Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(6): 2069-2074
Received: 21-09-2019
Accepted: 25-10-2019

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Effect of integrated nutrient management on yield attributing characters and productivity of maize in acid *Inceptisols*

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Abstract
To investigate the continuous effect of inorganic fertilizers and organic manures, an integrated nutrient management practices on maize was initiated since the year 2010 in acid *Inceptisols*. The field is situated in College of Agriculture, OUAT, Bhubaneswar. Maize is the 17th crop in the sequence (*kharif* 2016). The integrated nutrient management practices include i) soil test dose (STD) @ 130-36-70-20 kg N-P_2O_5-K_20-SO_4 ha^{-1} as pure inorganic source ii) Combination of inorganic with organic in the form of either FYM @5 t ha^{-1} or vermicompost @2.5 t ha^{-1}, iii) inclusion of microbial inoculant / bio fertiliser (Azotobacter, Azospirillum and PSB (1:1;1) and soil amendment in the form lime @ 0.2lime requirement (LR) compared with iv) Absolute control i.e. without any fertilisation. The treatment with the inclusion of inorganics, organics (FYM/VC), biofertilizers and lime proved to be the best package of practices in terms of relative growth of maize, root density, yields attributing characters. Without application of any organic manure there was a 53% yield loss in the chemical fertilizer treated plot and only 8.3% yield advantage of INM practices including bio fertiliser over only organic and inorganic combination. STD + FYM + BF + L has showed highest plant height at 43, 55 and 100 days after sowing (2.77, 4.85 and 2.29 cm respectively). The root density (0.86 g/cc) and yield parameters like length (18.5 cm) and diameter of cob (15cm), volume of cob (862.8 cm^3), number of rows per cob (15), number of grains per cob (570) and test weight (326) was also found to be highest with this treatment. The relative agronomic efficiency, uptake of nutrients and the apparent recovery of N (78%) and P (46.4%) were found to be highest in treatment with STD+FYM+BF+L. But in case of apparent potassium recovery the highest value was obtained in 50% STD + BF (110%). The result for the present study confirms that because the soil is acidic, it is mandatory to include lime as one of the key component of INM for better growth and greater crop yield. The continuous application of balanced nutrition through integration of lime, FYM or VC with microbial inoculants improved the growth parameter and yield attributing characters of maize crop.

Keywords: Maize, INM, plant parameters, productivity, uptake, apparent recovery.

Introduction
Today, for the country of India's dimension, with no scope for horizontal expansion and complexity of problems and challenges, there is no alternative but continue to improve productivity without further degrading its natural resources that too in a sustainable manner (Narayanswamy *et al.*, 1994) [12]. This has led to the concept of integrated nutrient management (INM) gain momentum in recent years to improve and maintain the soil health. Besides this, with escalating cost of energy based fertilizer material, limited fossil fuels, INM approach combines the use of organic sources along with fertilizers, which would be remunerative for getting higher yields with considerable fertilizer economy (Subbian and Palaniappan, 1992).
Maize has high genetic yield potential than other cereal crops. Hence it is called as 'miracle crop' and also as 'queen of cereals'. Being a C_4 plant, it is very efficient in converting solar energy in to dry matter. As heavy feeder of nutrients, maize productivity is largely dependent on nutrient management. Therefore, it needs fertile soil to express its yield potential. However, long term use of chemical fertilizers also led to a decline in crop yields and soil fertility in the intensive cropping systems (Dadhich *et al.*, 2011) [6]. As the mineral fertilizer alone cannot meet the requirements of crops and cropping systems because of high cost and also environment related risks involved in its application and usage. Integrated use of organics which includes biofertilizers and vermicompost as a source of macro, micro and secondary nutrients and inorganics is desired to attain the sustainability of a system. Therefore, an integrated use of inorganic fertilizers with organic manures is a sustainable approach for efficient nutrient usage which enhances efficiency of the chemical fertilizers while reducing

nutrient losses (Schoebitz and Vidal, 2016). Integrated use of biofertilizers offers a cheaper low capital intensive and eco-friendly route to boosting farm productivity (Thavaprakaash *et al.*, 2005) [21]. *Azotobacter*is a free-living aerobic diazotrophic (with the ability to use N2 as the sole nitrogen source) microorganism commonly occurring in soil. *Azotobacter chrococcum* among various species is the most commonly occurring species in Indian soil (Sudhaker *et al.*, 2000) [19]. Keeping the above facts under consideration, the present experiment was conducted to study the performance of maize cultivar as affected by integrated nutrient management practices.

