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Integrated nutrient management in taro in relation to nutrient dynamics and fractionation of major nutrients in an Alfisol of Eastern India

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Abstract

Taro (*Colocasia esculenta* L) is an important tropical tuber crop widely grown in many locations of northeastern India particularly due to the popular use of both its leaves and cormels as a traditional food. Moreover, the nutritive significance of the crop with respect to many valuable phytochemicals too helped in the widespread cultivation of this crop in these areas. The integrated nutrient management strategy for the crop is standardised and efforts were made to determine the different organic and inorganic fractions of the major nutrients under different combinations of nutrients on the yield and proximate composition of the cormels. Hence, field experiments were conducted for two kharif seasons during 2018-2020 with 14 treatments replicated thrice in RBD in an Alfisol of eastern India. The soil of the experimental site is Typic Haplaqualf, which is slightly acidic, non-saline, very low in organic carbon (0.20%), and medium in available P and K. The effect of the treatments revealed that the inorganic fractions and available N, P and K contents were highest under integrated application of FYM along with half the recommended dose of N:P:K @ 40:15:40 kg ha^{-1} followed by application of chemical fertilizer alone as N:P:K @ 80:30:80 kg ha^{-1}. Available N in the soil was contributed mostly by NO_3-N and transformation of total N into inorganic fractions. The available P fractions occurred as reductant soluble P (42.39 mg kg^{-1}) > Fe-P (38.10 mg kg^{-1}) > Ca-P (30.23 mg kg^{-1}) > Al-P (23.71 mg kg^{-1}) > Bray's-1-P (17.86 mg kg^{-1}) > water soluble P (2.94 mg kg^{-1}). All the inorganic P fractions contributed significantly to the available P pool and the correlation coefficient (r^2) was found 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**). Occurrence of different K fractions was in the order of NH_4OAc-K (210.05 kg ha^{-1}) > exchangeable-K (186.56 kg ha^{-1}) > non-exchangeable K (111.54 kg ha^{-1}) > water soluble-K (23.49 kg ha^{-1}). However, exchangeable K and total K contributed significantly towards the available K content of the soil. Ammoniacal N showed highly positive and significant relationship with corm yield and biochemical constituents. Iron bound P and Al-P fractions contributed mostly towards the P nutrition of taro as these two fractions showed highly positive and significant correlation with yield and proximate composition. Of all the K fractions, non-exchangeable K recorded higher 'r' values for corm yield and biochemical constituents of taro. Integrated application of FYM and half the recommended dose of NPK not only enhanced the yield and quality of cormels and sustained the soil quality, but also influenced the NPK transformations for plant uptake in Alfisols.

Keywords : Integrated nutrient management, Organic manures, Inorganic fertilizers, Taro, NPK fractions

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Introduction

Colocasia (*Colocasia esculenta* L.), popularly known as taro belongs to the family Araceae, is a tropical tuber crop with high yield potential. The tuber comprised of corms and cormels. It is grown as a food crop as well as an animal fodder. Taro is widely cultivated in tropical and subtropical regions like West and North Africa, West Indies, South and Central China and many islands of the Pacific including Papua New Guinea. It is grown in almost all the states of India. The corm of taro is relatively low in protein (1.5%) and fat (0.2%), but it is a good source of starch (70-80 g 100 g^{-1} dry taro), fiber (0.8%) and ash (1.2%). Taro contains thiamine, riboflavin, iron, phosphorus, zinc, vitamin B6, vitamin C, niacin, potassium, copper, and manganese (Quach et al., 2003). Taro tuber can also be used for entrapping flavouring compounds. The taro starch grains are very fine, easily digestible and gluten free with hypoallergenic properties (Tari et al., 2002).

To improve the yield and quality of taro tubers, it is imperative to standardize the optimum doses of nutrients along with maintaining the physicochemical properties of the soil. In this regard, the integrated nutrient management (INM) approaches are the best as they are eco-friendly, easily practicable and cost-effective. It is better to integrate the chemical fertilizers and organic manures for nutrient management in tuber crops. The previous studies related to INM and site-specific nutrient management (SSNM) strategies in tuber crops proved to be beneficial in enhancing the crop productivity and improving the fertility status of the soil (Laxminarayana, 2016; Laxminarayana, 2017; Laxminarayana, 2021; Laxminarayana et al., 2015). Though sufficient information is available on nutrient management aspects of taro, very scanty information is available on nutrient fractionation studies in cropping systems involving tuber crops especially taro. Hence, the present study aimed at assessing the distribution of inorganic fractions of major nutrients *viz*., nitrogen, phosphorus and potassium in relation to the yield and biochemical constituents of taro in an Alfisol of Eastern India.

