

Nutrient release characteristic of multinutrient pellet for organic farming in rice (*Oryza sativa*.L) for acid sulphate soils

ABSTRACT

Aim: To develop a multinutrient pellet for organic farming in rice and investigation on the nutrient release characteristics of pellet in acid sulphate soils of Kuttanad.

Study design: This experiment was conducted through completely randomized design with 8 treatments and 3 replications.

Place and duration of study: The research was appraised at the Department of Soil Science, College of Agriculture Vellayani, between July 2022- September 2022.

Methods: Pellets were prepared using organic nutrient sources permitted in NPOP and a 60 day laboratory incubation experiment was performed to evaluate the nutrient release pattern of pellets. Standard procedures were used to analyze the nutrient content in pellets and quantity of nutrients in soil samples drawn from incubation experiment.

Results: Nutrient availability increased from the 15th to the 60th day, and the maximum was observed on 60th day. The soil pH, EC, dehydrogenase activity, and humic acid content increased throughout the incubation period, while organic carbon and fulvic acid content declined. The gross nutrient release was found to be the highest in pellet containing bloodmeal, rockphosphate and potassium sulphate.

.Keywords *Acid sulphate soils, pellets, bloodmeal, rockphosphate, potassium sulphate.*

INTRODUCTION

Kuttanad is the rice bowl of Kerala lying below mean sea level and soils are acid sulphate in nature [1]. Pyrite levels are significant in this poorly drained potential acid sulphate soils [2]. Hence these soils are classified under the order Entisols, suborder Aquents, great group Sulfaquents and sub group Typic Sulfaquents [3]. Fe and Al toxicity is widespread resulting in yield losses upto 70% [4]. In addition, low inflow of water into Kuttanad during the summer months (February-May) raises the salinity, acidity, and a shortage of water [5].

Amelioration of soil acidity, regulation of nutrients, lime and fertilizer application has been carried out over the years. Practice of liming can enhance the physical, chemical and biological properties of acid sulphate soils in Kuttanad [6]. Increased use of chemical fertilizers has been observed in this region and its application resulted in the negative impact on Atterberg limits and compressive strength of clay, besides excessive accumulation of agrochemical residues were reported [7] [8].

In acid sulphate soils, organic matter has a greater alkalizing impact than inorganic salts (e.g. Ca_2SO_4). Organic matter oxidation is widely recognized for producing carbonic and other organic acids. Plant leftovers are a common source of organic matter because they may regulate moisture levels, recycle nutrients, and increase soil fertility [8] [10].

Plethora of studies regarding organic nutrient sources as pellets highlight the importance of utilization of organic multinutrient pellets in crop production. Pellets are better for long-distance transportation, durable enough without disintegration and produce less of the dust [11]. Also Pellets are convenient to store, handle, transport, and uncomplicated to use in the field [12]. Jeng et al [13] developed a manure pellet for the cereals in Norway, which was prepared by concentrated organic manure that can supply large amount of nitrogen, phosphorous and calcium to the soil. The development and productivity of rice are further impacted by the nitrogen shift that organic manure caused in the soil, combined with changes to the microbial populations in the rice field [14]. The research work of Conner [15] depicts that application of organic manure with blood meal could accord high bulky carbon to the soil that could improve the soil structure and microbial biomass. Organic manure provides several advantages, including a balanced supply of nutrients, higher soil nutrient availability owing to increased soil microbial activity, the breakdown of hazardous components, soil structure improvements and root growth, and improved soil water availability [16].

Blood meal has the potential to improve the physical and biological qualities of soil [17]. According to Bhattacharyya and Bhupal [18], rock phosphate was more slowly accessible but not as fast fixed in the soil as other soluble forms of phosphate. Since acidic soils have high amounts of Fe and Al, as well as strong activity of Al_2O_3 and Fe_2O_3 , soluble forms of phosphate fertilizers are transformed into less soluble aluminum phosphate (Al-P) and iron phosphate (Fe-P) when applied to such soils. Potassium sulphate did not limit nitrification at higher pH levels, but it did encourage nitrogen buildup in the soil and increased EC content. It also inhibited nitrification in acidic soil, which decreased nitrogen losses [19]. Day et al [20] discovered that langbeinite translocate sodium in high concentrations while also contributing magnesium and potassium at an effective rate. Solubilized langbeinite, which contains Mg and K ions that promote flocculation, kept electrolyte concentrations high [21].

This study delved into the development of multinutrient pellets for organic farming in rice and evaluation on its applicability in acid sulphate soil through a laboratory incubation study conducted in a controlled condition.

2. Materials and Methods

2.1 Organic multinutrient pellet preparation

For the preparation of organic multi nutrient pellets, nutrient sources approved under the National Programme for Organic Production (NPOP) were selected and 8 different pellets were prepared using a pelletizing machine by combining different N, P and K nutrient sources, taking into account the nutritional requirement of rice ($\text{N} : \text{P}_2\text{O}_5 : \text{K}_2\text{O} - 90 : 45 : 45$) and the fertility status of the experimental soil. The pellets are P1 (Blood meal +Rock phosphate +Potassium sulphate), P2 (Blood meal +Rock phosphate +Langbeinite), P3 (Blood meal +Steamed bone meal +Potassium sulphate), P4 (Blood meal +Steamed bone meal +Langbeinite), P5 (Groundnut cake +Rock phosphate +Potassium sulphate), P6 (Groundnut cake +Rock phosphate +Langbeinite), P7 (Groundnut cake +Steamed bone meal +Potassium sulphate), and P8 (Groundnut cake +Steamed bone meal +Langbeinite). Bentonite clay and humic acid were used as binding agents.

2.2 Pellet characterization

Physical properties such as bulk density (Volume and weight method [22], water holding capacity (Centrifugation method [23]), stability on storage (simple finger test [24]) and disintegration in water (distilled water method [24]) and chemical properties such as pH and EC (Potentiometry Conductometry [25]) organic carbon (Walkley and Black rapid titration method [26]), total N (Macrokjeldahl distillation and titrimetry after extraction with 2 M KCl [27]), P and K (Diacid (HNO₃:HClO₄ in the ratio 9:4) digestion and estimation using spectrophotometer for P and flame photometer for K, [28]), Ca and Mg (Diacid (HN O₃:HCl O₄ in the ratio 9:4) digestion and estimation using versanate titration method [27]), S (Diacid (HN O₃:HCl O₄ in the ratio 9:4) digestion and turbidimetry [29]), Fe, Mn, Zn, Cu (Diacid (HNO₃:HClO₄ in the ratio 9:4) digestion and estimation using atomic absorption spectrometry [28]) and B (Spectrophotometry - Azomethine-H method [30]) along with organic acids such as humic acid and fulvic acid (0.1N sodium hydroxide and concentrated HCL method [28]) were estimated.

2.3 Incubation pot preparation

A laboratory incubation experiment was carried out to investigate the nutrient release pattern of the pellets after addition to soil. Five kilograms of acid sulphate soil from Kuttanadwere placed in pots. The organic multi nutrient pellets were added into the pots depending on the weight of soil taken and the nutritional requirement of rice. The pots were maintained at saturated condition.