Material and Methods

A long term field experiment was conducted from 2010 at College of Agriculture, OUAT, Bhubaneswar to study the effect of integrated nutrient management on productivity of maize. The present crop maize (var. monsanto hybrid) was 17th crop in the sequence (kharif 2016). The succeeding crops were green gram, maize, cabbage, and cowpea followed by crop maize (under discussion).The residues of individual crops were incorporated *in situ*. The soil was loamy sand in texture in the beginning. It was strongly acidic in reaction [pHw (1:2.5) was 5.18]. The organic carbon status was low (2.7 g/kg). The available nitrogen, bray's 1 phosphorus, ammonium extractable potassium and $CaCl_2$ extractable sulphur was low (207 kg/ha), high (37 kg/ha), low (84 kg/ha) and low (25 kg/ha) respectively. The experiment was laid out in a randomized block design with ten treatments with different organic and inorganic sources of nutrients (Treatment details are given in Table 1) and replicated three times. The test crop received N-P_2O_5-K_2O-SO_4 @ 130-36-70-20 kg ha^{-1} in the form of, Navaratna (20-20-0-13), urea and MOP respectively. The FYM and vermicompost were applied @ 5.0 and 2.5 t ha^{-1} respectively. The inorganic nutrients as fertilizers were applied in three splits and organics and bio fertilizers as basal. The *Azotobacter*, *Azospirillum* and PSB (1:1:1) @4 kg each ha^{-1}, inoculated to limed (5%) vermicompost, incubated for 7 days at 30% moisture and applied as basal. Lime was applied @ 0.2 LR as paper mill sludge as per the treatment specificity.

Table 1: Treatment details of the soil under study

T_1	Absolute control	T_6	STD + VC + BF
T_2	STD	T_7	STD + FYM + L+ BF
T_3	STD + FYM	T_8	STD + VC + L + BF
T_4	STD + VC	T_9	BF
T_5	STD + FYM + BF	T_{10}	½ STD + BF

*STD = soil test dose, FYM = farm yard manure, VC = vermicompost, BF= biofertilizer and L = lime.

Intercultural operations like hoeing, weeding, earthing up, irrigation and plant protection measures were carried out as and when required. Fresh active leaf samples were collected at harvesting time for analysis (3rd from top), five plants from each treatment were selected randomly (avoiding boundary line).The roots from different treatments were collected at the time of harvest of the crop by moisturing the rhizosphere, uprooting the plants without disturbing the roots with the help of spade. The entire root and adhered soils were loosen in a bucket of water, saving the roots. Then washed thoroughly and dried. The mass (weight) and volume was estimated by water displacement method and the density was calculated. The different plant parts like leaf, shoot, cob and roots were kept in separate envelops, washed, labeled properly and dried in hot air oven till a constant weight was recorded. Each sample was grinded separately and was used for analysis of different elements. For plant height about five plants from each plot were selected, the height was measured and also for chlorophyll content SPAD reading was taken. The average of five plants was considered as the height of the crop plant under each treatment. Maize crop was harvested at maturity (100 DAS). The plants were oven dried at 70 ^{0}C temperature. The data was expressed as kg/ha for biomass calculation.

The oven dried weight of grains was measured in an electric balance. The grain yield was expressed in kg/ha. For uptake studies the concentration of individual nutrients were multiplied with the oven dry weights of grain and stover weights.

