The Bioscan 14(2): 145-150, 2019
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
www.thebioscan.com

EFFECT OF INM ON NUTRIENTS UPTAKE AND YIELD OF MAIZE-WHEAT CROPPING SEQUENCE AND CHANGES IN NUTRIENT AVAILABILITY IN TYPIC HAPLUSTEPTS

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KEYWORDS
Fertilizers
Manure
Cropping system
Yield
Uptake
Balance

Received on :
03.09.2018

Accepted on :
14.04.2019

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ABSTRACT

Integrated nutrient management (INM) is an important tool to sustain of nutrients availability plants and improve soil fertility without any risk to environment. Field experiments were carried out during 2014-15 and 2015-16 under the ongoing AICRP on LTFE with Maize-Wheat cropping in Typic Haplustepts that initiated during *kharif* 1997 at the Instructional Farm of Rajasthan College of Agriculture, Udaipur. The experiment consisted of 12 treatment combinations *viz.*, 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- 100% NPK + FYM 10 t ha^{-1}, T_{10}- FYM 10 t ha^{-1} + 100%NPK (-NPK of FYM), T_{11}- 150%NPK and T_{12}- FYM @ 20 t ha^{-1} with four replications in a RBD. Results showed that the nutrients availability in soil, nutrient uptake, and yield of crops were significantly response to combined application of organic and inorganic. The highest maize grain yield 4033 and 4053 kg ha^{-1} and stover yield 5290 and 5320 kg ha^{-1} were recorded fewer than T_9 during 2014-15 and 2015-16, respectively. Similarly, the highest wheat grain yield 4939 and 5107 kg ha^{-1} and straw yield 7217 and 7270 kg ha^{-1} was recorded under T_9 during both years. Maximum uptake of macro and micro nutrients by maize and wheat crop was recorded under application of integrated use of fertilizers along with manure i.e. T_9. Soil enrichment with T_{11} resulted in highest positive balance of nitrogen and phosphorus in soil However, negative potassium balance was observed under all treatments.

INTRODUCTION

Integrated Nutrient Management (INM) is the concept of combined application of organic, inorganic, and biological nutrient sources to increasingly promote as a means of improving nutrient use efficiency by matching soil nutrient availability with crop demand (Graham *et al.,* 2017). The modern agricultural technology emphases wide spread continuous use of chemical fertilizers divers behaves differently than that of integrated use of chemical fertilizers and organic inputs (Tamilselvi *et al.,* 2017). The quantity and quality of crop residue (cereals versus pulses), farmyard manure, and biofertilizers also modify the soil microbiome and soil enzymes (Nath *et al.*, 2017). In India, intensive cropping with nutrient exhaustive high yielding varieties coupled with the use of high analysis fertilizer for enhancing food grain production have catalyzed the rapid depletion of micro nutrients in soil (Singh, 2009). Hence, the long-term impact of inorganic fertilizers and integrated nutrient management (inorganic fertilizers + organic amendments) practices on soil biological properties needs to continue. Integrated nutrient management (INM) has been shown to considerably increasing crop yields by minimizing nutrient losses to the environment and by managing the nutrient supply, and thereby results in high resource-use efficiency, cost reductions, and improved nutrient availability (Parkinson, 2013; Zhang *et al.*, 2012). INM can thus be considered an effective agricultural model to ensure food security and improve environmental quality worldwide, especially in countries with rapidly developing economies.

Continuous dressing with FYM was found to be effective in stabilizing productivity under low to medium cropping intensity, while integrated use of organic and chemical fertilizers provided stability in crop production under the modern intensive farming (Rao and Reddy, 2005). In recent years the deterioration in soil health associated with global predicament of energy along with escalation in the prices of chemical fertilizers lead to emphasize on supplementation of chemical fertilizers with low priced nutrient sources such as organics and bio-sources (Kumar and Dhar, 2010). The biofertilizers are eco friendly, low cost and non bulky agricultural inputs. Most soils of Rajasthan state are very low in organic matter content and poor in nutrient supply, hence introduction of suitable strains of biofertilizers in such soils may help in boosting up production because of increased microbial population and increased fixation of nitrogen and mobilization of phosphorus.