2.4 Nutrient release characterization

Samples were drawn at 15th, 30th, 45th, and 60th day of incubation, and analysis was done for the following parameters. Chemical parameters such as pH, EC (Potentiometry Conductometry by [25]), organic carbon (Walkley and Black rapid titration method [26]), Available N (Alkaline potassium permanganate method [31]), Available P (Bray No.1 extraction and estimation using spectrophotometer [32]), Available K (Neutral normal ammonium acetate extraction and estimation using flame photometry by [28]), Exchangeable Ca and Mg (Versanate titration method [27]), available S (CaCl₂ extraction and estimation using spectrophotometer [30]), B (Spectrophotometry - Azomethine-H method [30]), available Fe, Mn, Cu, and Zn (0.1 N HCl extraction and estimation using atomic absorption spectrometry [33]), dehydrogenase activity (Colorimetric determination using 2,3,5-triphenyl formazan (TPF) [34]) and humic acid and fulvic acid content (Using 0.1N sodium hydroxide and concentrated HCL method [28]).

3. RESULTS AND DISCUSSION

3.1 Pellet Characterization

3.1.1 Physical Characters of pellets

Physical attributes of organic multinutrient pellets (Table 1) clearly specified that the bulk density of pellet P₆ (3.21 Mg m⁻³) was highest whilst P₄ (2.23 Mg m⁻³) gave the lowest value and the pellets P₈ (3.15 Mg m⁻³) and P₅ (3.12 Mg m⁻³) were on par with P₆. This might be due the moisture content and peanut material used for pellet preparation [35]. Water holding capacity of pellets expressed that P₅ (29.12%) had higher WHC than other treatments and it was followed by P₁ (28.32%) and P₆ (28.32%) with equal capacity to hold water. This may be due the presence of finer particles and porosity of pellets. All the pellets are found to be stable along the storage period without exhibiting any kind of variations in the shape, structure and texture. The pellets are able to sustain at least 2 hours in water without disintegration. Pellets P₅, P₆, P₇ and P₈ prolonged for more than 2.5hrs

*

without disintegration. This might be due to the high compactness and compressibility of pellets and due to the potential of binding agents.

Table 1 Physical characteristics of organic multinutrient pellet

Pellets	Bulk Density (Mg m ⁻³)	WHC (%)	Stability on Storage	Disintegration in water (minutes)
P ₁	2.96	28.32	Stable	160
P ₂	2.99	28.06	Stable	150
P ₃	2.23	27.12	Stable	120
P ₄	2.39	26.77	Stable	120
P ₅	3.12	29.12	Stable	170
P ₆	3.21	28.32	Stable	165
P ₇	2.54	27.71	Stable	170
P ₈	3.15	26.35	Stable	180

3.1.2 Physio-chemical properties of pellets

pH, EC and organic carbon concentrations of pellets are represented in the Table 2. pH of P₁ (5.98), P₃ (5.87), P₆ (5.82), P₂ (5.77), P₇ (5.71) and P₄ (5.65) were slightly acidic. The hexacoordinated Fe (III) present in blood meal can be coordinated by OH⁻ ion and by a Cl⁻ ion; hence pH may have increased. In addition, the application of organic compounds with blood meal would have increased the pH [36] [37]. The Electrical conductivity of pellets exhibited slight variations where P₆ had the highest EC followed by P₈, P₅ and P₂. It is because of the release of mineral salts from potassium langbeinite. All those pellets were blazoned high organic carbon content within a range of 17.5% - 23.5%. P₁ (23.13 %) and P₂ (20.94 %) had higher OC content above 20%. The presence of blood meal in pellet contributed high organic matter content in pellet [36].

3.1.3 Nutrient content of pellets

Nutrient concentrations in the pellets are depicted in the Table 2. P₃ (8.47%), P₁ (8.23%), P₂ (7.61%) and P₄ (7.56%) had the highest concentration of nitrogen than P₅, P₆, P₇ and P₈. It is because they contain blood meal which contains 10-12% N. The nitrogen content in blood meal is easily mineralizable so that it is easily available to plants [36] [37] [39]. The phosphorous and potassium contents of pellets were closer to the trend of nitrogen. P₁ exhibited larger concentration of phosphorous (4.24%) and potassium (4.21%). Rock phosphate contains high total phosphate content and on application, it increases the reserve P and available P concentration in soil. It is more suitable for acid soil [40] [41]. Sulphate of potash has high quantity of K in available form, which can be applied in acid soils with leaching problem [42].

Table 2. Chemical characterization of organic multi nutrient pellets

Pellets	pH	EC (dSm ⁻¹)	OC (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (mgkg ⁻¹)	Fe (mgkg ⁻¹)	Mn (mgkg ⁻¹)	Zn (mgkg ⁻¹)	Cu (mgkg ⁻¹)
P ₁	5.98	1.44	23.13	8.23	4.24	4.21	5.08	1.02	2.74	1.17	244.26	35.93	22.71	4.21
P ₂	5.77	1.64	20.94	7.61	3.64	3.58	4.55	2.65	4.18	1.08	312.86	31.23	18.97	3.53
P ₃	5.87	1.35	20.19	8.47	4.06	4.09	2.04	0.12	0.59	1.06	350.53	31.56	15.57	3.26
P ₄	5.65	1.60	20.38	7.56	3.78	3.66	1.82	1.88	3.87	1.17	255.60	18.50	17.85	4.13
P ₅	5.28	1.69	19.19	4.77	2.74	2.49	2.98	0.60	0.65	1.11	183.43	40.60	22.34	2.57
P ₆	5.82	1.89	19.32	4.46	2.46	2.25	2.78	1.62	2.57	1.09	169.23	17.13	21.91	5.62
P ₇	5.71	1.23	18.71	4.89	2.49	2.41	1.17	0.10	0.34	1.82	203.50	34.00	24.73	3.62
P ₈	5.39	1.79	19.38	4.57	2.21	2.28	1.10	1.14	2.34	1.90	185.40	34.13	21.95	4.27

*P₁ (Blood meal +Rock phosphate +Potassium sulphate), P₂ (Blood meal +Rock phosphate +Langbeinite), P₃ (Blood meal +Steamed bone meal +Potassium sulphate), P₄ (Blood meal +Steamed bone meal +Langbeinite), P₅ (Groundnut cake +Rock phosphate +Potassium sulphate), P₆ (Groundnut cake +Rock phosphate +Langbeinite), P₇ (Groundnut cake +Steamed bone meal +Potassium sulphate), P₈ (Groundnut cake +Steamed bone meal +Langbeinite). Bentonite clay and humic acid were used as binding agents.

P₁ (5.08%) reported higher Ca concentration and P₈ (1.10%) least Ca content. Ca content is high in rock phosphate. This leads to a higher Ca content rock phosphate containing pellets. Higher magnesium content was observed in P₂, P₄, P₆ and P₈. It may be because of the presence of Mg in langbeinite used in these pellets [20]. Regarding sulphur, highest concentration was observed in P₂ (4.18%) followed by P₄ (3.87%), because of the presence of sulphate in langbeinite used in these pellets [20].