Nitrogen in the processed sample was determined by Kjeldahl digestion method as described in AOAC (1960) [1]. For other elements like P and K the samples were digested in diacidmixure [HNO_3: $HClO_4$ (3:2)]. P was estimated spectrophotometrically and K flame photo metrically, (Jackson, 1973). The biometric data, nutrient uptake, cob and stover yield were recorded, compiled in appropriate tables and analyzed statistically as per the procedure prescribed for Randomised block design. Based on the uptake use efficiency of fertilizernutrients was worked out separately for N, P and K as nitrogenuse efficiency (NUE), phosphorus use efficiency (PUE) and potassium use efficiency (KUE) by using apparent nutrientrecovery (ANR) formula as given below.

$$\text{A) Apparent Recovery of Nutrient (\%)} = \frac{\text{(Uptake of nutrient in desired treatment)} - \text{(Uptake in absolute control)}}{\text{Amount of nutrient added (kg ha}^{-1}\text{)}} \times 100$$

$$\text{B) Harvest index (HI)} = \frac{\text{Economical yield}}{\text{Total Biomass production}} \times 100$$

$$\text{C) Relative Agronomic Efficiency (RAE)} = \frac{\text{(Total Biomass production in treatment)} - \text{(Total Biomass production in Absolute Control)}}{\text{(Total Biomass production in STD)} - \text{(Total Biomass production in Absolute Control)}} \times 100$$

Results and Discussion

Effect of organics, inorganics, biofertilizers and INM practices on growth parameters growth of maize

The relative growth rate of maize gradually increased with the advancement in the growth intervals of the crop till flowering stage under all the treatments. The treatment receiving recommended dose of NPKS with FYM, biofertilizer and lime recorded maximum plant height in all the growth stages of maize and the minimum was found in case of control (Table 2). There was no significant difference in plant height among the organics, inorganics and INM treatments. Only sole application of biofertilizers showed significant changes in plant heights. Increase in relative growth rate could be attributed to the enhanced nutrient use efficiency in the presence of organic manure, biofertlizer and lime. Many research studies showed that the composted organic materials release nutrients slowly and may reduce the leaching losses, particularly N (Naveed *et al*., 2008) [13].

Table 2: Influence of organics, inorganics, microbial inoculants and INM practices on relative growth rate of plants (cm/day)

S. No	Treatment	Vegetative (43DAS)	Flowering (55 DAS)	Harvest (100 DAS)
1	Absolute Control	1.57	3.36	1.58
2	STD	1.98	3.35	1.64
3	STD+F	2.33	4.02	1.94
4	STD+VC	2.34	4.14	1.98
5	STD+F+BF	2.38	4.32	2.03
6	STD+VC+BF	2.76	4.08	1.94
7	STD+F+BF+L	2.77	4.85	2.29
8	STD+VC+BF+L	2.62	4.46	2.13
9	BF	1.48	2.95	1.50
10	50%STD + BF	1.83	3.71	1.77
LSD(p=0.05)		0.85	0.50	0.25

Root characteristics

Perusal of results (Table 3) indicated that addition of chemical fertilizer improved the root morphology significantly over control. Again addition of organic manure improved the root structure over chemical fertilizer or control. Inclusion of biofertilizers in the organic manure increased the root density. Even biofertilizer alone (0.78 g/cc) caused the significant change in root density over solo application of chemical fertilizers. The sequence of root density was as follows: STD + organics + lime + BFs > STD + organics + BFs > STD + organics> STD.

A striking variation in root mass as a result of lime addition in INM practices was noted. Among the various plant parts the roots are directly or indirectly affected by the pH of the solution or growth medium. Low pH injury or H^+ injury is one of the factors responsible for growth retardation in acid condition (Alam *et al*., 1999) [2]. As the concentration of H^+ in soil increases, it can inhibit root growth, disrupt functions of plasma membrane, cell wall or by increasing Al^{3+} toxic levels. Toxic level of Al^{3+} in the soil solution affect root cell division and the ability of the root to elongate. Lime application reduces the acidity of the growth medium by counteracting the effect of excess H^+ and Al^{3+} ions. Microbial inoculants improves seed germination and plant growth by producing B vitamins, NAA, IAA, GA, cytokinins and phytohormones that are inhibitory to certain root pathogens (Mazid *et al*., 2011) [9]. Neutralisation of acidity create better environment for microbial activity and efficiency of beneficial microorganisms increases leading to better response to biofertilizer application.

