7.20	7.05
T4 = 100% NPK	1.41	1.39	1.40	45.77	46.54	46.15	46.88	47.05	46.97	10.20	10.60	10.40
T5 = 100% NPK + Zn	1.41	1.40	1.40	45.77	46.15	45.96	44.36	44.60	44.48	10.60	10.80	10.70
T6 = 100% NPK+ S	1.40	1.38	1.39	46.36	46.92	46.64	47.62	47.94	47.78	10.30	10.50	10.40
T7 = 100% NPK+ Zn + S	1.40	1.38	1.39	46.15	47.13	46.64	43.48	43.71	43.60	10.50	10.60	10.55
T8 = 100% NPK + *Azotobacter*	1.42	1.40	1.41	45.38	46.15	45.77	45.23	45.40	45.32	10.40	10.50	10.45
T9 = 100% NPK + FYM 10 t ha^{-1}	1.33	1.31	1.32	48.65	49.22	48.94	48.92	49.20	49.06	16.80	17.40	17.10
T10 = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	1.34	1.32	1.33	48.26	49.03	48.65	48.56	48.66	48.61	16.40	17.10	16.75
T11 = 150% NPK	1.39	1.38	1.39	46.54	46.92	46.73	47.38	47.58	47.48	10.70	10.90	10.80
T12 = FYM 20 t ha^{-1}	1.30	1.29	1.30	49.61	50.00	49.81	49.00	49.10	49.05	18.20	18.80	18.50

S.Em.±	0.03	0.03	0.02	1.14	1.15	0.81	1.11	1.11	0.78	0.29	0.30	0.21
C.D. (P = 0.05)	0.08	0.08	0.07	2.90	2.92	2.29	3.19	3.20	2.22	0.83	0.86	0.58

Table 2: Effect of organic and inorganic fertilization on pH, EC (dS m^{-1}), CEC {c mol (p^+) kg^{-1}}, SOC (g kg^{-1}) and TOC (g kg^{-1}) of soil after harvest of maize under wheat-maize cropping sequence

Treatments	pH			EC			CEC			SOC			TOC		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
T_1 = Control	8.29	8.28	8.29	0.86	0.86	0.86	9.20	9.19	9.20	5.40	5.10	5.25	7.80	7.56	7.68
T2 = 100% N	8.34	8.35	8.32	0.84	0.85	0.85	9.60	9.70	9.65	6.60	6.50	6.55	9.75	9.70	9.73
T3 = 100% NP	8.29	8.26	8.28	0.89	0.89	0.89	10.00	10.10	10.05	6.90	7.00	6.95	10.24	10.35	10.30
T4 = 100% NPK	8.29	8.25	8.27	0.85	0.87	0.86	10.50	10.50	10.50	7.40	7.60	7.50	11.28	11.47	11.38
T5 = 100% NPK + Zn	8.22	8.24	8.23	0.86	0.90	0.88	10.60	10.70	10.65	7.50	7.70	7.60	11.40	11.55	11.47
T6 = 100% NPK+ S	8.20	8.22	8.21	0.86	0.87	0.86	10.40	10.60	10.50	7.40	7.60	7.50	11.30	11.42	11.36
T7 = 100% NPK+ Zn + S	8.23	8.25	8.24	0.87	0.92	0.90	10.50	10.50	10.50	7.60	7.70	7.65	11.70	11.74	11.72
T8 = 100% NPK + *Azotobactor*	8.26	8.24	8.25	0.87	0.88	0.87	10.60	10.70	10.65	7.50	7.80	7.65	11.35	11.43	11.39
T9 = 100% NPK + FYM 10 t ha^{-1}	8.19	8.20	8.19	0.85	0.86	0.86	12.40	12.60	12.50	8.90	9.40	9.15	13.68	13.95	13.82
T10 = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	8.25	8.26	8.26	0.86	0.86	0.86	12.20	12.30	12.25	8.80	9.20	9.00	13.60	13.92	13.76
T11 = 150% NPK	8.30	8.27	8.29	0.89	0.95	0.92	10.50	10.60	10.55	7.80	8.10	7.95	12.10	12.40	12.25
T12 = FYM 20 t ha^{-1}	8.18	8.17	8.18	0.82	0.81	0.82	12.80	13.10	12.95	9.50	9.90	9.70	14.86	15.45	15.16
S.Em.±	0.20	0.20	0.14	0.02	0.02	0.01	0.26	0.27	0.19	0.18	0.19	0.13	0.28	0.28	0.20
C.D. (P = 0.05)	NS	NS	NS	0.034	0.035	0.030	0.76	0.77	0.53	0.53	0.54	0.37	0.80	0.81	0.56

Table 3: Effect of organic and inorganic fertilization on available N, P, K and S (kg ha^{-1}) of soil after harvest of maize under wheat-maize cropping sequence

