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Soil fertility dynamics in the groundnut-maize cropping system under integrated nutrient management

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Abstract
A field experiment was conducted on "Integrated Nutrient Management in Groundnut (*Arachis hypogaea* L.)- Maize (*Zea mays* L.) Cropping System" during two consecutive years (2015-2016 and 2016-2017) at the Agricultural Research Station, Vizianagaram of Acharya N.G. Ranga Agricultural University (ANGRAU), in the North - Coastal Agro-Climatic Zone of Andhra Pradesh, to study the effect of integrated nitrogen management practices on growth, nutrient dynamics and yield of *kharif* groundnut and succeeding *rabi* maize. Among all the RDF along with bio-fertilizers application, maximum values for vegetative parameters, nutrient uptake and organic carbon content, available N, P & K were recorded with the application of 150% RDF + FYM 5 t ha^{-1} and the higher pod yield and yield attributes were recorded with 125% RDF + FYM 5 t ha^{-1} which was, however, comparable with with100% RDF + FYM 5 t ha^{-1}. The research results of succeeding maize revealed that, growth parameters, yield attributes, yield, nutrient uptake and organic carbon content, available N, P & K were significantly influenced by the treatments given to preceding groundnut crop in the sequence. Among all the treatments, the dry matter production, yield attributes, yield, nutrient uptake and organic carbon content, available N, P & K maximum recorded with the treatment combination of 100%RDF+ *Azospirillum*+ PSB+ VAM+ with groundnut crop residue incorporation which was, however, comparable to combinations RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM and RDF_{100}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM.

Keywords: Groundnut-maize cropping system, integrated nutrient management, biofertilizers, growth, yield, nutrient dynamics, system productivity

Introduction
Generally, fertilizer dose is recommended on the basis of individual crop response. As the determination of the fertilizer dose for cropping system is complex due to factors like soil, nutrient fixation and residual effects. To encourage rational use of fertilizer, it is essential that the cultivators are made aware of profitability of fertilizer application under sequence cropping. The importance of growing legumes for sustaining and improving soil fertility has been known since long. The maize productivity increased due to preceding legume crop. Groundnut-maize is one of the cropping systems that is gaining popularity under intensive cultivation on *Alfiisols*. Information on nutrient requirement for this intensive cropping system is limited, particularly when nutrients are supplied through integrated nutrient management practices. Sustainability of higher yield could be achieved through integrated nutrient management. Therefore, the present experiment on integrated nutrient management in groundnut-maize crop sequence was conducted.

Materials and Methods
A field experiment was conducted at the Agricultural Research Station, Vizianagaram of Acharya NG. Ranga Agricultural University (ANGRAU), in the North - Coastal Agro-Climatic Zone of Andhra Pradesh. The results of the soil analysis indicated that the experimental site was sandy loam in texture, neutral in reaction, low in organic carbon, medium in available nitrogen, high in available phosphorus and medium in available potassium (Table 1). Soil samples were drawn plot wise, immediately after harvest of each of the crop to assess soil fertility dynamics. The weather conditions prevailed during crop growth period of groundnut and maize were quite normal and congenial for the better growth and performance of the crops, during both the years of experimentation.

The field experiment was laid in a Randomized Block Design with groundnut as *kharif* season crop with six treatments and replicated four times. The treatments consisted of T_1-RDF_{100}+FYM_{5t} (Control); T_2-RDF_{125}+ FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM; T_3-RDF_{150}+ FYM_{5t} + *Rhizobium* inoculation + PSB + VAM; T_4-RDF_{100}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM; T_5-RDF_{75}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM and T_6-RDF_{50}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM. During the succeeding *Rabi*, the experiment was laid out in a split-plot design on maize with six treatments given to *kharif* groundnut as main plot treatments and each of these divided into four sub-plots to receive four rates of RDF application *viz.*, S_1-RDF_{100} + *Azospirillum* + PSB + VAM (Control); S_2-RDF_{100} + *Azospirillum* + PSB+ VAM + with groundnut residue incorporation; S_3-RDF_{75} + *Azospirillum*+ PSB+ VAM+ with groundnut residue incorporation and S_4-RDF_{50} + AS+PSB+VAM+ with groundnut residue incorporation.
The test variety groundnut cultivar, K-9 with spacing of 30cmX10cm and maize cultivar DHM-117 with spacing 60cm x20cm was adopted. Different growth parameters at various stages and yield were recorded and statistically analysed following the analysis of variance for randomized block design as suggested by Panse and Sukhatme (1978) [9].

Table 1: Physico-chemical properties of the experimental soil

	Particulars	Field Numbers		Method of Analysis
		19	25	
I	Mechanical Analysis			
	1. Sand (%)	74.50	73.80	International Pipette method (Piper, 1950) [12]
	2. Silt (%)	11.20	12.70	
	3. Clay (%)	14.30	13.50	
	4. Texture (%)	Sandy loam	Sandy loam	
II	Chemical Analysis			
	1. pH (1:2 soil-water suspension)	6.60	6.80	Glass electrode pH meter (Jackson, 1973) [5]
	2. Ec (dS m^{-1})	0.52	0.48	Conductivity bridge (Jackson, 1973) [5]
	3. Organic Carbon (%)	0.42	0.38	Walkey and Black modified method (Walkley and Black, 1934) [19]
	4. Available nitrogen (kg ha^{-1})	248.00	243.0	Alkaline permanganate (Subbiah and Asija, 1956) [16]
	5. Available P_2O_5 (kg ha^{-1})	23.50	22.40	Olsen's extractant (Olsen *et al.*, 1954) [8]
	6. Available K_2O (kg ha^{-1})	216.00	210.00	Flame photometry (Jackson, 1973) [5]