Table 3: Influence of organics, inorganics, microbial inoculants and INM practices on root characteristics

S. No	Treatment	Mass (g)	Volume (cc)	Root density (g/cc)	pH
1	Absolute Control	4.47	13.7	0.32	4.74
2	STD	20.0	27.4	0.70	4.22
3	STD+F	24.1	34.2	0.72	4.37
4	STD+VC	29.1	34.2	0.82	4.47
5	STD+F+BF	32.2	41.0	0.78	4.22
6	STD+VC+BF	34.7	41.0	0.84	4.34
7	STD+F+BF+L	44.4	52.9	0.86	5.49
8	STD+VC+BF+L	44.0	54.7	0.86	5.49
9	BF	10.7	13.7	0.78	4.39
10	50%STD + BF	10.7	13.7	0.78	4.36
	LSD(p=0.05)	2.74	1.87	0.04	0.31

Influence of organics, inorganics, microbial inoculants and INM practices on yield attributing characters of maize

Experimental findings regarding to different yield attributing characters *viz*., cob length, cob girth, volume of cobs, number of rows/cob, number of grains/cob, seeds per cob and test weight are given in Table 4. All the above said characters was found to be highest in case of treatment with combination of STD+organics+BFs+L and the lowest was observed in case of control. It was noticed that cob length was significantly higher in treatments with inclusion of organics and biofertilizers as compared to solo application of chemicals. There was no significant difference between treatments in case of cob diameter. All the treatments were found to be significant over each other in case of volume of cob and vermicompost treated plot resulted better cob volume than FYM. There was no significant difference found in lime application in case of grains per cob and biofertilizer inclusion in the organic manure showed significant change in number of grains per cob compared to STD only. The test weight of the grain is the weight of 1000 seeds of maize crop. The data regarding the 1000 grain weight confirmed the significant influence of biofertilizers with organic inputs on grain weight. A comparative study of means showed considerable variation in treatments from 187.5 g to 326 g weight of 1000 grains.

Table 4: Influence of organics, inorganics, microbial inoculants and INM practices on yield contributing characters of maize

Sl. No	Treatment	Cob (cm)		Volume of cob (cm^3)	No. Of rows/ cob	No. of grain/ row	Grains /cob	Test weight (g)
		Length	diameter					
1	Absolute Control	12.5	12.2	479.3	13	27	351	187.5
2	STD	14.3	13.8	620.2	14	34	476	278
3	STD+F	14.9	13.8	647.3	14	33	492	262.1
4	STD+VC	15.7	13.6	671.1	15	33	495	270.3
5	STD+F+BF	16.4	14.4	740.3	15	36	540	304.5
6	STD+VC+BF	18.5	14.6	848.9	15	38	570	310
7	STD+F+BF+L	18.3	15.0	862.8	15	38	570	326
8	STD+VC+BF+L	17.2	14.7	794.7	15	38	570	315
9	BF	12.9	13.3	547.4	14	30	420	274
10	50%STD + BF	16.4	14.1	726.8	14	30	420	243
	LSD(p=0.05)	2.65	1.11	3.13	1.68	4.22	70.29	17.13

These results corroborate the findings of Nanjappa *et al*., 2001. Organic manures contain all macro and micro nutrient elements essential for plant growth. Besides, application of organic manures encourages microbial population and improves physical condition of the soil and thereby affects yield attributing characters. The number of grains per row varied to applied nutrients as there outcomes substantiate by the findings of Bakry *et al*., 2009 [4]. The increment in number of grains per cob might be due to presence of magnesium in organic manures as grain number are direct index of pollen viability where magnesium is proved to be increases fruit set and significant aspect on pollen formation (Mahgoub *et al*., 2010 [8]; Siam *et al*., 2008) [16]. The weight of grains depend on flabbiness of grains and transport of assimilate to the seed (Siam *et al*., 2008) [16]. The potassium and magnesium exerted a positive influence on the weight of grains, since both elements participate in the transportation of carbohydrates to the sink organs (Barlog *et al*., 2008) [5].