Treatments	Available N			Available P			Available K			Available S		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
T_1 = Control	252	250	251	15.90	15.76	15.83	478	465	471	15.72	15.40	15.56
T2 = 100% N	286	298	292	16.12	16.30	16.21	485	470	477	15.83	15.70	15.77
T3 = 100% NP	305	317	311	23.05	25.45	24.25	494	480	487	16.55	16.40	16.48
T4 = 100% NPK	345	358	351	24.78	25.95	25.37	552	560	556	17.45	17.31	17.38
T5 = 100% NPK + Zn	339	351	345	27.02	28.17	27.59	554	561	558	16.65	16.51	16.58
T6 = 100% NPK+ S	338	355	346	25.96	26.76	26.36	547	557	552	23.76	23.90	23.83
T7 = 100% NPK + Zn + S	340	353	346	25.56	26.80	26.18	561	567	564	23.64	23.70	23.67
T8 = 100% NPK + *Azotobactor*	351	363	357	24.82	25.70	25.26	558	566	562	16.72	16.65	16.69
T9 = 100% NPK + FYM 10 t ha^{-1}	380	392	386	30.38	32.10	31.24	580	589	584	18.25	18.40	18.33
T10 = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	370	384	377	27.12	28.05	27.59	576	582	579	17.98	18.15	18.07
T11 = 150% NPK	394	405	399	32.12	34.86	33.49	595	602	598	17.37	17.30	17.34
T12 = FYM 20 t ha^{-1}	320	327	323	22.56	23.38	22.97	540	551	545	18.42	18.51	18.47
S.Em.±	8.04	8.27	5.77	0.58	0.60	0.42	13.14	13.14	9.29	0.42	0.42	0.30
C.D. (P = 0.05)	23.16	23.83	16.30	1.67	1.74	1.18	37.85	37.82	26.25	1.21	1.21	0.84

Table 4: Effect of organic and inorganic fertilization on available Zn, Fe, Cu and Mn (ppm) of soil after harvest of maize under wheat-maize cropping sequence

Treatments	Available Zn			Available Fe			Available Cu			Available Mn		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
T_1 = Control	1.95	1.90	1.93	2.60	2.55	2.58	1.60	1.56	1.58	9.02	9.00	9.01
T2 = 100% N	2.11	2.07	2.09	2.62	2.57	2.60	1.61	1.58	1.60	9.34	9.29	9.32
T3 = 100% NP	2.31	2.28	2.30	2.95	2.90	2.93	1.82	1.75	1.79	9.36	9.31	9.34
T4 = 100% NPK	2.33	2.28	2.31	2.96	2.87	2.92	1.75	1.70	1.73	9.55	9.51	9.53
T5 = 100% NPK + Zn	3.59	3.67	3.63	3.08	3.02	3.05	1.80	1.73	1.76	9.62	9.59	9.60
T6 = 100% NPK+ S	2.35	2.31	2.33	3.26	3.18	3.22	1.78	1.72	1.75	9.70	9.62	9.66
T7 = 100% NPK+ Zn + S	3.55	3.58	3.57	3.38	3.29	3.34	1.81	1.76	1.79	9.65	9.59	9.62
T8 = 100% NPK + *Azotobactor*	2.38	2.35	2.37	3.24	3.18	3.21	1.72	1.63	1.68	9.71	9.65	9.68
T9 = 100% NPK + FYM 10 t ha^{-1}	3.21	3.29	3.25	3.88	4.12	4.00	2.48	2.59	2.54	12.65	12.79	12.72
T10 = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	3.15	3.19	3.17	3.70	3.95	3.83	2.35	2.41	2.38	12.48	12.55	12.52
T11 = 150% NPK	2.37	2.34	2.36	2.82	2.72	2.77	1.72	1.69	1.71	9.40	9.37	9.39
T12 = FYM 20 t ha^{-1}	2.95	3.05	3.00	4.15	4.35	4.25	2.62	2.75	2.69	13.36	13.50	13.43
S.Em.±	0.06	0.07	0.05	0.08	0.08	0.06	0.05	0.05	0.03	0.26	0.26	0.18
C.D. (P = 0.05)	0.19	0.19	0.13	0.22	0.23	0.16	0.14	0.14	0.10	0.75	0.75	0.52

Available manganese

Data presented in the Table 4 revealed that the highest manganese content 13.50 and 13.36 ppm was recorded by application of FYM @ 20 t ha^{-1} treatment during 2016-17 and 2017-18, respectively. This treatment was found significantly superior than all other treatments. Data also indicated that either application of NPK alone or with manures treatments significantly improve manganese content in soil. The pooled analysis reveals that FYM @ 20 t ha^{-1} treatment gave 49.05 and 40.92 per cent higher available manganese as compare to control (9.01 ppm) and 100% NPK treated plot (9.53 ppm).

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