Micro nutrient content in the eight different pellets are represented in Table 4. The boron content of pellets was in the range of 1.9 mg kg⁻¹ – 1.06 mg kg⁻¹, where P₈ had the highest B content. Fe content was found highest in P₃ with 350.53 mg kg⁻¹ followed by P₅ (312.86 mg kg⁻¹). Fe content was higher in these treatments because of the presence of Fe in blood meal [44]. Mn content of pellets were in an order of P₅ (40.60 mg kg⁻¹) > P₁ (35.93 mg kg⁻¹) > P₈ (34.13 mg kg⁻¹) > P₇ (34.00 mg kg⁻¹) > P₃ (31.56 mg kg⁻¹) > P₂ (31.23 mg kg⁻¹) > P₄ (18.50 mg kg⁻¹) > P₆ (17.13 mg kg⁻¹). Zn content in pellets occurred in the range of 24.73 mg kg⁻¹ (P₇) to 15.57 mg kg⁻¹ (P₃). Cu content was found in the range of 5.62 mg kg⁻¹ (P₆) - 2.57 mg kg⁻¹ (P₅). This might be due to ability of slow release organic fertilizers to provide micro nutrients [44].

3.1.4 Organic acid content in the pellets

Humic acid (3.05%) and fulvic acid (3.23%) contents (Table 3) revealed that both organic acids were found highest in P₁ and lower values were obtained by P₇ and P₈. This might be due to the presence of higher organic carbon in this pellet. A variety of organic molecules, including proteins, lipids, carbohydrates and pigments, are present in biodegrading organic wastes. These molecules eventually appear to produce complex organics, including humic acids (HA), fulvic acids (FA), and other substances [45].

Table 3. Organic acid content in multi nutrient pellets

Combination	Humic Acid (%)	Fulvic Acid (%)
P ₁	3.05	3.23
P ₂	2.59	2.41
P ₃	2.74	2.55
P ₄	2.36	2.64
P ₅	2.10	2.25
P ₆	1.92	2.35
P ₇	1.88	2.02
P ₈	1.33	2.28

3.2 Nutrient Release characteristics of pellets

3.2.1 Initial soil analysis

Table 27 delineates the initial physio-chemical and chemical properties of the soils used for the field experiment. It conveyed that the soil was strongly acidic (4.66) and the EC was found low (0.06 dS m^{-1}). The soil had high OC content of 3.34% and medium content of available N, P and K which was 362.5 Kg ha^{-1} , 24.8 Kg ha^{-1} and 185.6 Kg ha^{-1} respectively. Availability of secondary nutrients such as Ca, Mg and S were found excess in the soil. In case of micronutrients Fe was found in higher concentration while Mn, Zn, Cu and B were in sufficient level.

Table 4. Characterization of initial soil

OC	4.66
EC (dS m^{-1})	0.06
OC (%)	3.34
N (Kg ha^{-1})	362.5
P (Kg ha^{-1})	24.8
K (Kg ha^{-1})	185.6
Ca (mg Kg^{-1})	480
Mg (mg Kg^{-1})	165
S (mg Kg^{-1})	16.2
B (mg Kg^{-1})	0.52
Fe (mg Kg^{-1})	280
Mn (mg Kg^{-1})	2.75
Zn (mg Kg^{-1})	1.55
Cu (mg Kg^{-1})	1.20

3.2.2 Soil pH

Soil pH was found to increase during the incubation days (Table 5). P_1 was able to reduce more acidity on comparing with others. P_2 and P_6 also exhibited a tendency to reduce pH. Application of combined organic compounds increases soil pH along incubation period in acid soils, which is thought to be associated with the basic cation concentration availability in pellets and its slow release characters which is found consistent with other studies [46] [47] [48]. In addition the organic acid content of the manure could raise soil pH [10].

3.2.3 Soil EC

Application of multinutrient pellets did not significantly influence electrical conductivity until the 45th day of incubation (Table 5). P₁ (0.167 dSm⁻¹) was able to create an influence on EC on the 60th day and it was followed by P₄ (0.136). This might be due to the higher concentration of dissolved solutes in an organically improvised soil [49]. Conner [15] reported that application of blood meal can influence the electrical conductivity of soil due to the presence of inorganic nitrogen. Similar increasing trend in EC has observed by Fernandez-Sanjurjo et al [50] in a study with NPK fertilizer tablets.

3.2.4 Soil Organic Carbon

Organic carbon content of soil was found non-significant by the application of organic multinutrient pellets up to 45th day (Table 5). A minor fall in OC content was observed on 60th day, within a scale of 3.79% (P₁) to 3.59% (P₆). Applications of manure along with blood meal can contribute in soil C due to increased concentration of water soluble carbon with days [15] [51]. Similar increasing OC content were observed from the study of Ciavatta et al [38].

3.2.5 Soil Available Nitrogen

The influence of treatments on available nitrogen content of soil is presented in Table 6. Significant contribution of nitrogen content was observed with an increase in nitrogen content from the 15th day to the 60th day (Fig 1). The range of nitrogen obtained on 15th day was 397.33 kg ha⁻¹ (P₁) to 357.01 kg ha⁻¹ (P₅). P₂ (396.37 kg ha⁻¹) and P₄ (388.21 kg ha⁻¹) were on par with P₁. Same trend was also recorded on 30th day. On the 45th day the highest N content was reported by P₂ (429.09 kg ha⁻¹) which was on par with P₁ (428.33 kg ha⁻¹). Identical tendency has marked on the observation of the 60th day. This might be due to the higher net mineralization rate observed in blood meal [38] [52]. As the initial inorganic N concentration was relatively high, the blood meal had the highest total plant available nitrogen percentage. According to Hartz and Johnstone [53], the microbial community accelerated the enzymatic hydrolysis of easily broken down N-compounds during the first 14 days of blood meal mineralization would be slower, but thorough degradation of more intricate organic forms occurred later.

3.2.6 Soil Available Phosphorous

Available phosphorous content obtained is detailed in Table 6 (Fig 2). It is clear that, increase in phosphorous content is seen on the 15th day from the initial reading (24.8 kg ha⁻¹), which exemplifies the significant addition of phosphorous to the soil by the multinutrient pellets. It ranged from 31.98 kg ha⁻¹ (P₁) to 25.47 kg ha⁻¹ (P₇), where P₂ (32.42 kg ha⁻¹) was on par with P₁. The P availability had been built up peacemeal on 60th day. P₁, P₂ and P₅ reported higher values initially and on the second observation P₂ released more P and it is followed by P₁. In a similar study of Mahawar [54] it was observed that with the application rock phosphate the quantity of P available in soil was high for more than 60 days. The studies of SanthoshKumar [55] and Jalali and Ranjbar [56] also put forward similar results regarding rockphosphate.

3.2.7 Soil Available Potassium

Potassium concentration in soil is represented in Table 6. Significant contribution to available potassium was observed after the application of pellets (Fig 3). An increasing trend in potassium content was recorded from the initial soil reading (185.6 kg ha⁻¹) towards the reading on the 60th day. The range of potassium obtained on the 15th day was 198.60 kg ha⁻¹(P₁) to 184.06 kg ha⁻¹ (P₈), and P₂, P₃, P₅, P₆ and P₇ were on par with P₁. Highest P content was reported by P₁ (209.06 kg ha⁻¹) on the

45th day of incubation and P₃, P₅ and P₇ were on par with P₁. Similar trend was observed on the observation of 60th day also. The pellets P₁, P₃, P₅ and P₇ which contain sulphate of potash, recorded comparatively higher value of K throughout the incubation period. According to Tian et al [57], cumulative K release from sulphate of potash was found higher along the incubation period and the available K content in soil was found to be increased with the rate of application. Steady release of K ions in soil through the application of NPK fertilizer gave a positive impact on release rate [50].