Materials and Methods

Field experiments were conducted in two *kharif* (rainy) seasons during 2018-19 and 2019-20 using the variety, Muktakeshi at the farm of the Regional Station, ICAR-Central Tuber Crops Research Institute (CTCRI), Bhubaneswar, Odisha, India to study the effect of integrated use of inorganic fertilizers and organic manure on soil fertility, yield and proximate composition of taro in an Alfisol. The experimental soil was loamy in texture (Typic Haplaqualf), slightly acidic in soil reaction (pH 6.09), non-saline (0.22dS m^{-1}), and very low in organic carbon (0.20%). The soil available N, P_2O_5 and K_2O contents were 200, 35 and 182 kg ha^{-1}, respectively. The soil was found higher in micronutrients *viz*., Fe, Cu, Mn and Zn (10.4, 1.43, 4.18 and 0.622 mg kg^{-1}, respectively). The experiment was laid out with 14 treatments replicated thrice in a randomized block design (RBD). The treatments included N @ 40, 80,120 kg ha^{-1}, P_2O_5 @ 30 kg ha^{-1}, K_2O @ 40, 80,120 kg ha^{-1}, N and P_2O_5 @ 80: 30 kg ha^{-1}, N and K_2O @ 80: 80 kg ha^{1}, P_2O_5 and K@ 30: 80 kg ha^{-1}, N, P_2O_5, K_2O @ 80:30:80 kg ha^{-1}, farmyard manure (FYM) @ 10 t ha^{-1}, and FYM @ 10 t ha^{-1} + N, P_2O_5 & K_2O @ 40-15-40 kg ha^{-1}.

Farmyard manure @ 10 t ha^{-1} (containing N, P, K @ 0.50: 0.28: 0.60%, respectively) was applied one month in advance of planting the taro in the respective plots which in turn can supply N, P and K, respectively @ 50, 28 and 60 kg ha^{-1}. Cormels were planted at a spacing of 50 × 30cm. As per the treatments, one-third of N, entire P_2O_5 and half K_2O was applied as basal, one third of N at 45 days after planting and the remaining one third of N and K_2O each at 90 days after planting in the form of urea, single superphosphate and muriate of potash, respectively were applied. All the intercultural practices were followed as per the schedule and the crop was harvested at maturity of 165 days after planting. Yield parameters such as number of cormels $plant^{-1}$, average cormel weight and cormel yield per plot were recorded. Cormel samples were collected, washed thoroughly, oven dried at 60ºC and dry weights were recorded. The total starch and sugar contents in the fresh cormel samples were estimated as per the standard procedure (Moorthy and Padmaja, 2002).

Surface soil samples were collected from individual treatment plots after harvest of the crop, shade dried, pounded, sieved (2.0 mm) and was used for the estimation of soil physicochemical properties by using standard analytical procedures outlined by Jackson (1973). Inorganic forms of N, *viz*., NH_4-N and NO_3-N were determined through steam distillation method (Black, 1965). Inorganic P fractions (water soluble P, Fe-P, Al-P, Ca-P, reductant soluble P) were determined by sequential fractionation method (Jackson, 1973). Inorganic K fractions (water soluble K, exchangeable K and non-exchangeable K) were determined by boiling nitric acid method (Wood and DeTurk, 1941). Relationship of different fractions of N, P and K with yield and proximate composition of taro was worked out by determining simple correlation coefficients by employing standard procedure as described by Gomez and Gomez (1984).

Results and Discussion

Effect of single, two and three nutrient combinations of N, P and K on yield of taro

The mean cormel yield was significantly increased with the application of graded doses of N up to 80 kg ha^{-1} and decreased at the higher dose of 120 kg ha^{-1} with yield response over control as 34.7, 56.9 and 55.5% under N @ 40, 80 and 120 kg ha^{-1}, respectively. Application of 30 kg P_2O_5 ha^{-1} recorded a mean cormel yield of 16.23 t ha^{-1}. The low level of P_2O_5 was taken as the experimental site has a high available P. Graded doses of K fertilizers up to 120 kg K_2O ha^{-1} showed an increasing trend on cormel yield during both the years and the mean yield responses were found to be 40.6, 56.3 and 63.2% over control, respectively. Relatively higher yield response was observed under the application of K fertilizer rather than N since the crop responded to higher doses of K in the sandy loam soil, which is low in available N and medium in available K.