Results and Discussion

Growth parameters of *kharif* groundnut

Growth parameters like plant height (cm) and dry matter production were significantly influenced by integrated nutrient management practices (Table 2).
During both the years of investigation, plant height of *kharif* groundnut recorded at different growth stages exhibited significant increase with the advancement in the age of the crop. Plant height at harvest was significantly affected due to integrated nutrient management practices. The maximum plant height of groundnut at harvest was recorded with RDF_{150}+ FYM_{5t} + *Rhizobium* inoculation + PSB + VAM (T_3). Increased plant height may be due to the application of recommended dose of NPK, *Rhizobium* inoculation, phosphate solubilizing bacteria and VAM fungi along with FYM. This increase in growth of groundnut could be attributed to the enhanced nutrient use efficiency in the presence of organic manure. Further, the organic manure release nutrients slowly and may reduce the leaching losses, particularly N and simultaneously the ability of biofertilizers to transport major nutrients like N and P besides secreting plant growth promoting substances such as IAA and gibberellins might have helped in increasing the plant height. The superior performance of groundnut plant height under the influence of INM practices as projected in the present findings are in agreement with those of Dhadge and Satpute (2014) [4].
Dry matter accumulation also followed the similar trend, as that of plant height. The highest dry matter accumulation was recorded with RDF_{150}+ FYM_{5t} + *Rhizobium* inoculation + PSB + VAM (T_3) applied to groundnut (Table 2). It was significantly superior to the rest of the treatments. Each successive increment of fertilizers significantly increased the dry matter accumulation of groundnut up to the highest level *i.e.*, RDF_{150}+ FYM_{5t} + *Rhizobium* inoculation + PSB + VAM (T_3). Adequate fertilization to crops is known to improve the physiological and metabolically processes in the plant system creating a favourable environment for higher availability of nutrients. Thus could have helped the groundnut crop growth and development and hence the higher dry matter at higher level of nutrient application. Enhanced dry matter accumulation under INM practices, as recorded in this investigation corroborates the findings of Chavan *et al*. (2014) [2] and Patil *et al*. (2014) [11].

Yield attributes and yield of *kharif* groundnut

Number of gynophores $plant^{-1}$ of groundnut were significantly influenced by the different INM treatments (Table 2). The maximum number of gynophores $plant^{-1}$ was recorded in the treatment RDF_{150}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_3), which was however comparable with RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_2) and RDF_{100}+FYM_{5t}+ *Rhizobium* inoculation +PSB+ VAM(T_4). The increased number of gynophores $plant^{-1}$ under the treatments RDF_{150}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_3) could be attributed to balanced application of nutrition comprising both organic manure and inorganic fertilizers along with biofertilizers. The performance of groundnut above soil surface exhibited a significant increase in the formation of higher number of gynophores which might be due to increased plant height and corresponding increase in number of branches and profuse flowering. This finding is in the accordance with the results reported by Singh *et al.* (2011) [3].
Various INM practices in different combinations have exerted significant influence on number of pods $plant^{-1}$ (Table 2). The highest number of pods $plant^{-1}$ was recorded with combination of RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_2), which was however comparable with other combination receiving RDF_{100}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_4). Increased number of pods $plant^{-1}$ under RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation +PSB+

VAM (T_2) might be attributed to integrated application of fertilizers, manure along with biofertilizers that produced adequate and balanced nutrition in readily available forms throughout the growth period. The uptake lead to greater photosynthetic activity, production of metabolites and the enzymatic activity might have increased the proliferation of the root system in increasing pods plant^{-1}. However, the applied nutrition in the combination of RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation + PSB+VAM (T_2) with other integrated treatments did not exhibit extensive and lanky vegetative growth thus preventing the formation of gynophores at greater height. The greater production of metabolites and their translocation to various sinks especially productive structures could have rendered in the transformation of maximum number of gynophores into development of pods. These results exhibited in the present study corroborates the findings of Choudhary *et al.* (2011) [3] and Singh *et al.* (2011) [3].

Pod yield of groundnut was significantly influenced by different integrated management practices (Table 2). The highest pod yield (2542 and 2453 kg ha^{-1} during 2015-16 and 2016-17, respectively) was recorded with the application of RDF_{125} + FYM_{5t} + *Rhizobium* inoculation + PSB + VAM (T_2), which was however comparable to RDF_{100} + FYM_{5t}+ *Rhizobium* inoculation + PSB + VAM (T_4). Among the different rates of fertilizers and their combination with FYM and biofertilizers, the combined use of 125% RDF through fertilizer has remarkably recorded the highest pod yield of groundnut over all other RDF, FYM and Biofertilizers management practices. This might be attributed to efficient and greater partitioning of metabolites and adequate translocation and accumulation of photosynthates, amino acids, vitamins, etc., to developing reproductive structures under adequate fertilization. This seems to have resulted in increased yield attributing characters and finally yield. Similar findings were also reported by Chavan *et.al.* (2014) [2] and Sheetal *et al*. (2014) [14].

Haulm yield of *kharif* Groundnut

Different integrated nutrient management practices exerted significant influence on the haulm yield of groundnut. Haulm yield was the highest (7718 and 7339 kg ha^{-1} during 2015-16 and 2016-17, respectively) with RDF_{150}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_3) (Table 2). The increase in haulm yield with the treatments that received combination of organic and inorganic fertilizers along with biofertilizers might be due to the application of *Rhizobium*, PSB and VAM fungi. These have helped in readily available form of nutrients throughout the growth period. Thus the increase in nutrients availability in the root zone and their uptake increased significantly resulting in greater photosynthesis production of metabolites and accumulation of more drymatter, which finally reflected in more haulm yield. The findings are in accordance with those of Choudhary *et al.* (2011) [3].