Influence of organics, inorganics, microbial inoculants and INM practices on crop productivity, harvest index and relative agronomic efficiency

Appraisal of data revealed that the grain and stover yields of maize under the influence of different integrated nutrient management practices ranged from 2.6 to 7.0 t ha^{-1} and from 2.5 to 7.7 t ha^{-1} respectively. The total dry matter production varied from 5.1 to 14.4 t ha^{-1}, lowest with no nutrient control and highest with STD + F + BF + L (Table 5). This might be due to more availability of nutrients from organic manure and beneficial effects due to *Azotobacter*, *Azospirillum* and PSB inoculation which provide nitrogen and phosphorus to plant growth. It might also be due to production of amino acids, vitamins and growth promoting substances secreted by these introduced beneficial microorganisms which resulted increased plant growth characters and in obtaining economically profitable yield (Singh *et al*., 2006 and Suke *et al*., 2011). Sole application of STD increased the total yield by 53% over absolute control, whereas use of BF alone increased the total yield by 39.2% over control. If no mineral fertilizer was added, only BFs was able to produce same level of grain yield where fertilizer was added. When the mineral fertilizers dose was reduced to half along with BF increased the yield by only 4% over full dose of STD. Application of mineral fertilizer alone had a noticeable increase in grain yield over control, this might be due to relatively higher response to maize to N and its role in protein formation, constituent of chlorophyll and involved in carbohydrate utilization which resulted in higher grain and straw yield.

Table 5: Influence of organics, inorganics, microbial inoculants and INM practices on crop productivity, harvest index and relative agronomic efficiency

Treatment	Grain (t/ha)	Stover (t/ha)	Total (t/ha)	Harvest index (%)	Rae (%)
Absolute Control	2.6	2.5	5.1	51	-
STD	4.0	3.8	7.8	51.3	40
STD+F	6.1	5.8	11.9	51.2	100
STD+VC	6.0	5.7	11.8	51.7	97
STD+F+BF	6.3	6.2	12.5	50.4	106
STD+VC+BF	6.5	5.6	12.1	53.7	111
STD+F+BF+L	6.7	7.7	14.4	46.5	117
STD+VC+BF+L	7.0	7.4	14.4	48.6	126
BF	3.9	3.2	7.1	55.0	37
50% STD + BF	4.3	3.8	8.1	53.1	49
LSD (p=0.05)	0.73	1.6	-	-	-

Influence of organics, inorganics, microbial inoculants and INM practices on Nutrient uptake and apparent nutrient recovery

The data related to Nutrient uptake by maize crop presented in Table 6 revealed that higher uptake of nutrients was recorded when nutrients were applied through integrated application of 100% NPK along with organic manure, microbial inoculants with soil amendment. The increase in the uptake under INM might be ascribed to more availability of these nutrients from the added fertilizers and also to the solubilizing action of organic acids produced during decomposition of organic manure thus rendering more release of nutrients from the soil (Arulmozhiselvan *et al*., 2013) [3]. In case of nitrogen (78%) and phosphorus (46.4%) highest apparent recovery was found in case of STD+F+BF+L whereas in case of apparent potassium recovery treatment with 50% STD + BF (110%) gave the highest result. This may be due to the fact that among the microbial inoculants, *Azospirillum* was shown to exert beneficial effects on plant growth and crop yields. Interestingly it was observed that *Azospirillum* inoculation can change the root morphology via producing plant growth regulating substances via siderophore production (Sahoo *et* *al*., 2014) [14]. It also increases the number of lateral roots and enhances root hair formation to provide more root surface area to absorb sufficient nutrients (Mehdipour *et al*., 2012) [10].