Combined application of N_{80} P_{30}, N_{80} K_{80} and P_{30} K_{80} showed an increase in yield as 50.7, 74.0 and 59.9% respectively over the control. Combined application of N_{80} K_{80} showed higher yield response followed by P_{30} K_{80} and N_{80} P_{30}. Balanced application of N, P_2O_5 and K_2O @ 80:30:80 kg ha^{-1} recorded higher mean cormel yield of 23.57 t ha^{-1} with a yield response of 85.2% over the control. Application of all the three major nutrients (NPK) had shown higher yield response over that of single or two major nutrient application, indicating that a balanced fertilizer application can enhance crop yields. Taro is a heavy feeder of nutrients, and the yields were increased considerably due to the application of higher doses of NPK fertilizers in low and marginally fertile soils since the present study showed significant response to optimum doses of NPK rather than single or two nutrient application of higher doses of N, P and K. These results are in agreement with the findings of Halavatau et al., (1998) and Nizamuddin et al., (2003).

Effect of integrated nutrient management on cormel yield

Integrated application of FYM @ 10 t ha^{-1} along with N, P_2O_5 and K_2O @ 40:15:40 kg ha^{-1} significantly increased cormel yield. The highest mean cormel yield was 24.27 t ha^{-1} with highest yield response of 90.7% over the control (Table 1). Incorporation of FYM alone had recorded almost equal cormel yield to individual application of N and K @ 80 kg ha^{-1}, indicating that application of organic manure alone can reduce the cost on chemical fertilizers. Incorporation of FYM alone has recorded a mean corm yield of 19.37 t ha^{-1} with a yield response of 52.2% over the control, emphasizing the beneficial effect of organic sources over chemical fertilizers. Organic manures typically release both macro and micronutrients gradually and supply the crops throughout their growth period and this might have contributed in the cormel yields. In taro, it is understood that though the organic manures contain relatively low content of nutrients, there has been large increase in their use over inorganic chemical fertilizers as nutrient source for sustaining their productivity. The reason being the enhanced soil organic matter content, improvement in the soil physical and chemical properties, and stimulation of soil microbial activities due to the effect of manures (Geng et al., 2019, Kamara and Lahai, 1997) as well as their decomposition and nutrient release pattern in the soils (Mubarik Ali, 1999).

Effect of integrated nutrient management on proximate composition of taro

Integrated application of FYM @ 10 t ha^{-1} along with N, P_2O_5 and K_2O @ 80:30:80 kg ha^{-1} based on soil test was on par with the combined application of FYM @ 10 t ha^{-1} along with half the above dose of NPK which in turn resulted in significantly higher dry matter (24.67%), starch (12.92%) and total sugars (1.26%) in the cormels of taro (Table 2). Graded doses of N and K_2O fertilizers showed an increasing trend in biochemical constituents of taro up to 120 kg ha^{-1}. Two nutrients application of N_{80} K_{80} recorded relatively highest starch content on fresh weight basis (12.39%) and dry matter (24.22%) over P_{30} K_{80} and N_{80} P_{30}. Highest mean starch content was recorded under N_{80} P_{30} K_{80} (12.92%) followed by FYM + N_{40} P_{15} K_{40} (12.87%) followed by K_2O @ 120 kg ha^{-1} (12.11%). Starch content in the cormels ranged from 10.86 to 12.92 %. The total sugar content in the cormels ranged from 0.86 to 1.26% with the highest under integrated application of FYM + N_{40} P_{15} $K_{40.}$ Incorporation of organic manure increased the starch content, which might be due to the increased rate of mineralization of the organic manure causing nutrient transformations resulting in their enhanced mobility into the plant system. Increased doses of N and K fertilizers up to 120 kg ha^{-1} showed significant effect on starch, total sugars and dry matter content.

Significantly highest dry matter (24.76%) was recorded due to combined application N, P_2O_5 and K_2O @ 80:30:80 followed by FYM + ½ NPK (N_{40} P_{15} K_{40})

Table 1. Effect of organic and inorganic nutrients on yield and proximate composition of taro (2018-2020)