Table 2: Plant height (cm), Dry matter production (kg ha^{-1}), yield attributes and pod yield (kg ha^{-1}) of groundnut as influenced by different integrated nutrient management practices during *kharif* 2015 and 2016

Treatments	2015						2016					
	Plant height at harvest	Dry matter at maturity	No. of gynophores Plant^{-1}	No. of Pods Plant^{-1}	Haulm yield	Pod yield	Plant height at harvest	Dry matter at maturity	No. of gynophores Plant^{-1}	No. of Pods Plant^{-1}	Haulm yield	Pod yield
T_1= RDF_{100}+FYM_{5t} (Control)	82.50	6063	35.00	14.25	4578	1485	83.50	5800	34.25	14.25	4329	1471
T_2= RDF_{125}+FYM_{5t} +*Rhizobium* +PSB+VAM	95.65	7908	44.50	25.00	5366	2542	94.48	7795	44.50	24.50	5349	2453
T_3= RDF_{150}+FYM_{5t} + *Rhizobium* +PSB+VAM	102.75	9743	46.00	20.00	7718	2026	101.25	9228	45.50	18.50	7339	1889
T_4= RDF_{100}+FYM_{5t} + *Rhizobium* +PSB+VAM	93.65	7768	43.50	23.50	5388	2412	93.25	7470	43.25	23.00	5342	2353
T_5= RDF_{75}+FYM_{5t} + *Rhizobium* +PSB+VAM	92.40	7453	40.25	20.25	5357	2065	91.50	7320	40.00	19.50	5118	1971
T_6 = RDF_{50}+FYM_{5t} + *Rhizobium* +PSB+VAM	85.25	6207	37.00	17.00	4496	1711	85.00	6117	35.00	15.00	4551	1566
Mean	92.03	7524	41.04	20.00	5484	2040	91.50	7288	40.42	19.13	5338	1950
SEm ±	2.27	265.41	1.01	0.96	275.90	104.00	1.39	196.35	0.77	0.95	217.41	98.09
CD (P=0.05)	6.86	800.06	3.07	2.91	831.65	313.51	4.19	591.88	2.34	2.90	655.37	295.67
CV (%)	14.95	14.71	13.96	11.67	10.06	10.19	13.04	13.94	13.85	10.09	11.81	10.05

Nutrient Uptake in *kharif* Groundnut

N P K uptake estimated at harvesting was significantly influenced by integrated nutrient management practices (Table 3). A steady progressive increase in N P K uptake was noticed with increase of nutrient management practices. Application of RDF_{150}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_3) was recorded distinctively the highest nitrogen uptake. Increases in nitrogen, phosphorus and potassium contents in the by haulm with the application of farm yard manure along with *Rhizobium*, VAM, PSB might be due to enhanced supply of plant nutrients by direct addition through nitrogen fixation, solubilization of native phosphorus content of soil and dislodging the exchangeable K from soil clay and also by increasing nutrient use efficiency, better absorption and utilization of nutrient in balanced form as observed by researchers such as Chavan *et.al.*(2014) [2] agrees with the present investigation.

Table 3: N, P and K uptake (kg ha^{-1}) of haulms in groundnut at harvest as influenced by different integrated nutrient management practices during *kharif* 2015 and 2016

Treatments	2015			2016		
	N Uptake	P Uptake	K Uptake	N Uptake	P Uptake	K Uptake
T_1= RDF_{100}+FYM_{5t} (Control)	100.75	9.75	45.62	100.53	8.79	36.50
T_2= RDF_{125}+FYM_{5t} +*Rhizobium* +PSB+VAM	134.89	14.48	64.35	133.96	13.87	56.66
T_3= RDF_{150}+FYM_{5t} + *Rhizobium* +PSB+VAM	194.10	21.41	87.71	183.81	19.64	78.15
T_4= RDF_{100}+FYM_{5t} + *Rhizobium* +PSB+VAM	134.16	13.77	64.40	133.20	13.22	56.38
T_5= RDF_{75}+FYM_{5t} + *Rhizobium* +PSB+VAM	131.72	13.59	60.99	124.62	12.41	53.62
T_6 = RDF_{50}+FYM_{5t} + *Rhizobium* +PSB+VAM	103.18	10.25	46.44	106.40	9.91	41.53
Mean	133.13	13.88	61.59	130.42	12.97	53.81
SEm ±	6.48	0.71	2.26	5.64	0.59	2.41
CD (P=0.05)	19.53	2.15	6.84	17.02	1.79	7.28
CV (%)	10.73	10.31	12.65	10.66	12.29	10.98

Post- harvest Fertility Status after harvest of *kharif* Groundnut

The soil parameters *viz.,* organic carbon content, N P and K status in soil after *kharif* groundnut was significantly influenced by integrated nutrient management practices to groundnut (Table 4). The highest organic carbon content, N P and K status after harvest of groundnut was recorded with the combination of RDF_{150}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_3) which was, however, on par with treatments RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_2), RDF_{100}+FYM_{5t}+ *Rhizobium* inoculation +PSB+ VAM (T_4)