The maize -wheat cropping system is very important cropping system for meeting local food needs and ensuring food security. Maize (*Zea mays* L.) - wheat [*Triticum aestivum* (L.)] are the most prominent and popular double cropping system under irrigated conditions in north-western parts of India. Traditionally being a monsoon season crop, maize-wheat is still the predominant maize based system (1.8 M ha) and is 3rd major crop-rotation in India and contributes ~3.0% in national food basket (Jat *et al.,* 2013). Considering these facts, the present study was designed to find out the effect of INM on nutrients uptake and yield of maize–wheat cropping sequence and changes in nutrient availability in Typic Haplustept soil.

MATERIALS AND METHODS

The experiment was conducted at the Instructional Farm, Rajasthan College of Agriculture, Udaipur, during 2014-15 and 2015-16. The site is situated in south-eastern part of Rajasthan at an altitude of 579.5 m above mean sea level, at 24°35′ N latitude and 74°42′ E longitude. The region falls under agro-climatic zone IV a (Sub- Humid Southern Plain and Arawali Hills) of Rajasthan. The climate of the region is tropical characterized by mild winter and summer associated with high humidity particularly during July- September. The mean annual rainfall of the region ranges between 570-620 mm, most of which contributed by South-West monsoon from July to September. In summers maximum temperature goes up to 44°C and minimum temperature during December and January falls as low as 1°C. Initial status of available nutrients in LTFE field during 1997 was clay loam in texture having pH 7.45, EC 0.47 dSm^{-1}, Organic carbon 0.67%, available nitrogen 360.0 kg ha^{-1}, available phosphorus 22.67 kg ha^{-1} and available potassium 671.15 kg ha^{-1} and DTPA extract Zn, Fe, Cu and Mn values are 3.76, 2.52, 3.12, and 17.4 ppm, respectively. The experiment consisted of 12 treatment combinations *viz.,* 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- 100% NPK + FYM 10 t ha^{-1}, T_{10}- FYM 10 t ha^{-1} + 100%NPK (-NPK of FYM), T_{11}- 150%NPK and T_{12}- FYM @ 20 t ha^{-1} with four replications in a randomized block design. Maize variety PEHM-2 and wheat var. Raj-4037 was sown. The sources used for applying N, P and K were urea, DAP (adjusted for its N content) and muriate of potash, respectively. Gypsum and zinc sulphate ($ZnSO_4$. $7H_2O$) were used to supply S and Zn respectively. The other organic sources of nutrients were applied by FYM (farm yard manure) and bio fertilizer (*Azotobacter* sp.). Soil samples from two different depths (0-15 and 15-30 cm) from each plot were drawn before sowing and after harvest of crop. These samples were analyzed for Available N by alkaline permanganate method (Subbiah and Asija, 1956), available P by Olsen's method (Olsen *et al.* 1954), available K by ammonium acetate extraction method (Richards, 1954) and Available micronutrients (Zn, Cu, Fe and Mn) was extracted with DTPA and determined by atomic absorption spectrophotometer as described by (Lindsay and Norvell, 1978).

Nitrogen content in maize (grain and stover), wheat (grain and straw) was estimated by Nessler's reagent, spectrophotometrically (Snell and Snell, 1959), phosphorus by Vanadomolybdate phosphoric acid yellow colour method (Jackson, 1973) potassium by Flame photometer method (Jackson, 1973) and estimation of Micronutrients (Fe, Mn, Cu, Zn) on AAS (Lindsay and Norvell, 1978).

The experimental data were analyzed using analysis of variance (ANOVA) technique to RBD. The critical difference (CD) at 5 per cent level was computed wherever 'F' test was significant (Panse and Sukhatme, 1985). Grain and straw samples were taken and analyzed for these nutrients and yield was recorded to compute uptake by grain and straw.