Sl.No.	Treatment	Cormels $plant^{-1}$	Cormel weight (g)	Cormel yield ($t\ ha^{-1}$)			Yield response (%)	Proximate composition (%)		
				2018-19	2019-20	Mean		Starch	Total sugar	Dry matter
1.	Control	8.57	24.46	10.11	15.34	12.73	-	10.86	0.86	22.56
2.	40 kg N ha^{-1}	9.99	28.10	12.28	22.02	17.15	34.7	11.19	0.93	22.79
3.	80 kg N ha^{-1}	10.84	29.61	13.91	26.02	19.97	56.9	11.53	0.98	23.40
4.	120 kg N ha^{-1}	11.49	30.03	14.05	25.55	19.80	55.5	11.93	1.05	23.61
5.	30 kg P_2O_5 ha^{-1}	9.17	27.62	12.40	20.06	16.23	27.5	11.32	0.94	23.22
6.	40 kg K_2O ha^{-1}	10.31	29.32	12.56	23.24	17.90	40.6	11.57	0.90	23.10
7.	80 kg K_2O ha^{-1}	11.03	31.05	14.10	25.70	19.90	56.3	11.99	1.03	23.61
8.	120 kg K_2O ha^{-1}	11.25	32.33	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}	10.74	31.74	14.27	24.10	19.19	50.7	11.53	1.09	23.76
10.	80 kg N & 80 kg K_2O ha^{-1}	11.28	33.27	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}	11.33	32.58	15.21	25.52	20.36	59.9	11.95	1.11	24.03
12.	80-30-80 kg N, P_2O_5 & K_2O ha^{-1}	11.85	34.95	18.46	28.68	23.57	85.2	12.92	1.26	24.67
13.	13) FYM @ 10 t ha^{-1}	10.74	30.35	13.69	25.04	19.37	52.2	11.61	1.05	23.41
14.	FYM @ 10 t ha^{-1} + ½ NPK	11.70	34.40	19.28	29.26	24.27	90.7	12.87	1.26	24.59
	CD (P=0.05)	0.38	1.11	0.50	1.10	0.61	--	0.15	0.03	0.12

Table 2. Effect of application of organic and inorganic nutrients on soil physicochemical properties

Sl.No.	Treatment	pH	Organic C	Total N	Available nutrients ($kg\ ha^{-1}$)			Exchange-able Ca	Exchange-able Mg	Available S	Available micro nutrients ($mg\ kg^{-1}$)			
		(1:2.5)	(%)	($kg\ ha^{-1}$)	N	P_2O_5	K_2O	[c mol (p^+) kg^{-1}]		($mg\ kg^{-1}$)	Fe	Cu	Mn	Zn
1.	Initial soil	6.094	0.203	1791.3	200.8	35.2	182.8	24.46	7.56	8.24	10.35	1.43	4.18	0.622
2.	Control	6.233	0.206	1745.5	155.8	35.2	174.6	21.54	6.79	7.49	8.90	1.37	4.24	0.625
3.	N40	6.202	0.257	1790.8	166.9	36.8	188.7	24.93	7.17	7.56	10.17	1.39	4.23	0.680
4.	N80	6.225	0.273	1845.0	175.4	37.6	203.6	26.17	7.58	7.58	10.54	1.43	3.28	0.661
5.	N120	6.188	0.312	1864.9	193.3	38.1	225.5	26.84	8.27	7.62	10.74	1.42	3.56	0.704
6.	P30	6.272	0.255	1755.2	160.5	41.0	179.8	24.45	7.26	7.53	10.12	1.40	4.08	0.635
7.	K40	6.210	0.247	1775.3	162.3	37.5	196.2	25.13	6.77	7.58	10.84	1.51	3.94	0.697
8.	K80	6.262	0.257	1804.4	170.3	38.3	217.7	26.16	7.61	7.67	11.52	1.50	3.87	0.717
9.	K120	6.233	0.275	1839.8	189.8	40.95	231.0	25.85	7.47	7.71	10.93	1.52	3.79	0.709
10.	N80P30	6.262	0.237	1856.3	182.2	42.8	213.8	25.96	7.67	7.72	11.23	1.47	3.87	0.636
11.	N80K80	6.317	0.287	1892.7	194.3	40.6	232.2	26.79	8.74	7.79	11.58	1.48	3.76	0.685
12.	P30K80	6.307	0.263	1825.7	180.7	44.2	220.6	25.66	7.81	7.75	11.26	1.41	4.06	0.669
13.	N80P30K80	6.291	0.324	1923.2	220.9	46.2	247.5	27.34	9.06	8.07	11.48	1.46	4.50	0.717
14.	FYM	6.243	0.248	1856.8	176.1	38.7	191.3	25.83	7.70	7.78	10.37	1.40	4.32	0.674
15.	FYM + ½ NPK	6.326	0.373	1986.8	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	0.01	9.17	2.26	11.5	0.47	0.29	0.07	0.32	0.07	0.49	0.025

Table 3. Effect of organic and inorganic nutrients on distribution of inorganic fractions of nitrogen, phosphorus and potassium under taro cropping system

Treatment	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
N40	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
N80	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
N120	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
P30	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
K40	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
K80	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
K120	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
N80P30	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
N80K80	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
P30K80	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
N80P30K80	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 + N40P15K40	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
S 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

(24.67%). The dry matter content significantly increased due to combined application of NK (24.22%) followed by PK (24.03%) and NP (23.76%), whereas incorporation of FYM showed relatively higher dry matter content as compared to lower doses of N, P and K fertilizers.