Application of FYM and *Rhizobium* inoculation of legumes resulted in improved soil fertility, due to increase of the organic carbon, available N, P and K content of the soil. This might be due to direct addition of N to the soil, which enhanced the microbial activity leading to consequent release of organic complex substances (chelating agents) which turned into greater solubility of available nutrients. The enhanced available nitrogen content of soil might also be due to favourable soil conditions under organic manure with multi inoculation of biofertilizers which might have helped in the mineralization of soil nitrogen resulting in higher build up of available N. Organic manures along with biofertilizers *i.e*., *Rhizobium*, VAM, PSB significantly increased the available phosphorus content of the soil at harvest. Besides, carbon dioxide and organic acids released during the process of decomposition might have increased the availability of nutrient from native as well as applied fertilizers. The improvement in available P status is because, the roots of legumes secrete certain acidic substances which dissolve insoluble P convert into easily assimiable forms. The fixed and applied phosphate might have been solubilised by secretion of these organic acids and phosphatase enzymes. Application of biofertilizers registered significantly higher K availability in soil due to easy decomposition of mineral constituents and their effect on dislodging the exchangeable K in to the soil solution. As groundnut is a food legume, it plays an important role in improving the fertility status of soil with the help of *Rhizobium* bacteria present in the roots. They are known to enrich the soil with nitrogen through symbiotic nitrogen fixation. Legumes also make soil fertile due to better root penetration causing removal of nutrients from deeper soil layers and thus enriching the top soil with such nutrients. Further, legumes also add a sizable amount of root parts and other residues at maturity thereby improving the nitrogen status of soil after decomposition. The present findings are also in conformity with the findings of earlier studies *viz.*, Choudhary *et al.* (2011) [3] and Chavan *et al.* (2014) [2].

Table 4: Available OC (%), N, P and K (kg ha^{-1}) in soil after harvest of groundnut as influenced by different integrated nutrient management practices during *kharif* 2015 and 2016

Treatments	2015				2016			
	OC	N	P_2O_5	K_2O	OC	N	P_2O_5	K_2O
T_1= RDF_{100}+FYM_{5t} (Control)	0.38	251.00	23.59	216.50	0.33	243.50	22.50	211.00
T_2= RDF_{125}+FYM_{5t} +*Rhizobium* +PSB+VAM	0.47	293.75	30.60	281.75	0.44	283.75	28.30	277.25
T_3= RDF_{150}+FYM_{5t} + *Rhizobium* +PSB+VAM	0.49	297.50	32.62	287.50	0.45	287.50	29.62	280.50
T_4= RDF_{100}+FYM_{5t} + *Rhizobium* +PSB+VAM	0.46	290.63	29.84	277.25	0.42	280.63	27.41	269.25
T_5= RDF_{75}+FYM_{5t} + *Rhizobium* +PSB+VAM	0.44	282.50	28.32	268.50	0.40	272.50	25.32	262.50
T_6 = RDF_{50}+FYM_{5t} + *Rhizobium* +PSB+VAM	0.42	260.50	25.41	217.50	0.37	250.50	23.45	212.00
Mean	0.44	279.31	28.39	258.17	0.40	269.73	26.10	252.08
SEm ±	0.02	8.74	1.82	19.03	0.019	8.68	1.63	18.79
CD (P=0.05)	0.06	26.35	5.50	57.36	0.057	26.18	4.93	56.65
CV (%)	10.46	11.60	12.87	14.74	10.72	13.15	12.55	14.91

Drymatter Accumulation in *rabi* Maize

Drymatter accumulation at all stages by maize was affected significantly by the direct treatments as well as the residual effect of the treatments applied to preceding groundnut (Table 5). The interaction effects were, however, found non-significant. Different integrated nutrient management practices applied to preceding *kharif* groundnut had significant influence on dry matter accumulation of *rabi* maize. The treatment with the application of RDF_{150}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_3) recorded significantly the highest dry matter production which was, however, on par with the combinations supplying RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_2) and RDF_{100}+FYM_{5t}+ *Rhizobium* inoculation + PSB+VAM (T_4). Irrespective of the residual effect of the treatments adopted to the preceding groundnut, the treatments applied to the succeeding maize produced the highest dry matter with the combination supplying RDF_{100}+ *Azospirillum*

+PSB+VAM + groundnut residue incorporation (S_2), when compared to all other treatments which was, however, comparable with the treatments RDF_{75}+ *Azospirillum* + PSB+ VAM+ groundnut residue incorporation (S_3). Increased application of different INM practices to groundnut resulted in linear increase of drymatter accumulation in maize. Judicious supply of fertilizers is known to enhance chlorophyll content, which in turn increased the photosynthetic activity rendering to increased accumulation of drymatter. Drymatter accumulation in maize with different treatment combinations might be due to the improvement in soil N status owing to the biological nitrogen fixation of the legumes. This may be due to the ability of biofertilizers to transport major nutrients like N and P besides secreting plant growth promoting substances such as IAA and gibberellins (Umesha *et al.*, 2014) [17]. Irrespective of the stage of the crop and year of experimentation, incorporation of groundnut crop residue has resulted in significant improvement in drymatter accumulation as groundnut crop is a legume. A narrow C: N ratio enhanced the range of mineralization resulting in the availability of nitrogen and 'N' from added fertilizer might have been readily available to the succeeding crop. Prolonged availability of N owing to reduced losses and fermentation of mineral complexes was clearly evident from the residue incorporation treatments. Similar findings were also reported by Umesha *et al.* (2014) [17].