3.2.8 Soil exchangeable Calcium

Calcium content in soil increased with days (Fig 4). On the 15th day, the calcium level exhibited a range of 593.33 kg ha⁻¹ (P₂) to 480 kg ha⁻¹ (P₈) in which P₁ (586.67 kg ha⁻¹), P₅ (583.34 kg ha⁻¹) and P₆ (576.67 kg ha⁻¹) were found on par to P₂ (Table 7). The high value for P₂ was found until 60th day (616.67 Kg ha⁻¹) and it was followed by P₁ (611.34 kg ha⁻¹). The least content was recorded in P₈ from 15th day (480.00 kg ha⁻¹) to 45th day (560.00 kg ha⁻¹). The higher trends in Ca in these treatments may be due to the higher content of Ca in rock phosphate [40]. In a similar study of Bloukounon-Goubalan [58], higher quantity of Ca was released slowly in an organic mixture. Olowoake [59] also reported increase in Ca content along the incubation period.

3.2.9 Soil exchangeable Magnesium

Magnesium content in soil performed an increasing trend along the incubation period (Fig 5). P₂ (198.00 kg ha⁻¹) recorded the highest on 15th day (Table 7) which was followed by P₄ (196.00 kg ha⁻¹), P₆ (194.34 kg ha⁻¹) and P₈ (194.00 kg ha⁻¹). On the 60th day the highest Mg value was observed in P₆ (219.34 kg ha⁻¹) and P₁, P₂, P₄ and P₈ were found on par with it and P₇ had the lowest value during incubation days. Broschat [60] reported in his study that the release rate of Mg from Langbeinite was increased from the zeroth day of incubation to the final day of study due to highly mineralized MgSO₄ content. Close results were expressed in the study by Broschat and Moore [61].

3.2.10 Soil available Sulphur

Available Sulphur content of soil was found predominant in P₂ (35.50 mg kg⁻¹ on 15th day to 36.50 mg kg⁻¹ on 60th day) (Table 7). There was an increasing trend during incubation period (Fig 6). Islam et al [62] reported that S release increased with incubation and peaked in anaerobic conditions in 45–60 days. These results were concurred with those of Moharana et al [63], who observed rising net S release levels as the incubation time increased from 30 to 60, irrespective of treatment.

Table 5 .Effect of organic multi nutrient pellets on pH, EC and Organic Carbon in soil

Treatment	Days of Incubation											
	pH				EC (dSm ⁻¹)				Organic Carbon (%)			
	15	30	45	60	15	30	45	60	15	30	45	60
P ₁	4.90	5.01	5.13	5.20	0.103	0.143	0.187	0.167	3.70	4.06	3.94	3.79
P ₂	4.93	5.07	5.12	5.19	0.123	0.133	0.173	0.153	3.64	4.00	3.88	3.74
P ₃	4.86	5.00	5.10	5.18	0.117	0.133	0.173	0.153	3.58	3.94	3.82	3.68
P ₄	4.90	5.04	5.10	5.17	0.113	0.147	0.183	0.163	3.63	3.99	3.87	3.73
P ₅	4.85	4.99	5.09	5.16	0.113	0.117	0.157	0.127	3.67	4.03	3.91	3.73
P ₆	4.94	5.08	5.13	5.17	0.097	0.133	0.173	0.143	3.53	3.89	3.77	3.59
P ₇	4.86	5.01	5.09	5.19	0.100	0.123	0.163	0.133	3.57	3.93	3.81	3.63
P ₈	4.90	5.04	5.12	5.16	0.103	0.120	0.160	0.130	3.60	3.96	3.84	3.67
SEm (±)	0.015	0.01	0.008	0.008	0.008	0.008	0.008	0.008	0.036	0.035	0.036	0.036
CD (0.05)	0.031	0.029	0.025	0.024	NS	NS	NS	0.023	NS	NS	NS	0.107

*P₁ (Blood meal +Rock phosphate +Potassium sulphate), P₂ (Blood meal +Rock phosphate +Langbeinite), P₃ (Blood meal +Steamed bone meal +Potassium sulphate), P₄ (Blood meal +Steamed bone meal +Langbeinite), P₅ (Groundnut cake +Rock phosphate +Potassium sulphate), P₆ (Groundnut cake +Rock phosphate +Langbeinite), P₇ (Groundnut cake +Steamed bone meal +Potassium sulphate), P₈ (Groundnut cake +Steamed bone meal +Langbeinite). Bentonite clay and humic acid were used as binding agents.

Table 6 .Effect of organic multi nutrient pellets on primary nutrients in soil

Treatment	Days of Incubation											
	N (kg ha ⁻¹)				P (kg ha ⁻¹)				K (kg ha ⁻¹)			
	15	30	45	60	15	30	45	60	15	30	45	60
P ₁	397.33	408.63	420.13	428.33	31.98	33.37	34.04	35.05	198.73	202.00	209.06	211.27
P ₂	396.37	407.67	429.09	437.29	32.42	33.69	34.39	35.07	191.13	192.53	195.67	199.80
P ₃	380.45	391.75	411.01	419.21	27.41	28.70	29.72	31.01	195.93	198.20	202.73	205.94
P ₄	388.21	399.51	403.25	411.45	26.58	27.76	28.77	29.92	189.53	191.73	193.93	198.14
P ₅	357.01	368.31	377.21	388.61	31.32	32.60	31.80	32.54	198.60	200.00	202.80	206.00
P ₆	371.35	382.65	390.19	401.59	30.58	31.86	32.52	33.58	192.87	194.26	190.93	195.13
P ₇	368.85	380.15	391.22	402.62	25.47	26.67	27.68	28.94	196.86	198.26	201.13	204.34
P ₈	366.99	378.76	384.19	395.59	28.06	28.90	29.91	31.17	184.06	185.73	187.93	193.47
SEm (±)	4.16	4.137	4.777	4.776	0.420	0.439	0.403	0.334	2.369	2.687	3.039	3.176
CD (0.05)	12.47	12.40	14.32	14.32	1.26	1.32	1.21	1	7.10	8.06	9.11	9.52

*P₁ (Blood meal +Rock phosphate +Potassium sulphate), P₂ (Blood meal +Rock phosphate +Langbeinite), P₃ (Blood meal +Steamed bone meal +Potassium sulphate), P₄ (Blood meal +Steamed bone meal +Langbeinite), P₅ (Groundnut cake +Rock phosphate +Potassium sulphate), P₆ (Groundnut cake +Rock phosphate +Langbeinite), P₇ (Groundnut cake +Steamed bone meal +Potassium sulphate), P₈ (Groundnut cake +Steamed bone meal +Langbeinite). Bentonite clay and humic acid were used as binding agents.