Effect of integrated nutrient management on soil physicochemical properties

The pH of the soil after harvest of taro for the second kharif season during 2019-20 ranged from 6.188 to 6.326 from the initial value of 6.094 (Table 3), however, the highest increase in soil pH was under integrated application of FYM + ½ NPK. Application of graded doses of N or K fertilizers alone up to 80 kg ha^{-1} showed an increasing trend in pH and thereafter showed a declining trend at higher doses of respective nutrients. Application of K fertilizers showed an increase in soil pH compared to N fertilizers, whereas combined application of N and K fertilizers resulted in relatively higher soil pH over single nutrient application either as N or K. Incorporation of FYM has improved the soil pH to 6.24 and FYM in combination with limited doses of NPK has further increased the soil pH to 6.33. Under integrated application with FYM, the soil acidity was counteracted due to buffering of the soil. The rise in soil pH through addition of FYM could be due to the specific adsorption of organic anions and the corresponding release of hydroxyl ions (Hue, 1992) and consumption of H^+ ions by the humic type substances which have a large number of carboxyl, and phenolic functional groups (Stevenson and Vance, 1989). Moreover, the organic matter has high cation exchange capacity, and it facilitated the retention of exchangeable bases in the soil (Ossom and Rhykerd, 2008).

The post harvest soils are found non-saline irrespective of the continuous application for two years under different treatment combinations. The electrical conductivity ranged from 0.694 to 0.881dS m^{-1} from the initial value of 0.224 dS m^{-1}. Organic carbon in the soil acts as energy substrate for proliferating microorganisms and enhancing nutrient availability to the crops (Wu et al., 2020). Highest organic C content was observed due to integrated application of FYM + ½ NPK (0.373%) followed by $N_{80} P_{30} K_{80}$ (0.324%) from the initial status of 0.203%. Lowest organic carbon content was observed in control (0.206%) which can be due to the continuous cropping without fertilizer application or manuring of the soil which in turn led to reduction in organic C content. On the contrary, addition of inorganic fertilizers along with the organic source led to improvement in organic matter status of the soil, which might be due to enhanced root growth and production of more crop residues under INM leading to accumulation of more organic matter in the soil (Rani Kumari et al., 2019). The soil organic carbon content in all the treatment combinations was found deficient (< 0.50%). However, the incorporation of FYM alone showed an improvement in organic C (0.248%), emphasizing the fact that apart from yield gains, organic sources can contribute to soil organic matter, improve the soil physical and chemical properties and neutralize the soil acidity (Fageria, 2012). Addition of graded doses of N and K fertilizers showed a significant improvement in organic C status, however, two nutrient application of NK showed relatively higher organic C (0.287%) compared to PK (0.263%) and NP (0.237%).

Effect of integrated nutrient management on inorganic nitrogen fractions

Integrated application of FYM along with ½ NPK recorded the highest total N (1986.8 kg ha^{-1}) followed by N, P_2O_5, K_2O @ 80:30: 80 kg ha^{-1} (1923.16 kg ha^{-1}). This could be attributed to the N mineralization of the organic manure and its indirect influence on soil physicochemical characteristics (Singh et al., 2002). Total N in the soils varied from 1745.5 to 1986.8 kg ha^{-1} from the initial status of 1791.3 kg ha^{-1}. The total N was significantly increased with the graded doses of both N and K up to120 kg ha^{-1}. Combined application of $N_{80} K_{80}$ showed higher total N over 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, and improved the soil physicochemical properties as well as enzyme activities. Increased doses of K fertilizers also significantly increased the available N, which was probably due to synergistic effect between N and K. The humus produced from the organic manure on its decomposition, can supply the essential nutrients slowly but steadily to the growing crops besides the direct supply from the inorganic fertilizers might have contributed to the improvement of available nutrients in the soil.

The soil available nitrogen ranged from 155.8 to 220.9 kg ha^{-1} with the highest (220.9 kg ha^{-1}) under combined application of N, P_2O_5 and K_2O @ 80: 30: 80 kg ha^{-1}, followed by integrated use of FYM + ½ NPK (212.8 kg ha^{-1}). Addition of nitrogenous fertilizers increased the available N status of the soil by 7.1, 12.6 and 24.1% in respect of 40, 80 and 120 kg N ha^{-1} over the control. Combined application of N, P and K fertilizers relatively improved the available N status over that of application of individual nutrients. Dual application of $N_{80} K_{80}$

