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Influence of organic and inorganic fertilizers on dynamics of nitrogen, phosphorus and potassium in relation to yield and proximate composition of Colocasia

K. Laxminarayana[1]*, J.M. Anjana[2], Kalidas Pati[1] and R. Arutselvan[1]

[1]CAR-Central Tuber Crops Research Institute Regional Station, Bhubaneswar-751019, Odisha, India
[2]Odisha University of Agriculture & Technology, Bhubaneswar, Odisha, India

Abstract

Field experiments were conducted during 2018-2020 to study the effect of integrated use of inorganic fertilizers and organic manure on the dynamics of nitrogen, phosphorus and potassium in relation to yield and proximate composition of colocasia (*Colocasia esculenta* L) in an Alfisol. The inorganic fractions and available nutrient contents of N, P and K were found highest due to integrated application of FYM and ½ NPK followed by application of 80-30-80 kg ha^{-1} of N, P and K. Sequence of occurrence of inorganic P fractions (mg kg^{-1}) in the soils followed the order: Reductant soluble P (42.39) > Fe-P (38.10) > Ca-P (30.23) > Al-P (23.71) > Bray's-1-P (17.86) > Water soluble P (2.94). Occurrence of different K fractions (kg ha^{-1}) was in the order: NH_4OAc-K (210.05) > exchangeable-K (186.56) > non-exchangeable K (111.54) > water soluble-K (23.49). Available N was contributed mostly by NO_3-N and total N. All the inorganic P fractions contributed significantly to the available P pool and the relationship (r) was found to be in the order of water soluble P (0.97**) > Fe-P (0.96**) > RS-P (0.95**) > Al-P (0.94**) > Ca-P (0.90**). However, exchangeable K and total K contributed significantly towards the available K content of the soil. Ammoniacal N showed a highly positive and significant relationship with corm yield and biochemical constituents of taro. Iron bound P and Al-P fractions contributed mostly towards the P nutrition of colocasia. Of all the K fractions, non- exchangeable K has recorded higher 'r' values with cormel yield and bio-chemical constituents. Application of organic manure and half of the soil test based NPK not only sustain the soil quality and enhanced the productivity of colocasia but also had greater impact on NPK transformations in Alfisols.

Keywords: Inorganic fertilizers, Organic manure, NPK fractions, Colocasia, Correlations

Introduction

The fertility status of Indian soils has been declining continuously due to intensive cropping and non-restoration of nutrients in the soil. The replenishment of reserves of nutrients are necessary which are removed or lost from the soil for maintaining productivity and sustainability of the farming systems. Deficiency of major nutrients especially nitrogen (N) and potassium (K) is prevailing in the Indian soils resulting in sharp decline in production and productivity of nutrient responsive crops. Nitrogen is the most important nutrient for plant growth, yield and quality as it acts as a key component of amino acids, auxins, cytokinins, alkaloids, glucosinolates and proteins. There are three major forms of nitrogen in the soil- organic N, ammonium N and nitrate N. Organic

* Corresponding author
E-mail: klnarayana69@rediffmail.com; Ph: +91 9348568328

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forms of N make up for the highest percentage (>90%) of the total nitrogen in the soil, only a small part is in the inorganic or mineral nitrogen forms. Plants can use only ammonium and nitrate forms. Ammonium nitrogen exists in exchangeable and non-exchangeable forms. Potassium exists in four forms in the soil, which include the solution, exchangeable, nonexchangeable or fixed and mineral or structural K forms (Sparks, 2000). The amount of each K fraction varies, depending on cropping history, as well as application of chemical fertilizer or organic manures (Ioannou et al., 1994; Yawson et al., 2011). There is a dynamic equilibrium among different forms of soil potassium and any depletion in a given form would shift the equilibrium in the direction to replenish it (Ramamoorthy and Velayutham, 1976).

Application of chemical fertilizers alone causes problems not only to the soil health but also to the human health and physical environment. To combat this problem, it is necessary to use organic manures alone or with chemical fertilizers that will not only boost agricultural production but also save the environment. Low organic matter status of the soils combined with imbalanced use of inorganic fertilizers, less use of organic manures and inadequate attention given for its improvement and maintenance led to low crop productivity. Continuous cropping and long-term fertilization are liable to change the soil properties and crop production, depending upon the type of management practices. Long-term fertilizer experiments provide best possible means to study changes in the soil properties, dynamics of nutrients and future strategies for maintaining soil health.

Colocasia (*Colocasia esculenta* L.) is a tropical tuber crop with high yield potential of the corms and cormels, broadly grown as food crop and animal fodder which are widely cultivated in tropical and subtropical regions. It is widely cultivated throughout the West Indies and in West and North Africa with a global production of 12.396 Mt from 1.794 Mha with a productivity of 6.91 t ha^{-1}. In Asia, it is widely planted in south and central China and grown in almost all the states in India. Africa contributed 9.53 Mt and Asia contributed 2.395 Mt of production. In many islands of the Pacific including Papua New Guinea, it plays an important role in traditional gifts given in ceremonies. The corms of taro is relatively low in protein (1.5%), fat (0.2%), fiber (0.8%) and ash (1.2%) and high in starch (70-80 g/100 g dry taro). Taro is also a good source of vitamin B_1, B_2, B_3, B_6, C, and minerals such as iron, phosphorus, zinc, potassium, copper and manganese (Quach et al., 2003). Taro starch is easily digestible, hypoallergenic in nature and also the starch is gluten free (Kochhar, 1998).