RESULTS AND DISCUSSION

Yield

Grain and stover yield of maize -wheat crop as influenced by application of INM (organic manures + fertilizer application) presented in (Table 1). A perusal of data indicated that the grain and stover yield of maize -wheat increased significantly with the incorporation of 100% NPK + FYM 10 t ha^{-1} treatment (T_9) over control. The highest maize grain yield 4033 and 4053 kg ha^{-1} and stover yield 5290 and 5320 kg ha^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2014-15 and 2015-16, respectively (Table 1). Similarly, the highest wheat grain yield 4939 and 5107 kg ha^{-1} and straw yield 7217 and 7270 kg ha^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during both years on pooled basis (Table 1). This might be due to fact that application of INM as integrative chemical fertilizers and organic manures application was, however, found to be quite promising not only in maintaining higher productivity but also in providing greater stability in crop production by synergistic effect of FYM on improving efficiency of optimum dose of NPK and corrective deficiency of Zn. The results of the present study are in line with those reported by Behera and Singh (2010), Paradkar *et al.* (2010), Singh *et al.* (2014) and Kumar *et al.* (2014). Similarly results also showed that application of 100 % NPK with *Azotobacter* seed treatment increased the yield of maize and wheat over control. These are in confirmation with findings of Jaipaul *et al.* (2008).

Nutrient contents in maize and wheat

Application of INM brought about significant improvement in nitrogen, phosphorus and potassium content in grain and stover of maize and wheat during both the years of study (Table 2 and 3). The maximum improvement in nitrogen, phosphorus and potassium content in grain and stover of maize and wheat were recorded with the application of 100 % NPK with FYM 10 t ha^{-1} over other treatments. The amount of nutrients taken up by the plants primarily depends upon the concentration of these nutrients in the close proximity to the root surface and amount of fertilizers applied (Singh and Sarkar, 1985). Further, increases in the concentration of N, P, K are understandable as use of organics when applied with chemical fertilizers might have augmented the nutrient supply in the soil after their mineralization/decomposition. However, application of 25 kg $ZnSO_4$ along with S and 100% NPK application (T_7) resulted the highest zinc content in grain and stover of maize and wheat followed by 100% NPK + Zn (T_5). It is also observed to see that Zn content significantly improved in all treatments having FYM as compared to control. The highest iron, copper and manganese content in grain & stover of maize and wheat was recorded with application of 100% NPK + FYM 10 t ha^{-1} during both of years. The beneficial effect of FYM in increasing the concentration of micronutrients may be ascribed to direct supply of these cations on

Table 1: Effect of INM on yield of maize and wheat under maize-wheat cropping system

Treatments	Maize yield (kg ha^{-1})						Wheat yield (kg ha^{-1})					
	Grain			Stover			Grain			Straw		
	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled
T_1-Control	1327	1325	1326	2190	2200	2195	1552	1609	1326	2190	2200	2195
T_2-100% N	2169	2112	2141	3500	3470	3485	2915	3012	2141	3500	3470	3485
T_3-100% NP	2806	2829	2817	4090	4140	4115	3591	3620	2817	4090	4140	4115
T_4-100% NPK	3220	3266	3243	4610	4660	4635	4270	4320	3243	4610	4660	4635
T_5-100% NPK+Zn	3382	3390	3386	4790	4820	4805	4495	4520	3386	4790	4820	4805
T_6-100%NPK+S	3297	3313	3305	4730	4790	4760	4393	4430	3305	4730	4790	4760
T_7-100% NPK+Zn + S	3516	3530	3523	4870	4920	4895	4592	4610	3523	4870	4920	4895
T_8-100% NPK+*Azotobacter*	3402	3400	3401	4910	4880	4895	4401	4450	3401	4910	4880	4895
T_9-100%NPK+FYM 10 t ha^{-1}	4033	4053	4043	5290	5320	5305	4939	5107	4043	5290	5320	5305
T_{10}-FYM 10 t ha^{-1}+100% NPK (-NPK of FYM)	3490	3466	3478	4650	4635	4642	4585	4620	3478	4650	4635	4642
T_{11}-150% NPK	3605	3630	3618	5180	5250	5215	4640	4680	3618	5180	5250	5215
T_{12}-FYM 20 t ha^{-1}	2435	2414	2425	3160	3100	3130	3077	3105	2425	3160	3100	3130
SEm ±	91	93	65	151	159	110	119	124	65	151	159	110
CD (P = 0.05)	263	269	184	436	458	310	341	358	184	436	458	310