showed higher available N (194.3 kg ha^{-1}) compared to 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 might be due to the integrated application of mineral fertilizer N along with organic source which in turn had 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 -120.58 and 15.84 -24.93 kg ha^{-1}, respectively with highest NH_4-N and NO_3-N are seen under integrated application of organic manure (FYM) +½ NPK (120.58 kg ha^{-1}). Addition of nitrogenous fertilizers tends to increase the ammoniacal N status of the soil by 16.4, 40.5 and 58.8% in respect of 40, 80 and 120 kg ha^{-1} over the control. The combined application of N, P and K fertilizers relatively improved the NH_4-N status over that of application of individual nutrients. Addition of N fertilizers increased the NO_3-N status of the soil by 15.46, 29.86 and 43.18 in respect of 40, 80 and 120 kg ha^{-1} over the control. Combined application of N, P and K fertilizers relatively improved the NO_3-N status over that of application of individual nutrients. It was also confirmed that there was an increase in both NH_4^+- N and NO_3^--N levels in the soil with increase in the level of application of fertilizer nitrogen (Duraisami et al*.,* 2001).

Effect of integrated nutrient management on inorganic phosphorus fractions

The range of total phosphorus in the soil varied from 182.4 - 217.1 mg kg^{-1} from the initial status of 204.6 mg kg^{-1} (Table 3). Highest total P content was recorded due to integrated application of organic manure (FYM) + ½ NPK (217.1 mg kg^{-1}) followed by application of N, P_2O_5 and K_2O @ 80:30:80 kg ha^{-1} (215.7 mg kg^{-1}). Addition of 30 kg P_2O_5 ha^{-1} increased the total P status of the soil by 12.22 % over the control. Combined application of N, P and K fertilizers improved the total P status over that of application of individual nutrients. The available P in the soils varied from 15.71 - 20.97 mg kg^{-1} from the initial status of 15.70 mg kg^{-1} (Table 3). The highest available P was observed due to combined application of FYM and ½ NPK (20.97 mg kg^{-1}) followed by balanced application of N, P_2O_5 and K_2O @ 80:30:80 kg ha^{-1} (20.61 mg kg^{1}). Addition of 30 kg P_2O_5 ha^{-1} increased the available P status of the soil by 16.42% over the control. Combined application of N, P and K fertilizers improved the available P status over that of application of individual nutrients. Combined application of P_{30} K_{80} showed an increase of 25.7% soil available P followed by N_{80} K_{80} (21.48 %) and N_{80} P_{30} (15.29%) over the control.

Increase in available P content of the soil under integrated nutrient management involving FYM was attributed to the decomposition of organic manure which might have enhanced the labile P in the soil by complexing Ca, Mg and Al. Moreover, 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 in an effective solubilization of inorganic phosphates in the soil (Laxminarayana, 2017).

The sequence of occurrence of inorganic P fractions in the soils under the different treatments followed the order as reductant soluble SP > Fe-P > Ca-P > Al-P > water soluble P (WS-P). Integrated application of organic manure with the chemical fertilizers enhanced the build-up of all the forms of inorganic-P. The water-soluble P (WS-P) in the soils varied from 2.35 - 3.58 mg kg^{-1} from the initial status of 2.41 mg kg^{-1} (Table 3) with highest value of WS-P due to integrated application of FYM and ½ NPK (3.58 mg kg^{-1}). Addition of 30 kg P_2O_5 ha^{1} increased the WS-P in the soil by 34% over control. Combined application of N_{80} P_{30} showed an increase of 37.3% WS-P followed by P_{30} K_{80} (34.6%) over control. Most of the WS-P added to the soil is transformed into relatively insoluble inorganic compounds of Al and Fe and thereby reduces 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 (Fe-P) in the soil varied from 28.22 - 46.09 mg kg^{-1} from the initial status of 32.65 mg kg^{-1}. Highest value of Fe-P content was recorded with integrated application of FYM + ½ NPK (46.09 mgkg^{-1}) followed by N, P and K @ 80:30:80 kg ha^{-1} of (45.66 mgkg^{-1}). Addition of 30 kg P_2O_5 ha^{-1} increased the Fe-P content of the soil by 37.9% over control, however, combined application of P_{30} K_{80} recorded an increase of 53.7% Fe-P over control followed by N_{80} P_{30} (47.84%). The aluminium bound P (Al-P) in the soils varied from 19.6 - 28.2 mg kg^{-1} from the initial status of 20.58 mg kg^{-1} with highest Al-P content was due to application of FYM + ½ NPK (28.16 mg kg^{-1}). Addition of 30 kg P_2O_5 ha^{-1} increased the Al-P content of the soil by 26.6% over the control, whereas two nutrients application of N_{80} K_{80}, N_{80} P_{30} and P_{30} K_{80} showed an increase of 31.9, 31.2 and 30.1% Al-P over the control, respectively.