To improve the yield and quality of taro, there is a need to standardize the optimum dose of nutrients for better physico-chemical properties of soil. The integrated nutrient management (INM) approach helps to improve the quality of the produce andto improve the soil fertility including the biosphere. The previous studies related to INM and SSNM strategies in tuber crops proved to be beneficial in enhancing the crop productivity and improving the fertility status of soil (Laxminarayana, 2016; Laxminarayana, 2022; Laxminarayana et al., 2015). Very scanty information is available on nutrient fractionation studies under tuber crops based cropping systems. The present study aimed to assess the distribution of inorganic fractions of nitrogen, phosphorus and potassium in relation to the yield and bio-chemical constituents of colocasia in an Alfisol of Eastern India.

Materials and Methods

Field experiments were conducted for two *kharif* (rainy) seasons during 2018-19 and 2019-20 at the Regional Station of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India to study the effect of integrated use of inorganic nutrients and organic manure on dynamics of NPK fractions and residual soil properties in relation to yield and proximate composition of colocasia in an Alfisol. The experiment was laid out with 14 treatment combinations replicated thrice in a randomized block design. The treatments included control, 40 kg N ha^{-1}, 80 kg N ha^{-1}, 120 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1}, 40 kg K_2O ha^{-1}, 80 kg K_2O ha^{-1}, 120 kg K_2O ha^{-1}, 80-30 kg N & P_2O_5 ha^{-1}, 80-80 kg N &K_2O ha^{-1}, 30-80 kg P_2O_5&K_2O ha^{-1}, 80-30-80 kg N, P_2O_5 & K_2O ha^{-1}, Farmyard manure (FYM) @ 10 t ha^{-1}, and FYM @ 10 t ha^{-1} + 40-15-40 kg N, P_2O_5 & K_2O ha^{-1} (½ NPK).

Application of well rotten farmyard manure (FYM) (contained 0.50-0.28-0.60% of N, P & K, respectively) @ 10 t ha^{-1}) supplemented 50, 28 and 60 kg ha^{-1} of N, P and K, respectively. Colocasia (*cv* Muktakeshi) cormels were planted at a spacing of 50 × 30 cm. All the intercultural practices were followed as per the schedule and the crop was harvested at the maturity of 165 days after planting. Yield parameters like number of cormel splant^{-1}, average cormel weight, cormel yield per plot were recorded at harvest. Cormel samples were collected at harvest, washed thoroughly, oven dried at 60ºC and dry weights were recorded. Total sugars in the fresh cormels after washing were estimated in the alcohol filtrate and starch was determined in the residue as per the standard procedure.

Soil samples at a depth of 0.30 m were collected from individual treatments of the experiment after harvest of the crop, processed and estimated chemical properties by using standard procedures. Inorganic forms of N, namely NH_4-N and NO_3-N were determined by steam distillation method (Black, 1965). Inorganic P fractions were determined by sequential fractionation method as outlined by Jackson (1973). Inorganic K fractions were determined by boiling nitric acid method (Wood and deTurk, 1941). The relationship of different fractions of N, P and K with yield and proximate composition of colocasia was worked out by computing simple correlation coefficients by employing standard procedure as described by Gomez and Gomez (1984).

Results and Discussion

Effect of organic and inorganic nutrients on soil chemical properties

The pH of the soil after harvest of colocasia for the second kharif season during 2019-20 ranged from 6.188 to 6.326 in comparison to the initial value of 6.094 (Table 1); however, the highest increase of soil pH was observed due to integrated application of FYM + ½ NPK. Application of graded doses of N or K fertilizers alone showed an increasing trend of pH up to 80 kg ha^{-1} and showed a declining trend at higher doses of respective nutrients. Application of K fertilizers showed an increasing trend of soil pH in comparison to N fertilizers, whereas combined application of N & K fertilizers showed relatively higher soil pH rather than single application of N & K. Organic manure can buffer pH and thus counter the soil acidity. Incorporation of FYM has improved the soil pH to 6.24 and FYM in combination with limited doses of NPK has further improved the soil pH to 6.33. The rise of soil pH through addition of FYM could be caused by specific adsorption of organic anions and the corresponding release of hydroxyl ions (Hue, 1992) as well as the consumption of H^+ by the humic type substances which have a large number of carboxyl, and phenolic functional groups (Stevenson, 1994). This agrees with the findings of the present study also. Organic matter has high cation exchange capacity and it facilitated retention of exchangeable bases, which causes improvement of soil pH (Ossom and Rhykerd, 2008).