Table 6: Influence of organics, inorganics, biofertilizers and INM practices on uptake (kg ha^{-1}) and recovery (%) of N, P and K by maize crop

Treatment	Nitrogen		Phosphorous		Potassium	
	Total uptake (kg/ha)	ANR (%)	Total uptake (kg/ha)	APR (%)	Total uptake (kg/ha)	AKR (%)
Absolute Control	50.5	-	5.8	-	36.1	-
STD	84.8	26.4	8.4	16.3	51.9	27.2
STD+F	127.3	48.0	16.9	35.8	82.0	52.2
STD+VC	117.2	42.0	17.5	38.0	75.6	45.0
STD+F+BF	139.3	55.5	18.3	40.3	107.4	81.0
STD+VC+BF	147.7	61.0	18.4	41	102.6	76.0
STD+F+BF+L	174.9	78.0	20.2	46.4	110.9	85.0
STD+VC+BF+L	165.6	72.0	19.7	45	111.6	86.0
BF	68.3	-	8.0	-	39.7	-
50%STD + BF	75.3	38.0	8.8	37.5	67.9	110
LSD(p=0.05)						

ANR- Apparent nitrogen recovery, APR- Apparent phosphorous recovery and AKR- Apparent potassium recovery.

Relationship between nutrient uptake, yield attributing characters and yield, P and K fractions with yield, uptake and available nutrient

The coefficient of correlation amongst various growth character, yield attributing characters showed that all parameters were significantly correlated with each other (Table-7). There were also a positive significant correlation exist between grain yield of maize with yield attributing parameter and N,P,K and K uptake by plant. However, among the growth and yield parameter root density showed highest correlation with test weight (r=0.86**), cob length with cob diameter (r=0.91**). All the yield attributing characters equally contribute towards the grain yield (r=0.84**). Grain yield is highly influenced by P uptake as it showed highest correlation (r=0.99**) compared to N and S (r=0.96**) and K (r=0.94**).

Table 7: Correlation matrix between nutrient uptake, plant height, cob length, cob diameter, test weight and yield

	Root density	Cob length	Cob diameter	Test weight	Grain yield	N uptake	P uptake	K uptake
Root density	1.00	0.71*	0.84**	0.86**	0.76*	0.67*	0.66*	0.66*
Cob length	0.71*	1.00	0.91**	0.74*	0.84**	0.85**	0.80**	0.90**
Cob diameter	0.84**	0.91**	1.00	0.89**	0.84**	0.86**	0.77**	0.89**
Test weight	0.86**	0.74*	0.89**	1.00	0.84**	0.85**	0.78**	0.80**
Grain yield	0.76**	0.84**	0.84**	0.84**	1.00	0.96**	0.99**	0.94**
N Uptake	0.67*	0.85**	0.86**	0.85**	0.96**	1.00	0.97**	0.96**
P Uptake	0.66*	0.80**	0.77**	0.78**	0.99**	0.97**	1.00	0.94**
K Uptake	0.66*	0.90**	0.89**	0.80**	0.94**	0.96**	0.94**	1.00

* 5% level significant, ** 1% level significant

Conclusion

Integrated nutrient management on maize revealed that all growth parameters including plant height, root density, chlorophyll content and nutrient concentration in leaves increased to a satisfactory level by the combined application of organics, inorganics, microbial inoculants and lime. The integrated use of chemical fertilisers, organic manure, biofertilisers and lime as soil ameliorant provided better results in increasing yield contributing characters like cob length, cob diameter, number of grains per cob, test weight etc. Without application of any organic manure there was 34% yield loss over sole application of inorganic fertilisers. Inclusion of bio fertiliser in the organics and inorganics augmented the maize yield by 8.3% and there was a further yield advantage of 7.7% by lime application to the INM treatments. Also, inclusion of lime in the management practices is a crucial step in ameliorating soil acidity.

Acknowledgements

This study was financially supported by the Indian Council of Agricultural Research sponsored All Indian Network Project on Soil Biodiversity and Biofertilisers.

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