Table 5: Drymatter accumulation (kg ha^{-1}) of maize at maturity as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	Treatments applied to *rabi* maize (S)									
	2015-16					2016-17				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
T_1	14539	18430	17621	14545	16284	12434	17239	16420	13435	14882
T_2	18301	24101	22950	19302	21164	15126	22379	20017	17244	18691
T_3	18602	24216	22953	19524	21324	15992	22437	20067	17294	18948
T_4	17946	24005	22438	19085	20869	15031	22021	19833	17128	18503
T_5	14832	20654	20199	18861	18637	13792	20608	17971	15573	16986
T_6	14637	18864	18390	15076	16742	12572	17988	16560	13678	15199
Mean	16476	21712	20759	17732	19170	14158	20445	18478	15725	17202
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	211.10	636.31	12.62		T	201.85	608.43	12.23	
	S	773.18	2192.21	14.76		S	718.25	2036.48	14.73	
	T at S	1745.45	NS	14.76		T at S	1627.09	NS	14.73	
	S at T	1893.89	NS	14.76		S at T	1759.35	NS	14.73	

Kernel yield and stover yield of *rabi* Maize

Kernel and stover yield of maize that followed groundnut in sequence were affected significantly by the direct and residual effect of the treatments imposed to preceding groundnut, but, their interactions were found to be non-significant (Table 6 & 7). The variation in kernel yield observed across the treatments imposed in groundnut-maize sequence was consistent during both the years of the study. As observed with many yield attributing characters, kernel yield of maize following the INM treatments applied to preceding groundnut was higher than that of the INM treatment without biofertilizers. The maximum kernel yield and stover yield were recorded consistently following the residual effect of treatment associated with combination RDF_{150}+ FYM_{5t}+ *Rhizobium* inoculation + PSB+VAM (T_3) which was, however, comparable with combinations RDF_{125}+ FYM_{5t}+ *Rhizobium* inoculation+ PSB+VAM(T_2) and RDF_{100}+FYM_{5t}+ *Rhizobium* inoculation + PSB+VAM(T_4). In respect of direct treatments applied to maize, the treatment combination RDF_{100}+ *Azospirillum* + PSB+VAM + groundnut residue incorporation (S_2) recorded the maximum kernel yield of 8892 and 8466 $kgha^{-1}$ during 2015-16 and 2016-17, respectively which was, however, on par with combination RDF_{75}+ *Azospirillum* +PSB+VAM+ groundnut residue incorporation (S_3).

Significant improvement in the kernel yield of maize by taking groundnut as preceding crop could be attributed to higher biomass production and nutrient uptake. Increase in the soil microbial population subsequent to groundnut crop harvest as well as due to the residue incorporation might have led to increased solubilization of all the nutrients for absorption, which might have resulted in the enhanced kernel yield as compared to without residue incorporation. The incorporation of the groundnut residue after economic yield, interacted positively with the soil and the release of nutrients. This might have enabled the maize to get assured and continuous supply of nutrients and these are distributed during entire crop growth period. Decomposition and mineralization of residues might have coincided with the early growth stages of succeeding maize which might have contributed for better performance of the maize over no residue incorporation (Aniket Kalhapure *et al.*, 2014) [1].

The positive response of maize at higher levels of nutrients application could be attributed to the overall improvement in crop growth by drymatter accumulation, that has enabled the plants to absorb higher quantum of nutrients in order to manifest increased photosynthates and their translocation to sink which finally might have reflected in the kernel yield (Mohammadi and Sohrabi, 2012) [7]. The yield increased significantly over control with the inoculation of *Azospirillum*, PSB and VAM fungi. This might be due to enhanced nutrient uptake by the roots. The immobile ions in soil like phosphate lead to formation of a zone of phosphate depletion around roots in phosphate deficient soils. Mycorrhizal growth helps the roots to absorb phosphate ions much faster which are replenished at the root surface by diffusion. The VAM fungi hyphae attached to the roots extend beyond this depletion zone and promote nutrient translocation from the soil to the plants through the root cortex. The inoculation with VAM fungus enhanced the population of soil bacteria, fungi and actinomycetes. As evident from the results, the VAM fungal inoculation can effectively modify the soil microbe population and community structure by increasing the soil enzymatic activities. The beneficial role of INM practices as reflected in the present investigation in enhancing the yield components and in turn the kernel yield was very well established and also corroborated with the results as reported by Mahendra Singh *et al.* (2016) [6] and

Partha Sarathi Patra *et al.*, 2017 [10]. The superior performance of maize stover yield preceded by groundnut could be attributed to the production of higher biomass coupled with symbiotic nitrogen fixation that might have helped in the accumulation of increased biological yield, which in turn reflected in enhancing the morphological growth. The positive role of RDF in improving biological yield of maize was hitherto established by earlier researchers Partha Sarathi Patra *et al.*, 2017 [10] which corroborates with the present investigation.

Table 6: Kernel yield (kg ha^{-1}) of maize as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	Treatments applied to *rabi* maize (S)									
	2015-16					2016-17				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
T_1	7141	8331	7719	6561	7438	5306	7615	6649	6269	6460
T_2	7663	9406	9362	8267	8674	6697	9075	8611	7423	7951
T_3	8082	9442	9397	8313	8808	6774	9104	8663	7426	7992
T_4	7557	9404	9313	8241	8629	6424	8974	8395	7351	7786
T_5	7270	8423	8389	8138	8055	5997	8407	7223	6638	7066
T_6	7127	8347	7843	6990	7577	5494	7625	7121	6425	6666
Mean	7473	8892	8670	7752	8197	6115	8466	7777	6922	7320
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	77.27	232.92	13.08		T	75.08	226.33	12.51	
	S	284.11	805.55	14.98		S	289.51	820.86	14.26	
	T at S	641.09	NS	14.98		T at S	649.82	NS	14.26	
	S at T	695.93	NS	14.98		S at T	709.15	NS	14.26	