Integrated application of FYM + ½ NPK has recorded the highest organic C content (0.373%) followed by $N_{80}P_{30}K_{80}$ (0.324%) as compard to the initial status of 0.203%. Continuous cropping without fertilization or manuring of the soil led to reduction in organic C content in the control (0.206%). Addition of inorganic fertilizers along with organic sources led to improvement in organic matter status of the soil, which might be due to the enhanced root growth and production of more crop residues leading to accumulation of more organic matter in the soil (Rani Kumari et al., 2019). Incorporation of FYM alone showed an improvement in organic C (0.248%), emphasizing that apart from yield gains, organic sources add organic matter, improve the soil physical and chemical properties and neutralize the soil acidity (Fageria, 2012). Graded doses of N and K fertilizers showed a significant improvement in organic C status, however, dual application of NK showed relatively

Table 1. Effect of application of organic and inorganic nutrients on soil chemical properties

Treatment	pH (1:2.5)	Org. C (%)	Available nutrient (kg ha^{-1})			Exch. Ca	Exch. Mg	Avail. S (mg kg^{-1})	Available micro nutrient (mg kg^{-1})			
			N	P	K	[c mol (p^+) kg^{-1}]			Fe	Cu	Mn	Zn
Initial	6.094	0.203	200.8	35.17	182.8	24.46	7.562	8.24	10.35	1.43	4.18	0.622
Control	6.233	0.206	155.8	35.19	174.6	21.54	6.79	7.49	8.90	1.37	4.24	0.625
N_{40}	6.202	0.257	166.9	36.80	188.7	24.93	7.17	7.56	10.17	1.39	4.23	0.680
N_{80}	6.225	0.273	175.4	37.61	203.6	26.17	7.58	7.58	10.54	1.43	3.28	0.661
N_{120}	6.188	0.312	193.3	38.12	225.5	26.84	8.27	7.62	10.74	1.42	3.56	0.704
P_{30}	6.272	0.255	160.5	40.97	179.8	24.45	7.26	7.53	10.12	1.40	4.08	0.635
K_{40}	6.210	0.247	162.3	37.48	196.2	25.13	6.77	7.58	10.84	1.51	3.94	0.697
K_{80}	6.262	0.257	170.3	38.28	217.7	26.16	7.61	7.67	11.52	1.50	3.87	0.717
K_{120}	6.233	0.275	189.8	40.95	231.0	25.85	7.47	7.71	10.93	1.52	3.79	0.709
$N_{80}P_{30}$	6.262	0.237	182.2	42.76	213.8	25.96	7.67	7.72	11.23	1.47	3.87	0.636
$N_{80}K_{80}$	6.317	0.287	194.3	40.59	232.2	26.79	8.74	7.79	11.58	1.48	3.76	0.685
$P_{30}K_{80}$	6.307	0.263	180.7	44.24	220.6	25.66	7.81	7.75	11.26	1.41	4.06	0.669
$N_{80}P_{30}K_{80}$	6.291	0.324	220.9	46.17	247.5	27.34	9.06	8.07	11.48	1.46	4.50	0.717
FYM	6.243	0.248	176.1	38.73	191.3	25.83	7.70	7.78	10.37	1.40	4.32	0.674
FYM + $N_{40}P_{15}K_{40}$	6.326	0.373	212.8	46.97	245.7	28.12	9.94	8.10	11.75	1.57	4.59	0.701
CD (P=0.05)	0.065	0.029	9.17	2.26	11.5	0.47	0.29	0.07	0.32	0.07	0.49	0.025

higher organic C (0.287%) rather than PK (0.263%) and NP (0.237%). Organic carbon in the soil acts as energy substrate for proliferating microorganisms and enhancing nutrient availability to the crops (Wu et al., 2020).

Highest built up of exchangeable Ca & Mg [28.12 & 9.94 c mol (p^+) kg^{-1}] as well as available S (8.10 mg kg^{-1}) were recorded due to integrated application of FYM + ½ NPK, which can attributed to the combined application of organic fertilization and limited doses of NPK. The available S in the soils was found lower than the critical limit of 10.0 mg kg^{-1} in all the treatments. Higher buildup of available S was observed in the soil with the combined application of N, P and K rather than single application of graded doses of N and K fertilizers.

The available Fe & Mn contents were found toxic (>9.0 and 4.0 mg kg^{-1}, respectively) in all the treatments, which might be due to the soil forming factors and the nature of parent materials from which the soils are formed. Application of nitrogenous fertilizers have resulted higher accumulation of Fe & Mn rather than K; however, organic manure (FYM) showed lower accumulation of Fe & Mn, which might be due to the countering of soil acidity. The available Cu content in the post harvested soils was high (>0.40 mg kg^{-1}), whereas the available Zn content in the soils of the present study was medium (0.60-1.20 mg kg^{-1}). Incorporation of organic sources with inorganic chemical fertilizers showed lower available Fe & Mn and higher contents of available Zn than those of inorganic fertilized plots. The available Fe, Cu, Mn and Zn contents in the post harvest soils were found higher than the critical limits that was attributed to the nature of parent materials and other soil forming factors (Anderson, 1988).