Table 2: Effect of INM on pooled nutrient contents in grain and stover of maize under maize-wheat cropping system

Treatments	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Zinc (ppm)		Iron (ppm)		Copper (ppm)		Manganese (ppm)	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
T1	1.195	0.365	0.206	0.089	0.400	1.098	18.53	13.40	98	311	8.72	5.19	59.42	48.15
T2	1.365	0.397	0.238	0.113	0.425	1.335	18.87	13.67	99	313	8.99	5.35	59.67	48.81
T3	1.490	0.407	0.273	0.130	0.426	1.344	19.02	13.93	99	314	9.52	5.65	60.24	48.93
T4	1.474	0.473	0.283	0.131	0.442	1.373	19.45	14.62	102	318	10.43	7.31	60.36	49.38
T5	1.496	0.488	0.268	0.131	0.454	1.353	24.28	18.07	102	318	10.81	7.78	61.34	49.35
T6	1.530	0.498	0.251	0.126	0.465	1.348	20.54	14.49	102	318	9.64	7.61	61.66	49.77
T7	1.504	0.492	0.275	0.132	0.472	1.355	24.79	17.80	102	319	10.31	7.37	61.77	49.88
T8	1.597	0.492	0.280	0.144	0.476	1.370	19.43	13.72	101	309	11.46	7.26	60.27	48.70
T9	1.590	0.505	0.290	0.140	0.459	1.369	23.14	16.36	110	319	12.74	8.70	66.91	52.94
T10	1.552	0.488	0.277	0.140	0.467	1.417	22.40	16.15	109	317	12.54	8.48	66.37	52.01
T11	1.623	0.525	0.335	0.153	0.503	1.494	21.23	15.81	103	311	11.22	7.98	62.30	50.52
T12	1.390	0.420	0.267	0.128	0.440	1.265	19.67	13.14	101	309	11.76	7.55	61.94	50.39
SEm ±	0.015	0.005	0.003	0.001	0.005	0.015	0.224	0.145	0.81	4.42	0.079	0.077	0.539	0.651
CD (P = 0.05)	0.042	0.014	0.008	0.004	0.014	0.041	0.632	0.410	2.30	NS	0.224	0.218	1.523	1.838

Table 3: Effect of INM on pooled nutrient contents in grain and straw of wheat under maize-wheat cropping system

Treatments	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Zinc (ppm)		Iron (ppm)		Copper (ppm)		Manganese (ppm)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T1	1.135	0.300	0.205	0.084	0.360	0.913	16.33	11.45	96	305	7.02	4.94	56.92	46.31
T2	1.270	0.312	0.232	0.086	0.376	0.936	16.45	11.66	96	306	7.17	5.05	57.28	47.43
T3	1.335	0.320	0.258	0.095	0.389	0.950	16.70	11.78	97	307	7.68	5.29	57.77	47.75
T4	1.381	0.372	0.273	0.101	0.396	0.973	17.62	12.57	99	308	8.93	6.62	58.59	48.46
T5	1.396	0.381	0.269	0.103	0.405	0.948	19.34	14.62	98	307	8.81	6.83	58.80	48.58
T6	1.350	0.376	0.264	0.096	0.407	0.941	17.68	12.77	97	307	8.27	6.55	57.68	48.59
T7	1.409	0.388	0.272	0.101	0.406	0.952	19.48	14.89	98	307	8.87	6.75	58.81	48.80
T8	1.397	0.382	0.260	0.102	0.411	0.971	17.92	12.60	98	308	9.25	6.48	58.79	48.01
T9	1.430	0.393	0.280	0.117	0.418	1.010	19.17	14.05	108	313	10.77	7.89	63.74	51.64
T10	1.389	0.386	0.272	0.114	0.414	0.988	18.86	13.75	107	312	10.51	7.61	63.41	51.35
T11	1.453	0.410	0.290	0.133	0.439	1.040	18.45	13.65	101	309	9.73	7.15	60.42	50.32
T12	1.340	0.339	0.267	0.120	0.407	0.995	17.45	11.92	102	308	10.58	7.35	61.43	50.70
SEm ±	0.014	0.004	0.003	0.001	0.004	0.008	0.191	0.124	0.800	3.94	0.067	0.071	0.521	0.578
CD (P = 0.05)	0.039	0.011	0.011	0.002	0.012	0.022	0.539	0.350	2.259	NS	0.189	0.199	1.470	1.633