The Ca-P in the soils varied from 26.54 - 37.94 mg kg^{-1} from the initial status of 28.67 mg kg^{-1} with highest under integrated application of FYM + ½ NPK (37.94 mg kg^{-1}) followed by N, P and K @ 80:30:80 $kgha^{1}$ of (35.78 mg kg^{-1}). Addition of 30 kg P_2O_5 ha^{-1}alone showed an increase of 9.6% of Ca-P over control and two nutrients application of P_{30} K_{80} and N_{80} P_{30} recorded a build-up of 19.1 and 11.9% of Ca-P over control. The reductant soluble phosphorus (RS-P) in the soils varied from 36.65 - 49.06 mg kg^{-1} from the initial status of 40.17 mg kg^{-1} with highest RS-P was in integrated use of FYM + ½ NPK (49.06 mg kg^{-1}) followed by N_{80} P_{30} K_{80} (48.5 mg kg^{-1}). Single nutrient application of 30 kg P_2O_5 ha^{-1} recorded an increase of 21.7% of RS-P over the control, whereas two nutrients application of P_{30} K_{80} and N_{80} P_{30} resulted in a build-up of 26.6 and 17.5% of RS-P over the control, respectively.

Effect of integrated nutrient management on inorganic potassium fractions

The post-harvest total potassium status in the soils of the experimental site ranged from 2072 to 2470 kg ha^{-1} with a mean of 2266 kg ha^{-1} (Table 3) with the highest under integrated application of N_{80} P_{30} K_{80} (2470 kg ha^{-1}) followed by integrated application of FYM + ½NPK (2454 kg ha^{-1}). Lowest value of total K was observed in the control (2153 kg ha^{-1}). However, addition of graded doses of K showed an increase in the total K status of the soil by 6.59, 12.16 and 15.55% in respect of K @ 40, 80 and 120 kg ha^{-1} over control. Combined application of N_{80} K_{80} showed relatively higher total K (2364 kg ha^{-1}) followed by P_{30} K_{80} (2349.56 kg ha^{-1}) and N_{80} P_{30} (2250.29kg ha^{-1}) with an increase of 14.1 and 13.4 % of total K over the control. According to Srinivasa Rao et al., (2000), the distribution of K forms in the soil and the equilibrium between the different fractions determine the K status of the soil and the potential for K supply to plants.

The available potassium content of the soil ranged from 174.6 to 247.5 kg ha^{-1} from the initial status of 182.8 kg ha^{-1} with highest available K in the integrated application of N, P and K @ 80:30:80 kg ha^{-1} (247.46 kg ha^{-1}) followed by application of FYM + ½ NPK (245.66 kg ha^{1}). Addition of graded levels of potassium increased the available K status of the soil by 12.37, 24.64 and 32.28% with respect to K @ 40, 80 and 120 kg ha^{-1} over the control. Combined application of N_{80} K_{80} showed higher available K (232.2 kg ha^{-1}), followed by P_{30} K_{80} (220.6 kg ha^{-1}) and N_{80} P_{30} (213.8 $kgha^{-1}$). It is known that 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. In this regard, Svotwa et al., (2007) was of the view that the differential release pattern of non-exchangeable K from the soil reserves besides variation in K uptake by the crop will be the reason for such differences in the available K status of the soil.

The highest value of water-soluble potassium (WS-K) content was recorded in the combined application of N, P and K @ 80-30-80 kg ha^{-1} (30.52 kg ha^{-1}) followed by integrated application of FYM with half the above recommended dose (29.36 kg ha^{-1}). The WS-K was lowest in the control (17.45 kg ha^{-1}). Addition of graded levels of K increased the WS-K status of the soil by 27.16, 43.95 and 71% with K @ 40, 80 and 120 kg ha^{-1}, respectively over the control. Combined application of N_{80} K_{80} (27.80 kg ha^{-1}) showed higher WS-K followed by P_{30} K_{80} (26.04 kg ha^{-1}) and N_{80} P_{30} (21.32 kg ha^{-1}). The WS-K in the soil was generally low probably because of leaching and erosion losses from the applied K. The substantially higher content of water-soluble K under integrated nutrient management could be attributed to the fact that organic manure during their decomposition forms organic acids which might have the 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 157.16 to 216.94 kg ha^{-1} from the initial status of 162.38 kg ha^{-1} with highest under combined application of N, P and K @ 80:30:80 kg ha^{-1} (216.94 kg ha^{-1}). This might be due to the fact that addition of FYM could increase the CEC of the soil, which can hold more exchangeable K and convert K from non-exchangeable form to exchangeable form, consequent to mass action effect. Addition of graded levels of potassium increased the exchangeable K status of the soil by 10.7, 22.5 and 28.0 % with K @ 40, 80 and 120 kg ha^{-1} over the control. Two nutrient application of N_{80} K_{80} (204.38 kg ha^{-1}) showed relatively higher exchangeable K followed by P_{30} K_{80} (194.53 kg ha^{-1}) and N_{80} P_{30} (192.47 kg ha^{-1}). Combined application of N, P and K fertilizers relatively improved the exchangeable potassium status over the independent application of nutrients.