*

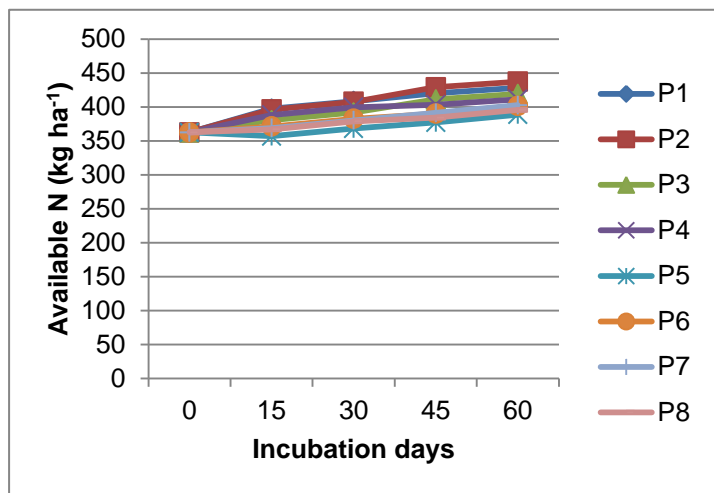


Fig 1. Effect of organic multinutrient pellets on available N in soil

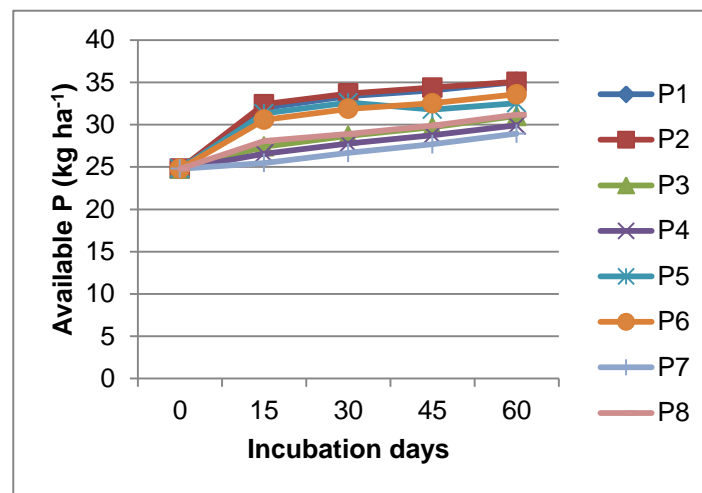


Fig 2. Effect of organic multinutrient pellets on available P in soil

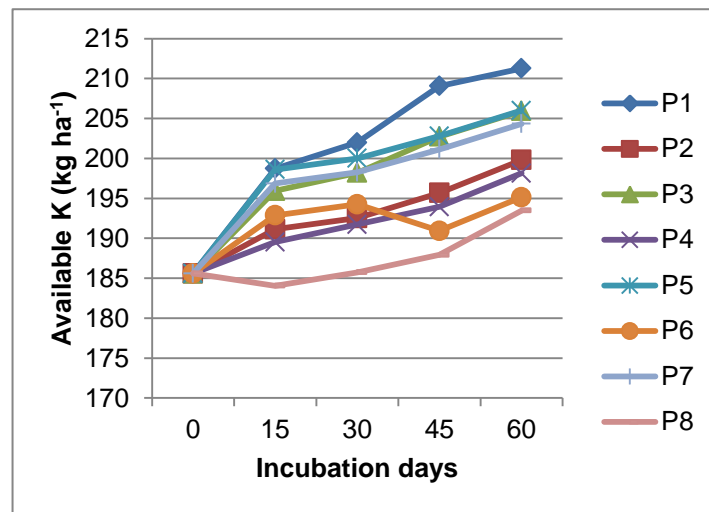


Fig 3. Effect of organic multinutrient pellets on available K in soil

3.2.11 Soil available micronutrients

Boron content was found increasing with each stage of incubation (Fig 7). P₈ was having significantly higher value along the incubation period and lowest values were reported by P₂ (Table 7). Boron content exhibited a tendency to increase with the application of organic fertilizer. Readily available B continuously increases for more than 12 weeks [64].

The influence of pellet on Fe, Mn, Zn and Cu content in soil was given in Table 8. Gradual increase in Fe content has noticed during the incubation period (Fig 8). P₁ reported the higher concentration of Fe from 15th day (324.94 mg kg⁻¹) to 60th day (347.07 mg kg⁻¹). It is clear that blood meal containing pellets released more Fe to soil. Ciavatta et al [37] reported that Fe content was found higher in blood meal containing organic compounds; also, the application of organic fertilizers can increase the Fe content in soil. Mn release was found higher in P₇, It was 4.04 mg kg⁻¹ on 15th day and at the end of incubation, it was 5.57 mg kg⁻¹ (Fig 9). P₅ was found close to P₇. In case of Zinc, P₁ had significantly higher values during incubation days and the inferior effect was expressed by P₇ (Fig 10). From the table it is clear that, on the 15th day available Cu was within a range of 1.64 mg kg⁻¹ (P₆) to 1.35 mg kg⁻¹ (P₅) which was gradually grown towards the 60th day (Fig 11). On the application of organic fertilizers the content of Mn, Zn and Cu exhibited gradual increase over time [44] [65] [66].

3.2.11 Dehydrogenase activity

From the Table 9 it was clear that dehydrogenase activity increased in soil throughout the incubation period. On the 15th day P₁ had the higher value, but from 30th day onwards P₅ reported significantly higher value. On 45th day P₈ recorded the lowest value and on 60th day it was lowest in P₂. The increased organic carbon content of soil on addition of pellets would have contributed to the dehydrogenase activity. Wolinska and Stępniewska [67] also reported that dehydrogenase activity increases with increase in total organic carbon in soil. They also recorded an increase in dehydrogenase activity with incubation days. Similar results were obtained by Radhakrishnan and Suja [66].

3.2.12 Humic acid and fulvic acid

Effect of multinutrient pellets on humic and fulvic acid content in soil is represented in Table 9. On 15th day, humic acid recorded the values in a range of 0.210% (P₁ and P₄) to 0.103% (P₈). On the 30th day the values were found within a range of 0.220% (P₄) to 0.170% (P₇) compared to the previous observation. But on 60th day the values were found high even though they were non-significant. In case of fulvic acid the values were higher on 45th and 30th days and lowest value was noticed in the 15th among the observations. Highest value of fulvic acid was recorded on the 45th day for P₆ (0.453%). The lowest value of fulvic acid was reported by P₈ (0.127%) on 15th day. On the 60th day fulvic acid ranged between 0.357% (P₂) to 0.117% (P₈). P₅ was found on par with P₂. Utomo [6] and Rendana et al [69] reported the tendency of humic acid and fulvic acid to increase along the incubation study.

Table 7 .Effect of organic multi nutrient pellets on Calcium, Magnesium, Sulphur and Boron in soil

Treatment	Days of Incubation															
	Ca (mg kg ⁻¹)				Mg (mg kg ⁻¹)				S (mg kg ⁻¹)				B (mg kg ⁻¹)			
	15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60
P ₁	586.67	600.67	606.67	611.34	182.00	192.67	198.34	213.67	25.75	26.34	27.83	29.17	0.54	0.62	0.67	0.78
P ₂	593.33	603.67	609.67	616.67	198.00	204.34	210.67	211.33	35.50	35.67	36.00	36.50	0.52	0.60	0.65	0.76
P ₃	543.34	553.00	562.34	583.34	184.00	192.34	199.33	207.00	19.00	21.34	23.16	26.17	0.57	0.65	0.70	0.79
P ₄	540.00	563.00	581.34	603.34	196.00	204.00	210.00	216.67	32.25	24.00	24.67	28.34	0.57	0.65	0.70	0.79
P ₅	583.34	584.67	601.34	603.34	182.00	190.00	197.00	202.67	23.50	29.00	29.50	30.34	0.55	0.64	0.72	0.80
P ₆	576.67	580.00	583.34	593.34	194.34	203.34	210.34	219.34	27.75	28.03	24.00	27.00	0.54	0.62	0.70	0.78
P ₇	543.34	557.34	563.34	580.00	174.00	182.34	189.34	200.34	18.00	21.67	28.00	29.00	0.56	0.64	0.74	0.80
P ₈	480.00	530.00	560.00	586.67	194.00	202.00	209.00	216.34	20.00	22.17	24.34	26.16	0.61	0.71	0.80	0.85
SEm (±)	12.076	11.961	10.765	7.473	5.018	4.684	4.631	3.665	0.779	0.803	0.932	0.833	0.004	0.003	0.003	0.004
CD (0.05)	36.20	35.87	32.27	22.40	15.04	14.04	13.88	10.99	2.34	2.41	2.80	2.498	0.013	0.01	0.01	0.013