Table 7: Stover yield (kg ha^{-1}) of maize as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	Treatments applied to *rabi* maize (S)									
	2015-16					2016-17				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
T_1	7398	10099	9902	7984	8846	7128	9624	9771	7165	8422
T_2	10638	14695	13588	11035	12490	8429	13305	11406	9822	10740
T_3	10520	14774	13556	11211	12516	9218	13333	11405	9868	10956
T_4	10389	14601	13125	10844	12240	8607	13047	11438	9778	10717
T_5	7562	12231	11810	10723	10582	7795	12201	10748	8935	9920
T_6	7510	10517	10547	8086	9165	7078	10363	9438	7253	8533
Mean	9003	12820	12088	9981	10973	8043	11979	10701	8804	9881
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	160.94	485.12	12.32		T	155.07	467.42	11.51	
	S	614.36	1741.90	14.18		S	503.41	1472.34	13.16	
	T at S	1380.45	NS	14.18		T at S	1154.45	NS	13.16	
	S at T	1504.86	NS	14.18		S at T	1233.10	NS	13.16	

Nutrient uptake *rabi* maize

N, P and K uptake by maize that followed groundnut in sequence was affected significantly by the direct and residual effect of the treatments imposed to preceding groundnut, but, their interactions were found non-significant (Table 8, 9&10). Significant difference in N, P and K uptake was observed in the combination RDF_{150}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_3) which was, however, comparable with other treatments imposed *viz.*, RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_2) and RDF_{100}+ FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_4). In case of direct treatments applied to maize, the combination of RDF_{100}+ *Azospirillum* + PSB+VAM + groundnut residue incorporation (S_2) recorded significantly increased uptake of N, P and K in maize which was, however, on par with combination RDF_{75}+ *Azospirillum* +PSB+VAM+ groundnut residue incorporation (S_3).

Highest uptake of N, P and K was observed with application of RDF + biofertilizers (*Azospirillum* + PSB) + ground nut residue. This might be owing to the combined effect of rapid release of nutrients by decomposition of groundnut residue and also because of the increased availability of N, P and K which added in the soil through organic and inorganic resources by *Azospirillum* and phosphate solubilising bacteria. *Azospirillum* that fixes the environmental nitrogen asymbiotically and phosphate solubilizing bacteria (*Bacillus megaterium*) are responsible for solubilization of phosphorus fixed in soil and made it available for absorption by plant roots in elemental form (Aniket Kalhapure *et al.*, 2014) [1].

Significant improvement in uptake of nitrogen by maize preceded by groundnut suggests that mineralized N was utilized efficiently by the crop plants for their growth. Higher uptake of N by maize due to incorporation of groundnut crop residue might be due to better availability of nitrogen in soil after their decomposition and consequent increase in drymatter production. Significant variation among different factors under investigation with regard to uptake of N, P and K may be due to increase in drymatter accumulation coupled with percent increase in nutrients content in drymatter that might have contributed to the increased uptake of N,P and K. These findings are in accordance with those of Aniket Kalhapure *et al.* (2014) [1].

Table 8: Nitrogen uptake by the stover (kg ha^{-1}) of maize as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	Treatments applied to *rabi* maize (S)									
	2015-16					2016-17				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
T_1	35.19	93.91	79.03	55.68	65.95	38.49	81.15	77.72	49.41	61.69
T_2	84.44	178.86	149.11	94.09	126.79	69.49	159.98	124.32	82.22	109.28
T_3	87.31	182.53	149.47	97.21	128.32	72.02	161.08	124.68	83.49	110.95
T_4	82.34	176.28	144.38	86.80	123.09	67.77	141.68	124.31	81.27	103.85
T_5	48.47	128.91	121.53	78.14	94.26	49.23	138.73	112.63	64.23	91.20
T_6	37.53	93.93	89.00	59.20	69.92	40.20	81.55	77.00	51.73	62.62
Mean	62.55	142.40	122.09	78.52	101.39	56.20	127.36	106.78	68.73	89.77
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	2.59	7.79	12.84		T	1.97	5.94	11.73	
	S	9.24	22.75	14.19		S	4.65	14.54	14.20	
	T at S	21.30	NS	14.19		T at S	19.18	NS	14.20	
	S at T	29.10	NS	14.19		S at T	21.19	NS	14.20	

Table 9: Phosphorous uptake by the stover (kg ha^{-1}) (P content in %) of maize as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	Treatments applied to *rabi* maize (S)									
	2015-16					2016-17				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
T_1	7.13	26.01	19.69	15.08	16.98	7.39	22.56	16.64	12.05	14.66
T_2	30.76	38.44	35.71	24.28	32.07	23.89	32.82	28.90	22.18	26.76
T_3	30.11	46.31	41.35	25.32	34.82	24.25	39.26	28.85	22.05	28.21
T_4	27.35	36.08	32.90	24.03	31.27	23.27	30.25	28.85	20.49	26.29
T_5	16.60	29.78	28.84	20.74	23.99	14.27	28.75	23.94	15.39	21.09
T_6	9.57	28.45	18.96	14.78	17.94	8.90	25.94	13.88	12.14	15.21
Mean	20.25	34.18	29.57	20.71	26.18	16.16	29.93	23.51	16.55	22.04
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	1.34	4.03	10.16		T	0.85	2.56	10.12	
	S	2.49	7.06	13.31		S	2.14	6.43	12.06	
	T at S	5.99	NS	13.31		T at S	4.96	NS	12.06	
	S at T	6.10	NS	13.31		S at T	5.02	NS	12.06	