Effect of organic and inorganic fertilization on inorganic nitrogen fractions

Total N in the soils was in the range of 1745.5 to 1986.8 kg ha^{-1} and that of the initial soil was1791.3 kg ha^{-1} (Table 2). The highest total N (1986.8 kg ha^{-1}) was observed in the integrated application of FYM combined with ½ NPK followed by 80-30-80 kg ha^{-1} of N, P_2O_5 and K_2O (1923.2 kg ha^{-1}). This could be attributed to N mineralization pattern of these organics and indirect influence on physico-chemical characteristics of the soil (Singh et al., 2002). Total N was significantly increased with the graded doses of both N and K up to120 kg ha^{-1}. Dual application of $N_{80}K_{80}$ showed relatively higher total N than that of $N_{80}P_{30}$ and $P_{30}K_{80}$. Long term application of organic manure combined with NPK fertilizers increased the contents of soil organic matter, N, P and K, as well as the enzyme activities. The humus produced from the organics on their decomposition, can supply the essential nutrients slowly but steadily to the growing crops besides direct supply from the inorganic fertilizers that contributed in improvement of available nutrient status of the soil (Magdoff and Harold Van Es, 2021).

Table 2. Effect of organic and inorganic nutrients on distribution of inorganic fractions of nitrogen, phosphorus and potassium under colocasia cropping system

Treat-ment	Nitrogen fractions (kg ha^{-1})				Phosphorus fractions (mg kg^{-1})							Potassium fractions (mg kg^{-1})				
	Total N	Avail. N	NH_4-N	NO_3-N	Total P	Avail. P	WS-P	Fe-P	Al-P	Ca-P	RS-P	Total K	Avail. K	WS-K	Exch. K	Non exch. K
Initial	1791.3	200.8	74.65	16.71	204.56	15.70	2.41	32.65	20.58	28.67	40.170	2153.2	182.8	20.44	162.38	106.24
Control	1745.5	155.8	72.78	15.84	182.47	15.71	2.35	28.22	19.6	28.09	36.650	2072.5	174.6	17.45	157.16	79.97
N_{40}	1790.8	166.9	84.72	18.29	197.69	16.43	2.63	34.78	20.36	27.8	39.420	2130.3	188.7	18.19	170.50	92.36
N_{80}	1845.0	175.3	102.23	20.57	205.29	16.79	2.87	35.26	22.39	28.16	40.260	2214.7	203.6	20.61	182.96	104.80
N_{120}	1864.9	193.3	115.64	22.68	204.78	17.02	2.82	35.89	21.74	27.98	42.720	2295.0	225.5	22.68	202.80	111.30
P_{30}	1755.2	160.5	80.76	17.12	219.32	18.29	3.15	38.92	24.82	30.8	44.580	2115.4	179.8	18.60	161.16	84.80
K_{40}	1775.3	162.3	82.98	17.65	199.58	16.73	2.74	35.15	22.57	26.54	38.190	2209.1	196.2	22.19	174.03	104.20
K_{80}	1804.4	170.3	92.46	18.36	204.63	17.09	2.81	35.94	23.84	27.3	39.980	2324.5	217.7	25.12	192.53	116.72
K_{120}	1839.8	189.8	104.13	18.83	206.32	18.28	2.95	37.12	24.12	28.19	41.850	2394.8	231.0	29.84	201.14	128.80
$N_{80}P_{30}$	1856.3	182.2	104.98	20.68	208.91	19.09	3.23	41.72	25.72	32.09	45.110	2250.3	213.8	21.32	192.47	108.90
$N_{80}K_{80}$	1892.7	194.3	110.45	22.14	205.88	18.12	3.08	39.69	25.86	29.84	42.060	2364.7	232.2	27.80	204.38	126.82
$P_{30}K_{80}$	1825.6	180.7	93.55	19.36	213.81	19.75	3.16	43.38	25.49	34.16	46.390	2349.6	220.6	26.04	194.53	124.84
$N_{80}P_{30}K_{80}$	1923.2	220.9	117.69	23.91	215.67	20.61	3.52	45.66	27.05	35.78	48.500	2470.2	247.5	30.52	216.94	138.60
FYM @ 10 t ha^{-1}	1856.7	176.1	92.87	17.29	206.19	17.29	2.74	38.10	23.42	30.15	40.940	2204.3	191.3	22.16	169.09	110.60
FYM + $N_{40}P_{15}K_{40}$	1986.8	212.8	120.58	24.93	217.08	20.97	3.58	49.06	28.16	37.94	49.060	2453.6	245.7	29.36	216.30	134.20
Mean	1836.9	182.8	96.70	19.62	206.15	17.86	2.94	38.10	23.71	30.23	42.39	2266.8	210.1	23.49	186.56	111.54
Em (+/-)	17.64	5.12	3.98	0.73	2.49	0.43	0.09	1.40	0.66	0.92	1.00	33.30	6.28	1.19	5.21	4.78

The available nitrogen ($KMnO_4$-N) status of the soil ranged from 155.8 to 220.9 kg ha^{-1} with the highest value observed for the balanced application of 80-30-80 kg ha^{-1} of N, P and K followed by FYM + ½ NPK (212.8 kg ha^{-1}). Addition of nitrogenous fertilizers tends to increase the available N status of the soil by 7.1, 12.6 and 24.1% with respect to 40, 80 and 120 kg N ha^{-1} respectively over the control. Dual application of $N_{80}K_{80}$ showed relatively higher available N (194.3 kg ha^{-1}) than application of $N_{80}P_{30}$ and $P_{30}K_{80}$. The available N was found deficient (<250 kg ha^{-1}) in all the treatments. Higher availability of N could be due to the integrated application of mineral fertilizer N along with organic sources which have contributed to the reduction of C:N ratio and thus increased the rate of decomposition resulting in faster availability of nutrients from manures (Varalakshmi et al., 2005).