The non-exchangeable potassium of the soil of the experimental site ranged from 79.97 to 138.60 kg ha^{-1} from the initial status of 106.24 kg ha^{-1} with highest under combined application of N, P and K @ 80:30:80 kg ha^{-1} of (138.60 kg ha^{-1}) followed by integrated use of FYM and half NPK (134.20 kg ha^{-1}). Addition of different levels of potassium increased the non-exchangeable potassium status of the soil by 30.3, 46.0 and 61.1% under K @ 40, 80 and 120 kg ha^{-1} over the control.

Two nutrients application of N_{80} K_{80} showed relatively higher non-exchangeable K (126.82 kg ha^{-1}) followed by P_{30} K_{80} (124.84 kg ha^{-1}) and N_{80} P_{30} (108.90 kg ha^{-1}). The significance of non-exchangeable K was revealed from many studies and is seen 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 the non-exchangeable form in soils containing minerals like vermiculite and illite shows higher K uptake by the crops and this interlayer K is also the major source controlling the long term K supplying potential of soils as per the reports of Escudey et al., (1997).

The non-exchangeable K fraction is released when the level of soil solution and exchangeable K are decreased by plant uptake and leaching (Srinivasa Rao et al., 2002). Conversion of exchangeable and water soluble K into non-exchangeable form is a slow process but this equilibrium also plays an important role in K nutrition of plants as it helps in maintaining the non-exchangeable K content of soils. It is also reported that in many soils, over time, K applied to soil changes into non-exchangeable form (Srinivasa Rao et al., 2000).

Relationship between yield and proximate composition with inorganic fraction of NPK

Among the inorganic fractions of N, NH_4-N showed higher positive and significant relationship with corm yield of taro ($r = 0.892^{**}$) rather than NO_3-N ($r = 0.845^{**}$) (Table 4), whereas the biochemical constituents also showed higher relationship with NH_4^+-N in comparison to NO_3^--N. The available K showed highly significant relationship with corm yield of taro ($r = 0.921^{**}$). Total K showed highest significant relationship with corm yield, starch, total sugars and dry matter and the 'r' values were found to be 0.929^{**}, 0.963^{**}, 0.918^{**}, 0.962^{**} respectively. Highly significant relationship was observed between total K with yield and biochemical constituents of taro rather than total N and total P, indicating that enhancement of total K and its fractions in the soil mostly contributed towards the yield and quality of tuber crops in general and taro in particular. In addition, application of K fertilizers based on soil test values and crop requirement is very essential to boost the productivity of tuber crops.

Table 4. Correlation coefficients (r) between cormel yield and proximate parameters of taro with inorganic fractions of nitrogen, phosphorus and potassium

Inorganic nutrient fractions	Mean cormel yield	Starch	Total sugar	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**

*$p < 0.05$; **$p < 0.01$

Of all the K fractions, non- exchangeable or fixed K was recorded higher 'r' values with cormel yield of taro ($r=0.943^{**}$), total sugars ($r=0.917^{**}$) and dry matter ($r=0.948^{**}$), indicating that, this fraction of K transferred 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 available form of K, also showed significant relationship with yield and quality parameters of taro rather than exchangeable K.

Conclusions

Integrated nutrient management involving combined application of half the recommended dose of NPK in combination with FYM enhanced the efficiency of applied chemical fertilizers, sustained productivity and improved the proximate composition of taro cormels in the acid Alfisols of Eastern India. Combined application of N, P and K fertilizers alone was found equally effective in obtaining higher crop yields, nutrient use efficiency, and residual soil fertility over single and two nutrient applications of either NP, NK or PK fertilizers. Taro showed greater response to graded doses of K application than graded levels of N fertilizer application. Incorporation of organic manure along with reduced doses of inorganic chemical fertilizers improved the nutrient transformations and hence availability to the crops. Different inorganic fractions of the major nutrients significantly influenced the cormel yield, biochemical constituents of taro and residual fertility status of the soil indicating that the inorganic fractions in the available plant usable form was influenced by integrated use of organic source combined with inorganic fertilizers which in turn helped to enhance the productivity of taro, improved cormel quality and sustained the soil quality.

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