Table 10: Potassium uptake by the stover (kg ha^{-1}) (K content in %) of maize as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	Treatments applied to *rabi* maize (S)									
	2015-16					2016-17				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
T_1	42.03	77.69	80.23	53.73	62.81	46.12	66.41	78.19	47.50	58.96
T_2	87.85	158.08	130.14	101.14	118.46	69.96	141.33	108.35	89.03	102.42
T_3	89.36	161.35	135.88	103.26	120.35	76.05	144.76	112.92	89.90	104.60
T_4	86.23	156.23	126.00	99.42	115.57	70.58	138.30	108.66	88.67	100.12
T_5	58.58	99.86	110.24	84.71	87.68	59.61	98.40	99.26	69.69	81.21
T_6	45.50	93.29	90.66	61.28	71.63	48.77	82.90	80.18	54.24	65.84
Mean	66.98	121.98	111.27	82.76(0.82)	94.63	61.33	109.90	97.44	72.12	84.23
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	3.38	10.14	12.42		T	2.46	7.39	11.95	
	S	5.38	15.25	14.47		S	6.47	18.34	12.27	
	T at S	12.05	NS	14.47		T at S	14.97	NS	12.27	
	S at T	13.17	NS	14.47		S at T	15.84	NS	12.27	

Post-harvest Status Fertility Status after harvest of *rabi* Maize

Organic carbon, N, P and K status of soil after maize that followed groundnut in sequence was affected significantly by the direct and residual effect of the treatments imposed to preceding groundnut, but, their interactions were found non-significant (Table 11,12,13&14). The highest organic carbon content after harvest of maize was recorded with the combination of RDF_{150}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_3) which was, however, on par with treatments comprising RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_2) and RDF_{100}+FYM_{5t}+ *Rhizobium* inoculation +PSB+VAM (T_4). In case of direct treatments applied to maize, the combination of RDF_{100}+ *Azospirillum* + PSB+VAM + groundnut residue incorporation (S_2) recorded significantly greater soil organic carbon after maize which was, however, comparable with the combination RDF_{75}+ *Azospirillum* +PSB+VAM+ groundnut residue incorporation (S_3).

Significantly higher values of organic carbon percentage, available N, P and K content of soil after completing two cycles of maize crop were recorded in treatments having different levels of RDF + biofertilizers (*Azospirillum* + PSB) + groundnut crop residue. Increased nutrient status and organic carbon content might be attributed to the combined effect of rapid release of nutrients by decomposition of residue and also because of the increased availability of N and P which added to the soil through organic and inorganic resources besides *Azotobacter*, phosphate solubilizing bacteria and VAM fungi inoculation. Groundnut residue is the rich sources of organic carbon, nitrogen, phosphorus, potassium and also different micronutrients. *Azospirillum* fixes the environmental nitrogen asymbiotically and phosphate solubilizing bacteria (*Bacillus megaterium*) are responsible for solubilization of phosphorus fixed in soil and made it available for absorption by plant roots in elemental form. All these sources of biofertilizers were found to be effective for addition of the essential plant nutrients into soil in available form. The similar effects of different organic and inorganic sources along with biofertilizers on the nutrient status of soil after harvest of the maize crop as found in the present experiment were also revealed by Satish *et al.* (2011) [13]. and Aniket Kalhapure *et al.*(2014) [1].

Table 11: Soil organic carbon (%) after harvest of maize as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	**Treatments applied to *rabi* maize (S)**									
	2015-16					**2016-17**				
	S_1	**S_2**	**S_3**	**S_4**	**Mean**	**S_1**	**S_2**	**S_3**	**S_4**	**Mean**
T_1	0.22	0.28	0.26	0.23	0.25	0.21	0.28	0.26	0.22	0.24
T_2	0.40	0.49	0.48	0.42	0.45	0.39	0.49	0.48	0.42	0.45
T_3	0.46	0.52	0.50	0.44	0.48	0.45	0.50	0.50	0.43	0.47
T_4	0.42	0.48	0.47	0.42	0.45	0.42	0.48	0.47	0.42	0.45
T_5	0.32	0.42	0.38	0.33	0.36	0.30	0.42	0.38	0.32	0.36
T_6	0.24	0.31	0.31	0.25	0.28	0.23	0.31	0.31	0.24	0.27
Mean	0.34	0.42	0.40	0.35	0.38	0.33	0.41	0.40	0.34	0.37
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	0.01	0.03	10.32		T	0.01	0.04	11.93	
	S	0.02	0.06	11.92		S	0.02	0.06	13.94	
	T at S	0.10	NS	11.92		T at S	0.09	NS	13.94	
	S at T	0.11	NS	11.92		S at T	0.10	NS	13.94	

Table 12: Available nitrogen in soil (kg ha^{-1}) after harvest of maize as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	**Treatments applied to *rabi* maize (S)**									
	2015-16					**2016-17**				
	S_1	**S_2**	**S_3**	**S_4**	**Mean**	**S_1**	**S_2**	**S_3**	**S_4**	**Mean**
T_1	158.50	220.00	202.50	177.50	189.63	148.75	214.25	207.25	166.00	184.06
T_2	185.00	265.00	255.00	195.00	225.00	186.00	264.25	243.00	191.00	221.06
T_3	188.00	267.50	260.00	196.25	227.94	188.75	266.75	247.50	193.13	224.03
T_4	182.00	262.50	249.38	192.50	221.59	185.00	260.50	241.88	190.63	219.50
T_5	169.00	241.25	215.00	189.38	203.66	183.75	229.25	223.13	179.13	203.81
T_6	161.00	221.25	211.50	180.00	193.44	160.00	216.25	208.75	173.00	189.50
Mean	173.92	246.25	232.23	188.44	210.21	175.38	241.88	228.58	182.15	206.99
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	2.43	7.34	11.47		T	2.00	6.04	13.92	
	S	8.13	23.05	12.94		S	8.14	23.08	14.07	
	T at S	18.56	NS	12.94		T at S	18.17	NS	14.07	
	S at T	19.90	NS	12.94		S at T	19.93	NS	14.07	