The range of ammoniacal N and nitrate-N in the soil varied from 72.78 to 120.58 and 15.84 to 24.93 kg ha^{-1}, respectively with the highest contents obtained for integrated application of FYM + ½ NPK. Addition of nitrogenous fertilizers tends to increase the NH_4-N status of the soil by 16.4, 40.5 and 58.8% with respect to 40, 80 and 120 kg ha^{-1} over the control. Addition of nitrogenous fertilizers enhanced theNO_3-N status of the soil by 15.5, 29.9 and 43.2%with respect to 40, 80 and 120 kg ha^{-1} over the control. Dual application of N, P and K fertilizers improved the NO_3-N status in comparison to application of single nutrients. It was also confirmed that the level of both NH_4^+- N and NO_3^--N increased with the increased level of fertilizer N, which was also reported by Duraisami et al., (2001).

Effect of organic and inorganic fertilization on inorganic phosphorus fractions

The total phosphorus in the soil varied from 182.4 to 217.1 mg kg^{-1} whereas the initial content was 204.6 mg kg^{-1} (Table 2). The highest total P content was recorded in the treatment of integrated application of FYM + ½ NPK (217.1 mg kg^{-1}). Combined application of N, P and K fertilizers enhanced the total P status in comparison to application of single nutrients. The available P (Bray's-1-P) in the soils ranged from 15.71 to 20.97 mg kg^{-1} when compared to the initial status of 15.70 mg kg^{-1}. The highest available P was observed in the combined application of FYM + ½ NPK (20.97 mg kg^{-1}). Addition of 30 kg P_2O_5 ha^{-1} increased the available P status of the soil by 16.4% over the control. Dual application of $P_{30}K_{80}$ showed an increase of 25.7% available P followed by $N_{80}K_{80}$ (21.48 %) over the control. Increase in available P content of the soil was attributed to the decomposition of organic manures which could have enhanced the labile P in the soil by complexing Ca, Mg and Al and solubilization of phosphate rich organic compounds through the release of organic acids upon decomposition of organic matter and chelation of organic anions with Fe and Al resulting effective solubilization of inorganic phosphates in the soil (Laxminarayana, 2022).

The sequence of occurrence of inorganic P fractions in the soil was in the order of RS-P > Fe-P > Ca-P > Al-P > Bray's-1-P > Water soluble P. Integrated application of organic manure with the chemical fertilizers enhanced the buildup of all the forms of inorganic-P (Rokima and Prasad, 1991). The water soluble P (WS-P) in the soils varied from 2.35 to 3.58 mg kg^{-1},whereas the initial WS-P

Table 3. Effect of organic and inorganic nutrients on yield and proximate composition of colocasia (2018-2020)

Sl. No.	Treatment	Cormel yield (t ha^{-1})			Yield response (%)	Proximate composition (%)		
		2018-19	2019-20	Mean		Starch	Total sugars	Dry matter
1	Control	10.11	15.34	12.73	-	10.86	0.86	22.56
2	40 kg N ha^{-1}	12.28	22.02	17.15	34.7	11.19	0.93	22.79
3	80 kg N ha^{-1}	13.91	26.02	19.97	56.9	11.53	0.98	23.40
4	120 kg N ha^{-1}	14.05	25.55	19.80	55.5	11.93	1.05	23.61
5	30 kg P_2O_5 ha^{-1}	12.40	20.06	16.23	27.5	11.32	0.94	23.22
6	40 kg K_2O ha^{-1}	12.56	23.24	17.90	40.6	11.57	0.90	23.10
7	80 kg K_2O ha^{-1}	14.10	25.70	19.90	56.3	11.99	1.03	23.61
8	120 kg K_2O ha^{-1}	14.81	26.73	20.77	63.2	12.11	1.11	24.24
9	80 kg N & 30 kg P_2O_5 ha^{-1}	14.27	24.10	19.19	50.7	11.53	1.09	23.76
10	80 kg N & 80 kg K_2O ha^{-1}	17.20	27.10	22.15	74.0	12.39	1.21	24.22
11	30 kg P_2O_5 & 80 kg K_2O ha^{-1}	15.21	25.52	20.36	59.9	11.95	1.11	24.03
12	80-30-80kg N, P_2O_5 & K_2O ha^{-1}	18.46	28.68	23.57	85.2	12.92	1.26	24.67
13	FYM @ 10 t ha^{-1}	13.69	25.04	19.37	52.2	11.61	1.05	23.41
14	FYM @ 10 t ha^{-1}+ ½ NPK	19.28	29.26	24.27	90.7	12.87	1.26	24.59
	CD (P=0.05)	0.50	1.10	0.61	--	0.15	0.03	0.12

was 2.41 mg kg^{-1} with the highest value observed for the integrated application of FYM and ½ NPK (3.58 mg kg^{-1}). Most of the WS-P added to the soil is transformed into relatively insoluble inorganic compounds of Al and Fe and thereby reduced its availability for plant use. However, after a time when intensity factor of the soil solution goes down, these inorganic P fractions may contribute to the P nutrition of crops.