mineralization of FYM and the solubilisation action of the organic acids produced during the decomposition of FYM and also indirectly to the positive effect of FYM on soil environment. The results are in conformity to the findings of Roshani *et al.* (2005) and Khan *et al.* (2006).

Nutrient uptake by maize and wheat

The data pertaining to nutrient uptake in grain and in straw by crop as significantly influenced by integrated nutrient management treatments is presented in (Table 4). The highest pooled N uptake by maize 91.09 kg ha^{-1} was obtained

Table 4: Effect of INM on nutrients uptake (total) by maize under maize-wheat cropping system

Treatments	Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})		Zinc (g ha^{-1})		Iron (g ha^{-1})		Copper (g ha^{-1})		Manganese (g ha^{-1})	
	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat
T1	23.86	24.97	4.69	5.20	29.40	27.07	540	527	8133	8693	229	172	1844	1985
T2	43.09	51.20	9.00	10.62	55.63	52.02	880	997	13008	16240	379	324	2978	3768
T3	58.75	65.43	13.04	14.43	67.34	65.29	1109	1238	15721	20075	501	420	3711	4658
T4	69.70	83.09	15.22	18.17	77.96	79.22	1308	1561	18036	23989	677	599	4245	5616
T5	74.08	88.16	15.35	18.95	80.40	81.01	1691	1840	18743	24814	740	618	4448	5865
T6	74.26	84.05	14.28	17.90	79.53	79.18	1369	1612	18508	24299	681	589	4407	5707
T7	77.09	91.31	16.14	19.43	82.96	83.49	1744	1903	19190	25444	724	647	4618	6027
T8	78.47	88.33	16.59	18.57	83.33	85.34	1333	1665	18544	25672	746	641	4435	5924
T9	91.09	100.23	19.13	22.25	91.16	93.15	1804	1987	21395	28159	977	813	5515	6944
T10	76.78	91.20	16.16	20.59	82.01	88.98	1531	1838	18547	26956	829	770	4725	6545
T11	86.05	94.05	20.07	22.03	96.15	90.67	1591	1735	19959	24604	822	685	4889	6040
T12	46.87	57.01	10.48	13.76	50.30	58.17	888	1086	12104	17305	521	505	3078	4221
SEm ±	1.38	1.980	0.313	0.403	1.796	1.847	26	36	381	523	11	45	74	110
CD (P = 0.05)	3.91	5.590	0.885	1.137	5.071	5.216	73	101	1076	1476	32	128	208	310

Table 5: Effect of INM on available nutrients (pooled) after harvest of wheat under maize-wheat cropping system at different depth (cm) in soil

Treatments	Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})		Zinc (ppm)		Iron (ppm)		Copper (ppm)		Manganese (ppm)	
Depth (cm) ⇒	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
T1	253	257	15.42	15.29	496	485	2.04	2.00	2.59	2.55	1.65	1.60	9.02	8.95
T2	266	269	15.61	15.38	479	471	2.22	2.11	2.67	2.60	1.63	1.61	9.75	9.66
T3	277	280	22.65	22.18	487	477	2.52	2.45	3.07	3.02	1.95	1.90	9.50	9.39
T4	347	348	23.41	23.14	549	552	2.44	2.38	2.95	2.90	1.93	1.94	9.70	9.58
T5	342	343	23.63	23.40	581	579	3.69	3.62	3.11	3.05	2.14	2.08	9.81	9.69
T6	342	344	24.38	24.19	554	549	2.46	2.41	3.30	3.26	2.25	2.14	10.34	10.18
T7	338	340	26.94	26.53	563	567	3.67	3.52	3.47	3.39	2.21	2.11	11.16	10.97
T8	375	376	26.74	26.30	558	552	2.54	2.51	3.26	3.17	1.75	1.70	11.09	10.92
T9	466	471	30.19	29.79	585	583	3.50	3.47	3.72	3.64	2.57	2.51	13.00	12.84
T10	402	404	25.79	25.36	595	591	3.45	3.40	3.55	3.45	2.49	2.44	12.85	12.73
T11	368	372	29.79	29.62	598	589	2.47	2.42	2.88	2.79	1.82	1.77	9.49	9.40
T12	304	308	24.45	24.19	581	578	2.75	2.70	2.95	2.91	2.35	2.29	13.58	13.42
SEm ±	3.20	3.43	0.224	0.240	5.57	4.94	0.029	0.030	0.032	0.032	0.022	0.022	0.112	0.114
CD(P=0.05)	9.05	9.69	0.631	0.677	15.72	13.94	0.083	0.085	0.089	0.090	0.061	0.062	0.317	0.323