Table 13: Available phosphorous in soil (kg ha^{-1}) after harvest of maize as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	**Treatments applied to *rabi* maize (S)**									
	2015-16					**2016-17**				
	S_1	**S_2**	**S_3**	**S_4**	**Mean**	**S_1**	**S_2**	**S_3**	**S_4**	**Mean**
T_1	15.00	27.36	22.34	16.83	20.38	11.73	23.33	20.32	17.66	18.26
T_2	17.90	35.44	33.00	22.45	27.20	20.52	33.08	32.25	20.95	26.70
T_3	18.17	35.50	34.10	23.34	27.78	21.00	33.75	32.50	21.87	27.28
T_4	17.87	35.27	30.40	22.26	26.45	19.74	32.86	31.25	20.73	26.15
T_5	17.74	32.81	29.38	22.14	25.52	18.37	32.03	30.89	20.37	25.42
T_6	15.44	28.66	23.83	17.33	21.32	12.84	23.50	22.15	19.46	19.49
Mean	17.02	32.51	28.84	20.72	24.77	17.37	29.76	28.23	20.17	23.88
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	0.45	1.37	12.57		T	0.44	1.34	14.12	
	S	1.38	3.91	10.24		S	1.41	4.01	11.06	
	T at S	3.19	NS	10.24		T at S	3.24	NS	11.06	
	S at T	3.37	NS	10.24		S at T	3.46	NS	11.06	

Table 14: Available potassium in soil (kg ha^{-1}) after harvest of maize as influenced by preceding groundnut and different integrated nutrient management practices during *rabi* 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	Treatments applied to *rabi* maize (S)									
	2015-16					2016-17				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
T_1	190.00	277.00	264.00	202.50	233.38	198.75	235.00	233.00	214.50	220.31
T_2	228.00	303.50	297.50	235.75	266.19	250.00	282.50	283.00	254.50	267.50
T_3	228.75	305.00	302.50	236.00	268.06	252.00	283.00	284.00	255.00	268.50
T_4	226.00	300.00	295.00	229.00	262.50	248.00	280.50	277.50	252.50	264.63
T_5	195.50	287.50	268.00	210.00	240.25	216.00	268.00	253.00	229.50	241.63
T_6	192.50	280.00	267.50	207.50	236.88	203.00	238.00	235.50	221.50	224.50
Mean	210.13	292.17	282.42	220.13	251.21	227.96	264.50	261.00	237.92	247.84
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	2.22	6.68	14.12		T	1.64	4.93	10.56	
	S	5.48	15.53	10.68		S	5.82	16.49	11.50	
	T at S	13.20	NS	10.68		T at S	13.17	NS	11.50	
	S at T	13.41	NS	10.68		S at T	14.24	NS	11.50	

System Productivity

System productivity in terms of groundnut equivalent yield under integrated nutrient management to groundnut- maize sequence was significantly influenced by the residual effect of preceding *kharif* groundnut and direct treatments applied to succeeding *rabi* maize. The interaction effect of nutrient management practices to preceding groundnut and fertilizer schedules along with biofertilizers and groundnut residue incorporation to *rabi* maize was found non-significant (Table 15). The distinctly highest system productivity was recorded with the residual effect of nutrients supplied to *kharif* groundnut through the combination RDF_{125}+FYM_{5t}+ *Rhizobium* inoculation + PSB+VAM (T_2) compared with that of combination of organic and inorganic sources. In addition, among the direct treatments applied to maize, the treatments RDF_{100}+ *Azospirillum* + PSB+VAM + groundnut residue incorporation (S_2) recorded the maximum system productivity, which was however, closely followed by the combination with RDF_{75}+ *Azospirillum* +PSB+ VAM+ groundnut residue incorporation (S_3). The integrated nutrient management treatments to *kharif* groundnut and its residue incorporation besides direct application of INM treatments to *rabi* maize influenced the production of *rabi* maize through their after effects probably by improving the soil fertility and microbial activity for increased mineralization and better nutrient use efficiency. Hence, the system productivity was more through this strategy than due to the inorganic fertilizers alone. These results are in accordance with the findings Usadadiya and Patel (2013) [18].

Based on the forgoing findings of the investigation, it could be inferred that groundnut-maize cropping system under integrated use of 125%RDF, FYM@ 5tha^{-1}, *Rhizobium* inoculation, PSB and VAM (T_2) to *kharif* groundnut followed by incorporation of groundnut residue in combination with 100% RDF and biofertilizers (S_2) to *rabi* maize has higher system productivity.

Table 15: System productivity in terms of groundnut equivalent yield (kg ha^{-1}) of the groundnut-maize cropping system for 2015-16 and 2016-17

Treatments applied to *kharif* groundnut (T)	Treatments applied to *rabi* maize (S)									
	2015-16					2016-17				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
T_1	3351	3662	3502	3199	3428	2829	3315	3208	3161	3128
T_2	4544	4999	4987	4701	4808	4171	4824	4518	4346	4465
T_3	4137	4493	4481	4197	4327	3705	4437	4077	3853	4018
T_4	4386	4868	4844	4565	4666	4031	4697	4385	4159	4318
T_5	3965	4266	4257	4191	4170	3538	4312	3938	3740	3882
T_6	3572	3891	3760	3537	3690	3102	3904	3526	3312	3461
Mean	3992	4363	4305	4065	4181	3563	4248	3942	3762	3879
		SEm+	CD (P=0.05)	CV (%)			SEm+	CD (P=0.05)	CV (%)	
	T	36.45	109.87	13.95		T	29.79	87.79	12.29	
	S	74.23	210.46	11.19		S	87.21	247.27	11.01	
	T at S	181.81	NS	11.19		T at S	203.28	NS	11.01	
	S at T	188.20	NS	11.19		S at T	213.62	NS	11.01	

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