The iron bound-P in the soil was in the range of 28.2-46.1 mg kg^{-1} and the initial status was 32.7 mg kg^{-1}. The highest Fe-P content of 46.2 mg $kg^{-1}$was observed in integrated application of FYM + ½ NPK followed by $N_{80}P_{30}K_{80}$ (45.7 mg kg^{-1}). Addition of 30 kg P_2O_5 ha^{-1} resulted in 37.9% increase in the Fe-P content of the soil than the control, however, dual application of $P_{30}K_{80}$ recorded an increase of 53.7% Fe-P. The aluminum bound P in the soils varied from 19.6 to 28.2 mg kg^{-1} when compared to the initial status of 20.6 mg kg^{-1} and the highest value was observed for FYM + ½ NPK (28.2 mg kg^{-1}). Addition of 30 kg of P_2O_5 ha^{-1}caused 26.6% increase in the Al-P content of the soil over the control, whereas dual application of $N_{80}K_{80}$, $N_{80}P_{30}$ and $P_{30}K_{80}$ showed an increase of 31.9, 31.2 and 30.1Al-P respectively over the control.

The initial status of Ca-P in the soil was 28.7 mg kg^{-1} whereas it varied from 26.5 to 37.9 mg kg^{-1}after harvest. The highest Ca-P was observed in the integrated application of FYM+½ NPK (37.9 mg kg^{-1}) followed by $N_{80}P_{30}K_{80}$ (35.8 mg kg^{-1}). Addition of 30 kg P_2O_5 ha^{-1} alone showed an increase of 9.6% and dual application of $P_{30}K_{80}$ and $N_{80}P_{30}$ recorded an increase of 19.1 and 11.9% of Ca-P over the control. The reductant soluble phosphorus (RS-P) in the soils ranged from 36.7 to 49.1 mg kg^{-1}, whereas the initial status was 40.2 mg kg^{-1} and the highest value of RS-P was due to the integrated use of FYM + ½ NPK (49.1 mg kg^{-1}). Addition of 30 kg P_2O_5 ha^{-1} recorded an increase of 21.7% of RS-P, whereas dual application of $P_{30}K_{80}$ and $N_{80}P_{30}$ resulted in a buildup of 26.6 and 17.5% of RS-P over the control, respectively.

Effect of organic and inorganic nutrients on inorganic potassium fractions

Total potassium in the soil ranged from 2072 to 2470 kg ha^{-1} with the highest being recorded for the application of $N_{80}P_{30}K_{80}$ (2470 kg ha^{-1}). Addition of graded doses of K fertilizers showed an increase intotal K status of the soil by 6.6, 12.2 and 15.6% in respect of 40, 80 and 120 kg ha^{-1} over the control. Dual application of $N_{80}K_{80}$ showed relatively higher total K (2364 kg ha^{-1}) than application of $P_{30}K_{80}$ (2350 kg ha^{-1}). The distribution of K forms in the soil and the equilibrium between them determine the K status of the soil and the potential of K supply to the plants (Srinivasa Rao et al., 2000). The available K (NH_4OAc-K) in the soils ranged from 174.6 to 247.5 kg ha^{-1} with the highest for the treatment of balanced application of 80-30-80 kg ha^{-1} of N, P and K (247.46 kg ha^{-1}). The available K (NH_4OAc-K) in the initial soil was182.8 kg ha^{-1}. Addition of potassium fertilizers resulted in an increase the available K status of the soil by 12, 25 and 32% respectively over the control. Dual application of $N_{80}K_{80}$ showed relatively higher available K (232.2 kg ha^{-1}) than other combinations. The crop requirements were partly met from the released K and both the applied K and released K brought out available K build up in the soil. Addition of limited doses of NPK combined with organic manure showed a comparatively marginal increase in available K than that of inorganic and organic sources. The differential release pattern of non-exchangeable K from the soil reserves besides variation in K uptake by the crop would be responsible for such differences in the available K status of the soil (Svotwa et al., 2007).