*P₁ (Blood meal +Rock phosphate +Potassium sulphate), P₂ (Blood meal +Rock phosphate +Langbeinite), P₃ (Blood meal +Steamed bone meal +Potassium sulphate), P₄ (Blood meal +Steamed bone meal +Langbeinite), P₅ (Groundnut cake +Rock phosphate +Potassium sulphate), P₆ (Groundnut cake +Rock phosphate +Langbeinite), P₇ (Groundnut cake +Steamed bone meal +Potassium sulphate), P₈ (Groundnut cake +Steamed bone meal +Langbeinite). Bentonite clay and humic acid were used as binding agents.

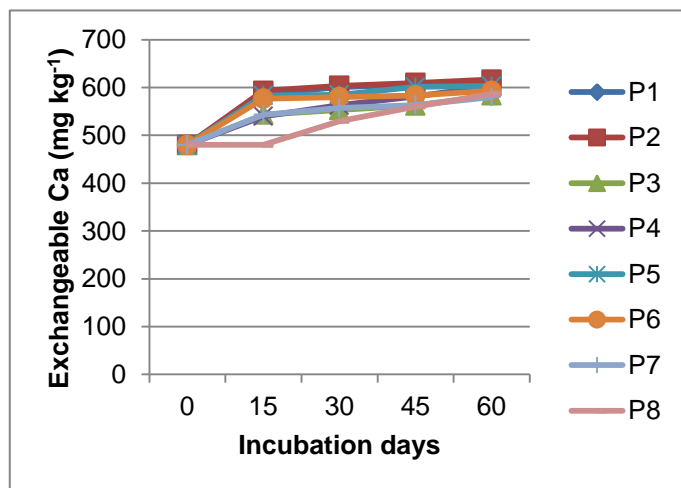


Fig 4. Effect of organic multinutrient pellets on exchangeable Ca in soil

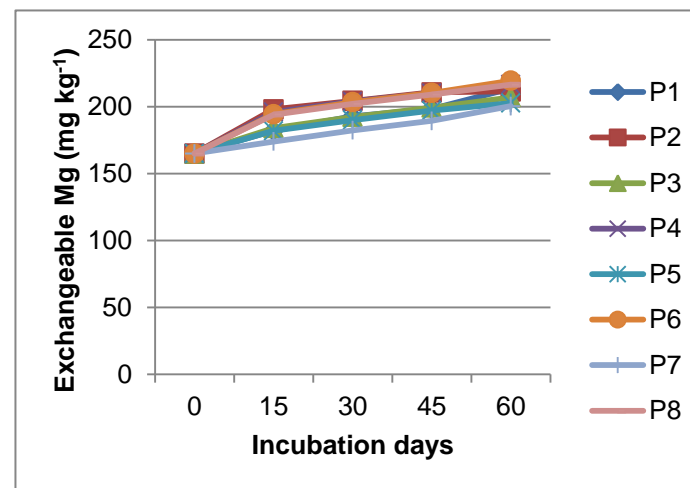


Fig 5. Effect of organic multinutrient pellets on exchangeable Mg in soil

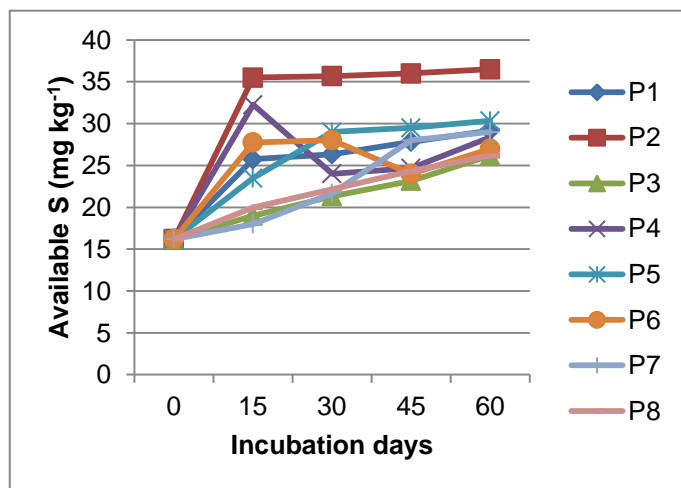


Fig 6 . Effect of organic multinutrient pellets on available S in soil

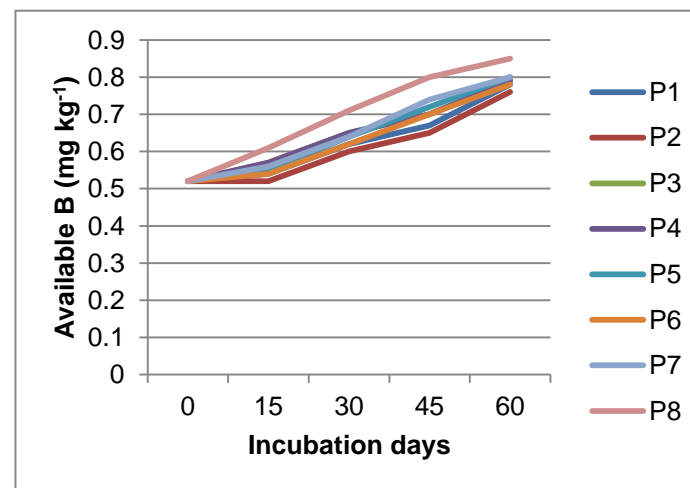


Fig 7. Effect of organic multinutrient pellets on available B in soil

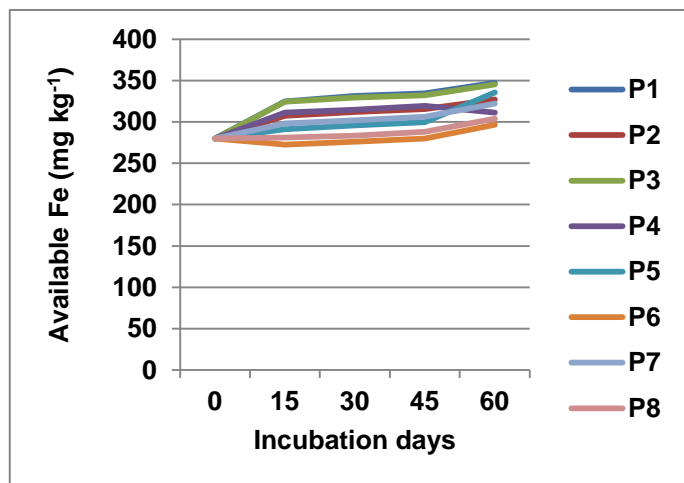


Fig 8. Effect of organic multinutrient pellets on available Fe in soil

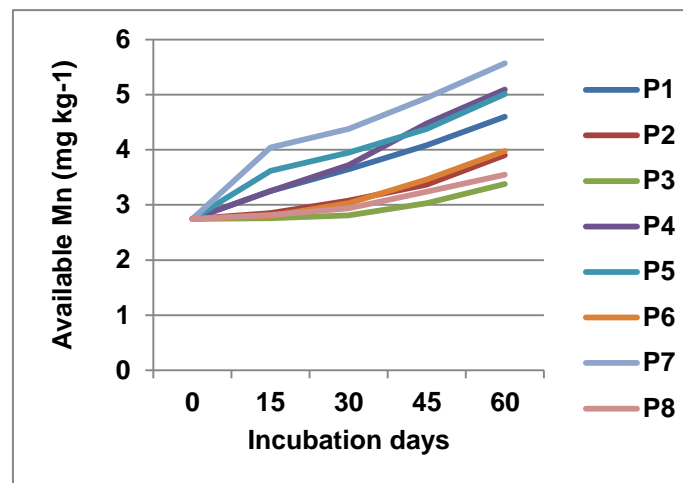


Fig 9. Effect of organic multinutrient pellets on available Fe in soil

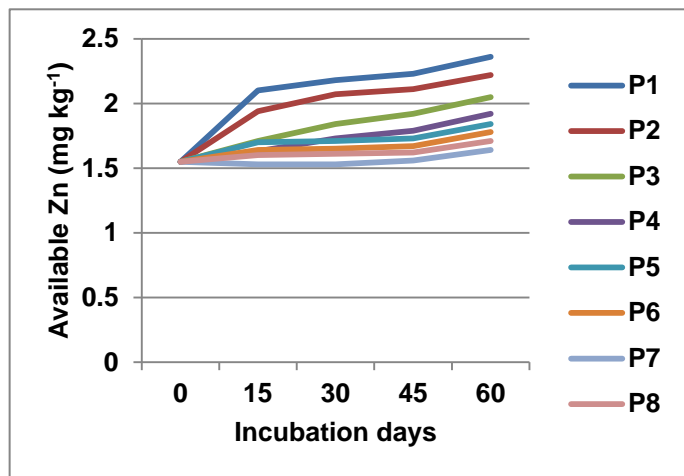


Fig 10. Effect of organic multinutrient pellets on available Zn in soil

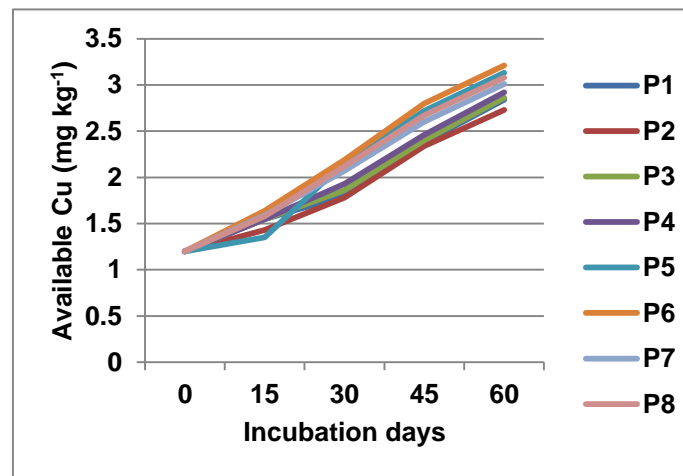


Fig 11. Effect of organic multinutrient pellets on available Cu in soil

*

Table 8 .Effect of organic multi nutrient pellets on micronutrients in soil

Treatment	Days of Incubation															
	Fe (mg kg ⁻¹)				Mn (mg kg ⁻¹)				Zn (mg kg ⁻¹)				Cu (mg kg ⁻¹)			
	15	30	45	60	15	30	45	60	15	30	45	60	15	30	45	60
P ₁	324.94	331.40	334.40	347.07	3.25	3.65	4.08	4.60	2.10	2.18	2.23	2.36	1.55	1.80	2.38	2.84
P ₂	307.40	312.20	315.34	327.27	2.85	3.08	3.37	3.90	1.94	2.07	2.11	2.22	1.43	1.78	2.34	2.73
P ₃	324.54	329.33	332.14	345.14	2.76	2.81	3.03	3.38	1.71	1.84	1.92	2.05	1.55	1.86	2.40	2.86
P ₄	311.30	314.90	319.50	311.40	3.25	3.72	4.48	5.09	1.63	1.73	1.79	1.92	1.55	1.93	2.46	2.92
P ₅	291.10	295.90	299.70	335.50	3.62	3.95	4.38	5.01	1.70	1.71	1.73	1.84	1.35	2.16	2.72	3.13