Table 6: Effect of different treatments on nutrient balance in soil during both maize-wheat cropping system (2014-15 and 2015-16)

Treatments	Nutrient addition through manure and fertilizers (kg ha^{-1})			Total nutrient uptake by maize-wheat sequence(kg ha^{-1})			Nutrient balance after completion of two years(kg ha^{-1})		
	N	P	K	N	P	K	N	P	K
T_1- Control	0	0	0	97.25	19.78	112.95	-97.65	-19.78	-112.95
T_2- 100% N	480	0	0	188.57	39.26	215.29	291.43	-39.26	-215.29
T_3- 100 NP	480	240	0	248.36	54.96	265.25	231.64	185.04	-265.25
T_4- 100% NPK	480	240	120	305.58	66.8	314.35	174.42	173.2	-194.35
T_5- 100% NPK + Zn	480	240	120	324.49	68.61	322.81	155.51	171.39	-202.81
T_6- 100% NPK+ S	480	240	120	316.63	64.38	317.41	163.37	175.62	-197.41
T_7- 100% NPK+ Zn + S	480	240	120	336.79	71.13	332.91	143.21	168.87	-212.91
T_8- 100% NPK +*Azotobacter*	480	240	120	333.61	70.32	337.34	146.39	169.68	-217.34
T_9- 100% NPK + FYM 10 t ha^{-1}	576	268	210	382.64	82.76	368.63	193.36	185.24	-158.63
T_{10}- FYM 10 t ha^{-1} +100% NPK (-NPK of FYM)	480	240	120	335.97	73.48	341.98	144.03	166.52	-221.98
T_{11}- 150% NPK	720	360	180	360.20	84.18	373.64	359.80	275.82	-193.64
T_{12}- FYM 20 t ha^{-1}	192	72	180	207.75	48.5	216.96	-15.75	23.5	-36.96

by 100% NPK + FYM application which was significantlly superior than other treatments. However, the highest P and K uptake in maize i.e. 20.07 and 96.15 kg ha^{-1} respevtively, was obtained by 150% NPK application which was closely followed by 100% NPK +FYM treatment. The highest pooled uptake of N, P and K by Wheat 100.23, 22.25 and 93.15 kg ha^{-1} respectively, was obtained under 100% NPK + FYM application which was followed by 150% NPK application. The highest uptake of micronutrients Zn, Cu, Fe and Mn by maize i.e. 1804, 21395, 977 and 5515 ppm respectively, and by wheat i.e. 1987, 28159, 813 and 6944 ppm respectively, was recorded under integrated use of 10 t ha^{-1} FYM and RDF i.e. 100% NPK. Zinc uptake under this treatment was at par with application of 100% NPK + Zn + S (T_7) and 100% NPK + Zn (T_5). These facts due to applications of FYM not only solubilize the unavailable nutrients but also contains significant amount of N, P, K and micronutrients. Thus application of FYM has resulted in an overall significant increase in uptake of nutrients at lesser cost for longer duration. Combined use of organic manure and chemical fertilizer has been found not only in maintaining higher productivity but also in providing stable crop yields for sustainable crop production. These results are in confirmation with findings of Sharma *et al.,* (2013) Behera and Singh (2010) and Das *et al.* (2010).