The highest water soluble potassium (WS-K) was recorded due to balanced application of 80-30-80 kg ha^{-1} of N, P and K (30.52 kg ha^{-1}) followed by FYM + ½ NPK (29.36 kg ha^{-1}). Addition of potassium fertilizers tends to increase the WS-K status of the soil by 27, 44 and 71% in respect of 40, 80 and 120 kg ha^{-1} over the control. Dual application of $N_{80}K_{80}$ showed relatively higher WS-K (27.80 kg ha^{-1}) followed by $P_{30}K_{80}$ (26.04 kg ha^{-1}). Water soluble K in the soil was generally low probably because of the leaching and erosion losses of applied K fertilizers. Organic materials, during their decomposition produce large number of organic acids which might have a tendency to dissolve potassium present either in mineral form or in the non-exchangeable form, thereby bringing it into water soluble form (Mukta Rani et al., 2020).

The exchangeable potassium (Ex. K) of the soil ranged from 157.2 to 216.9 kg ha^{-1} and the initial status was162.4 kg ha^{-1} with the highest being recorded due to the balanced application of $N_{80}P_{30}K_{80}$ (216.9 kg ha^{-1}) at par with FYM + ½ NPK (216.3 kg ha^{-1}). Addition of FYM could increase the CEC of the soil, which can hold more exchangeable K and convert non-exchangeable-K to exchangeable form, consequent to mass action effect (Srinivasa Rao et al., 2002). Addition of potassium fertilizers tends to increase the Ex. K status of the soil by 11, 23 and 28% in respect of 40, 80 and 120 kg ha^{-1} over the control. Dual application of $N_{80}K_{80}$ showed relatively higher Ex. K (204.38 kg ha^{-1}), which was followed by application of $P_{30}K_{80}$ (194.53 kg ha^{-1}). Combined application of N, P and K fertilizers showed greater exchangeable K status than that of individual nutrients. The non-exchangeable K of the soil ranged from 80.0 to 138.6 kg ha^{-1} and that of the initial soil was 106.2 kg ha^{-1}

with the highest being due to the balanced application of $N_{80}P_{30}K_{80}$ (138.6 kg ha^{-1}) followed by FYM + ½ NPK (134.2 kg ha^{-1}). Addition of potassium fertilizers resulted in an increase in non-exchangeable K status of the soil by 30, 46 and 61% in respect of 40, 80 and 120 kg ha^{-1} over the control. Dual application of $N_{80}K_{80}$ showed relatively higher non-Ex. K (126.82 kg ha^{-1}) than $P_{30}K_{80}$ (124.84 kg ha^{-1}). Studies have shown that a significant portion of K (70 - 90%) required by plants comes from the non-exchangeable pool in the absence of easily supplied K, thus indicating the beneficial role of the fixed K (Singh and Singh, 2002). The quantity of interlayer K in vermiculite and illite containing soils showed higher K uptake by the crops. This interlayer K is also the major source controlling the long-term K supplying potential of soils (Escudey et al., 1997). The non-exchangeable K fraction is released when the level of soil solution and Ex. K are decreased by plant uptake and leaching (Martin and Sparks, 1983). Conversion of exchangeable and water soluble K into non-exchangeable forms is a slow process but this equilibrium also plays an important role in K-nutrition of plants as it helps to maintain the non-exchangeable K content of the soils (Dhillon et al., 1985). It was also reported that in many soils applied K fertilizers transformed into non-exchangeable form with the passage of time and makes unavailable for K uptake by the crops (Kansal and Sekhon, 1976).

Effect of INM on yield and proximate composition of colocasia

The highest mean cormel yield of 24.27 t ha^{-1} was recorded with integrated application of FYM along with half of the soil test based NPK with a yield response of 90.7% over the control, followed by $N_{80}P_{30}K_{80}$ (23.57 t ha^{-1}). Incorporation of FYM alone has recorded almost equal yield response in comparison to 80 kg ha^{-1} of fertilizer N or K fertilizers, emphasizing that the application of organic manure alone minimizes the input cost and FYM has beneficial effect rather than chemical fertilizers (Laxminarayana, 2022). Organic manures typically release both macro and micronutrients gradually and supply the crops throughout their growth period and contributed in crop yields (Adediran et al., 2005). Though, the organic sources contain relatively low concentration of nutrients, there has been large increase in their use over inorganic chemical fertilizers for sustaining the productivity of colocasia. The organics help to enhance the retention and availability of all the essential nutrients as well as improve the soil physical and biological properties (Kamara and Lahai, 1997).

The mean cormel yield significantly increased by the application of graded doses of N up to 80 kg N ha^{-1} with yield responses of 35, 57 and 56% over the control due to the addition of 40, 80 and 120 kg N ha^{-1}, respectively. Since the experimental soil contained high status of available P, application of lower doses of P application was advocated. Graded doses of K fertilizers showed an increase in the yield response up to 120 kg K_2O ha^{-1}. Relatively higher yield response was observed with the application of K fertilizers rather than N as the crop responded to higher doses of K fertilization in the experimental sandy loam soil, which contained medium status of available K. Dual application of $N_{80}P_{30}$, $N_{80}K_{80}$ and $P_{30}K_{80}$ showed an increase of 51, 74 and 60% yield respectively over the control. Colocasia yields increased considerably due to the application of higher doses of NPK fertilizers in low and marginally fertile soils as it showed significant response to optimum doses of NPK rather than single application of higher doses of N, P and K. These results are in accordance with the findings of Halavatau et al., (1998).