P ₆	272.40	276.00	279.80	296.60	2.80	3.03	3.46	3.98	1.64	1.65	1.67	1.78	1.64	2.19	2.80	3.21
P ₇	298.20	301.80	306.37	322.00	4.04	4.38	4.94	5.57	1.53	1.53	1.56	1.64	1.59	2.07	2.60	3.01
P ₈	281.00	283.26	288.00	304.00	2.82	2.94	3.24	3.55	1.60	1.61	1.62	1.71	1.58	2.12	2.67	3.08
SEm (±)	1.755	1.988	1.87	1.974	0.152	0.199	0.267	0.29	0.018	0.019	0.02	0.022	0.053	0.012	0.049	0.012
CD (0.05)	5.26	5.96	5.61	5.92	0.46	0.60	0.80	0.87	0.055	0.056	0.059	0.066	0.16	0.035	0.15	0.035

*P₁ (Blood meal +Rock phosphate +Potassium sulphate), P₂ (Blood meal +Rock phosphate +Langbeinite), P₃ (Blood meal +Steamed bone meal +Potassium sulphate), P₄ (Blood meal +Steamed bone meal +Langbeinite), P₅ (Groundnut cake +Rock phosphate +Potassium sulphate), P₆ (Groundnut cake +Rock phosphate +Langbeinite), P₇ (Groundnut cake +Steamed bone meal +Potassium sulphate), P₈ (Groundnut cake +Steamed bone meal +Langbeinite). Bentonite clay and humic acid were used as binding agents.

Table 9 .Effect of organic multi nutrient pellets on dehydrogenase activity, humic and fulvic acid in soil

Treatment	Days of Incubation											
	Dehydrogenase activity in soil, ($\mu\text{g of TPF g}^{-1} \text{ soil } 24 \text{ h}^{-1}$)				Humic acid (%)				Fulvic acid (% ¹)			
	15	30	45	60	15	30	45	60	15	30	45	60
P ₁	18.80	21.75	29.47	34.23	0.210	0.220	0.230	0.260	0.227	0.257	0.387	0.320
P ₂	10.77	16.63	23.83	25.61	0.207	0.207	0.223	0.250	0.257	0.293	0.360	0.357
P ₃	9.87	19.11	23.32	32.54	0.167	0.210	0.193	0.250	0.133	0.420	0.337	0.117
P ₄	9.81	21.56	35.66	44.74	0.210	0.190	0.237	0.263	0.187	0.270	0.380	0.270
P ₅	15.97	37.01	48.81	52.91	0.197	0.220	0.197	0.247	0.250	0.410	0.407	0.343
P ₆	9.15	14.18	29.97	34.51	0.160	0.187	0.180	0.217	0.170	0.447	0.240	0.260
P ₇	10.36	19.51	26.25	27.45	0.160	0.177	0.180	0.210	0.203	0.437	0.453	0.297
P ₈	11.44	14.85	19.78	28.38	0.103	0.170	0.120	0.217	0.127	0.363	0.360	0.217
SEm (\pm)	0.063	2.125	0.203	0.266	0.007	0.002	0.006	0.013	0.008	0.013	0.006	0.007
CD (0.05)	0.189	6.372	1.189	0.678	0.021	0.006	0.019	NS	0.024	0.04	0.018	0.02