Nutrient availability

Combined application of various plant nutrients significantly increased their status in soil at harvest of wheat crop after maize-wheat sequence over control (Table 5). The highest available nitrogen at both depths was recorded with 100% NPK+ FYM 10 t ha^{-1} application. Nitrogen availability increased under INM treatments and higher values were obtained at sub-surface soils (15-30 cm). Results showed that enhanced application of nitrogen increased the available nitrogen content in soil after harvest of wheat crop during the year of experimentation as compared to initial values. Application of 100% NPK+ FYM 10 t ha^{-1} and 150% NPK increased availability of phosphorus at both depths as compared to other INM treatments. The higher availability of phosphorus in surface soils (0-15 cm) was observed as compared to sub-surface soil (15-30 cm). The application of phosphorus at STR and 150% NPK resulted in appreciable build up of available P status of soil in comparison to treatment without P application. As the level of phosphorus increased, its content in soil also increased, probably due to mobilization of native soil phosphorus resulting in increased P availability. Combined application of various nutrients could also result in acidification of the micro-environment of soil solution and mineralization of organic phosphorus may help to increase the availability of phosphorus. Available potassium in surface soils was maximum with 150% NPK application. However in sub-surface soils maximum potassium availability was observed under 100% NPK+ FYM 10 t ha^{-1} application. The higher levels of K in 150 per cent NPK treatment are due to higher application rates of K in this treatment and FYM is reported not only to be a direct source of K but also in minimizing the leaching loss by retaining K+ ions on exchange sites and release of K due to interaction of organic matter with clay. The results are in conformity to the findings of Totawat *et al.,* (2001); Verma *et al.* (2005); Singh *et al.* (2013) & Meena *et al.* (2017) from elsewhere in country and abroad.

Available zinc at both depths decreased as compared to initial values. The highest DTPA –Zn 3.69 and 3.62 ppm was observed with 100% NPK +Zn application at 0-15 and 15-30 cm, respectively. Goyal (2002) reported that addition of Zn with NPK in balanced proportion or at recommended level, enhanced efficiency of each other, thus maintained synergistic interaction. The results of present study are in agreement with those reported by Feiziasl and Valizadeh, (2005) and Dwivedi *et al.* (2007). The highest DTPA-Fe was obtained with the application of 100% NPK + Zn + S application. The availability also increased at both depths as compared to initial values. The highest available copper was recorded with application of 100% NPK+ FYM 10 t ha^{-1} at both depths. Application of FYM@ 20 t ha^{-1} recorded the highest available manganese in surface and subsurface soils. The increase in available nutrient status of soil might be due to microbial as well as chemical activities. An improvement in available nutrient status of the soil with the incorporation of chemical fertilizer could be attributed to conserved soil nitrogen and increased availability of other nutrients as being its constituent as well as mineralize from the native source in soil. The results of present investigation are in line with the finding of Gill (2003).

Nutrient balance

Available nitrogen decreased and phosphorus improved or maintained with INM treatments as compared to initial values (Table 6). Available potassium contents decreased under all treatments. Balance use of fertilizers alone or in combination with organic manure resulted in significant build up of available N and P. Phosphorus is immobile in soil as compared to N and K. The negative P balance is obviously due to absence of P in fertilization schedule whereas positive P balance is because of addition of P in excess of its uptake by the crop. These findings are in confirmation with findings of Dwivedi *et al.* (2007). A declining trend of available K from its initial status was noticed as a result of continuous cropping, which indicated considerable mining of available K. This is in confirmation with findings of Swarup (2000); Thakur *et al.* (2011) and Kumar *et al.* (2013).

CONCLUSIONS

It can be concluded from the present study based on the results, it can be inferred that on the hyper-thermic Typic haplustepts of Udaipur, maize cv. PEHM-2 and wheat cv. Raj-4037 should be supplied with 10 t ha^{-1} of FYM in conjunction with 100 % NPK (120 kg N, 60 kg P_2O_5 and 30 kg K_2O ha^{-1}) based on soil test for higher productivity and to maintain soil health.

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