Effect of organic and inorganic nutrients on proximate composition of colocasia

In the cormels of colocasia, significantly higher mean dry matter (24.67%), starch (12.92%) and total sugars (1.26%) were recorded for the treatment which involved soil test based application of 80-30-80 kg ha^{-1} of N, P_2O_5 and K_2O at par with FYM + ½ NPK (Table 2). Graded doses of N and K fertilizers up to 120 kg ha^{-1} showed an increase in the biochemical constituents. The highest mean starch content was recorded for the application of $N_{80}P_{30}K_{80}$ (12.92%) followed by FYM + $N_{40}P_{15}K_{40}$ (12.87%). Starch content in the cormels ranged from 10.86 to 12.92% and total sugars from 0.86 to 1.26%, with the highest being recorded for the integrated application of FYM + $N_{40}P_{15}K_{40.}$ Incorporation of organic manure enhanced the starch content, which might be due to the increased rate of mineralization of the organic manure resulting in nutrient transformations and their mobility into the plant system (Nizamuddin et al., 2003).

Relationship between yield and biochemical constituents with inorganic fractions of NPK

Among the inorganic N fractions, NH_4-N showed more significant relationship with the cormel yield as well as the biochemical constituents of colocasia ($r=0.892^{**}$) than NO_3-N ($r=0.845^{**}$). Of all the inorganic P fractions, Fe-P had highly significant relationship with cormel yield ($r = 0.806^{**}$), whereas Al-P showed highly significant relationship with starch, sugars and dry matter ($r = 0.804^{**}$, 0.855^{**} and 0.878^{**}, respectively), indicating that both the Fe-P and Al-P greatly contributed the yield and proximate composition of the crop.

Significantly positive correlation was observed between total K and corm yield, starch, total sugars and dry matter

Table 4. Correlation coefficients (r) between cormel yield and biochemical constituents of colocasia with inorganic fractions of nitrogen, phosphorus and potassium

Inorganic nutrient fractions	Mean cormel yield	Starch	Total sugars	Dry matter
Nitrogen fractions				
Total N	0.902**	0.862**	0.909**	0.843**
Available N	0.892**	0.923**	0.937**	0.909**
Ammoniacal N	0.892**	0.845**	0.872**	0.854**
Nitrate N	0.845**	0.831**	0.832**	0.792**
Phosphorus fractions				
Total P	0.675**	0.622*	0.643*	0.705**
Available P	0.781**	0.788**	0.828**	0.854**
Water Soluble P	0.781**	0.788**	0.828**	0.854**
Fe-P	0.806**	0.779**	0.848**	0.845**
Al-P	0.789**	0.804**	0.855**	0.878**
Ca-P	0.600*	0.650**	0.746**	0.701**
RS-P	0.704**	0.723**	0.799**	0.804**
Potassium fractions				
Total K	0.929**	0.963**	0.918**	0.962**
Available K	0.921**	0.944**	0.915**	0.942**
Water soluble K	0.874**	0.938**	0.882**	0.938**
Exchangeable K	0.911**	0.924**	0.903**	0.922**
Non-Exchangeable K	0.943**	0.939**	0.917**	0.948**

* $P < 0.05$; ** $P < 0.01$

and the 'r' values were found to be 0.929**, 0.963**, 0.918**, 0.962**, respectively. The correlation between total K and yield as well as biochemical constituents was more significant than that between total N or total P and yield/ biochemical constituents indicating that enhancement in total K and its fractions in the soil mostly contributed towards the yield and quality of tuber crops in general and colocasia in particular. Addition of potassium fertilizers based on soil test values and crop requirement are very essential to boost the productivity of tuber crops. Of all the K fractions, non-exchangeable or fixed K recorded higher 'r' values with cormel yield (r=0.943**), sugars (r=0.917**) and dry matter (r=0.948**), indicating that non exch. K transformed into exchangeable and water soluble K fractions for maintaining the equilibrium between different fractions and contributed towards the enhancement of yield and quality parameters of the crop. Water soluble K which is the readily permeable form of K nutrition of the crop also showed significant relationship with the yield and quality of colocasia rather than exchangeable K. These results are in accordance with the findings of Srinivasa Rao et al., (2014).

Conclusions

Application of half of the recommended doses of NPK fertilizers in combination with organic manure (FYM) enhanced the efficiency of applied chemical fertilizers that resulted in sustainable productivity and proximate composition of colocasia as well as the nutrient transformations in acid Alfisols of Eastern India. Application of soil test based N, P and K fertilizers was found equally effective in obtaining higher crop yields, nutrient use efficiency, and residual soil fertility. The tuber crops showed greater response to graded doses of K application rather than N fertilization. Different inorganic fractions of nutrients significantly influenced the cormel yield, biochemical constituents of cormels and the residual fertility status of the soil, indicating that the inorganic fractions as influenced by organic sources combined with inorganic fertilization in the present context of climatic scenario helps to enhance the productivity of tropical tuber crops and to maintain the soil quality.

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