*P₁ (Blood meal +Rock phosphate +Potassium sulphate), P₂ (Blood meal +Rock phosphate +Langbeinite), P₃ (Blood meal +Steamed bone meal +Potassium sulphate), P₄ (Blood meal +Steamed bone meal +Langbeinite), P₅ (Groundnut cake +Rock phosphate +Potassium sulphate), P₆ (Groundnut cake +Rock phosphate +Langbeinite), P₇ (Groundnut cake +Steamed bone meal +Potassium sulphate), P₈ (Groundnut cake +Steamed bone meal +Langbeinite). Bentonite clay and humic acid were used as binding agents.

CONCLUSION

Multinutrient pellets prepared using organic nutrient sources permitted by NPOP for organic farming in rice manifested their capability to supply nutrients to the acid sulphate soil. N content was highest in Pellet 3 (Blood meal +Steamed bone meal +Potassium sulphate) while P & K content were highest in Pellet 1 (Blood meal +Rock phosphate +Potassium sulphate). Soil pH and EC increased with days of incubation while organic carbon decreased. Nutrient availability increased from 15th day to 60th day and the maximum value was observed on 60th day. The dehydrogenase activity of soil and humic acid content increased with days of incubation while fulvic acid content decreased after days of incubation. The blood meal based pellets had the strong propensity to perpetuate and enhance the nutrient release to the soil on comparison with other pellets. The study indicates that Pellet 1 is supreme with respect to nutrient release characteristics, followed by Pellet 2 and Pellet 3. Pellet 1 prepared using blood meal, rock phosphate and potassium sulphate will provide sufficient quantities of all essential nutrients when applied to organically grown rice in acid sulphate soils of Kuttanad.

REFERENCES

1. Indira BVN, Covilakom MTK. Characterization of acidity in acid sulphate soils of Kerala. *Journal of Life Sciences*. 2013; 7(8): 907
2. Neenu S, Karthika KS. Kuttanad soils: the potential acid sulphate soils of Kerala. 2020; 3(2):19-23.
3. Beena, V I, Land evaluation and crop suitability rating of the acid sulphate soils of Kuttanad for sustainable land use planning. Ph .D. thesis. Kerala Agricultural University, Thrissur. 2005; 207p.
4. Thampatti KCM, Cherian S, Iyer MS. Managing iron toxicity in acid sulphate soils by integrating genetic tolerance and nutrition. *International Rice Research Notes*. 2005; 30:37-39
5. Aparna B, Gladis R, Aryanath V, Thampatti K C M. Studies on the Acid Sulphate Soils of Kuttanad of Kerala, *Indian Journal of Pure & Applied Biosciences*. 2020; 8(2): 421-428.
6. Bolan, N. S., Adriano, D.C., and Curtin, D. 2003. Soil acidification and liming interactions. In: Donald L. Sparks (ed.) *Adv. in Agron.* 78: 215-72.
7. Ravi BM, Suryaprakash S, Chandrakanth MG. Pricing of Surface Water in Bhadra Command Area: A Resource Economic Study. Department of Agricultural Economics, University of Agricultural Sciences; 2002.
8. Vijayan V, Salim S, Shaji S, Saji J, Jose T. Comparative Study of Shear Strength of Soil by Addition of Fertilizers. 2019.
9. Yan F, Schubert S, Mengel K. Soil pH changes during legume growth and application of plant material. *Biology and Fertility of Soils*. 1996;23:236-42.
10. Pocknee S, Sumner ME. Cation and nitrogen contents of organic matter determine its soil liming potential. *Soil Science Society of America Journal*. 1997;61(1):86-92.
11. Hara M. Fertilizer pellets made from composted livestock manure Taiwan: Food & Fertilizer Technology Center. 2001; 1-12.
12. Suppadit, T. 2009. Effect of pelleting process on fertilizing values of broiler litter. *J. Int. Soc. Southeast Asian Agric. Sci.* 15(2): 136-146.

13. Jeng A, Haraldsen T, Vagstad N. Meat and bone meal as nitrogen fertilizer to cereals in Norway. *Agricultural and Food Science*. 2004;13(3):268-75.
14. Su JQ, Ding LJ, Xue K, Yao HY, Quensen J, Bai SJ, Wei WX, Wu JS, Zhou J, Tiedje JM, Zhu YG. Long-term balanced fertilization increases the soil microbial functional diversity in a phosphorus-limited paddy soil. *Molecular ecology*. 2015;24(1):136-50.
15. Conner J.P. The Effects of Biochar and Reactive Iron Additions on Soil Carbon and Nitrogen Retention (Doctoral dissertation, Virginia Tech); 2022
16. Han SH, A JY, Hwang J, Kim S B, Park, BB. The effects of organic manure and chemical fertilizer on the growth and nutrient concentrations of yellow poplar (*Liriodendron tulipifera* Lin.) in a nursery system. *Foreign Science Technology*. 2016; 12(3):137-143.
17. Datt N, Sharma RP and Sharma GD (2003), Effect of supplementary use of farmyard manure along with chemical fertilizers on productivity and nutrient up-take by vegetable pea (*Pisum Sativum* Var *Arvense*) and buildup of soil fertility in Lahaul valley of Himachal Pradesh, *Indian J. Agri. Sci.* 73: 266-268.
18. Bhattacharyya NG, Bhupal S. Transformation of applied phosphate and its availability in acid soils. *Two and a Bud*. 1990; 37(1):24-30.
19. Martikainen PJ. Nitrification in forest soil of different pH as affected by urea, ammonium sulphate and potassium sulphate. *Soil Biology and Biochemistry*. 1985;17(3):363-7.
20. Tian XF, Li CL, Zhang M, Lu YY, Guo YL, Liu LF. Effects of controlled-release potassium fertilizer on available potassium, photosynthetic performance, and yield of cotton. *Journal of Plant Nutrition and Soil Science*. 2017;180 (5):505-15.
21. Day SJ, Norton J, Strom CF, Kelleners TJ, Aboukila EF. Gypsum, langbeinite, sulfur, and compost for reclamation of drastically disturbed calcareous saline-sodic soils. *International journal of environmental science and technology*. 2019; 16(1): 295-304.
22. Moliner C, Lagazzo A, Bosio B, Botter R, Arato E. Production, characterization, and evaluation of pellets from rice harvest residues. *Energies*. 2020;13(2):479.
23. Bühler JM, Dekkers BL, Bruins ME, Van Der Goot AJ. Modifying faba bean protein concentrate using dry heat to increase water holding capacity. *Foods*. 2020;9(8):1077.
24. Hignett TP. Physical and chemical properties of fertilizers and methods for their determination. *Fertilizer manual*. 1985:284-316.
25. FAI [Fertilizer Association of India]. The Fertilizer (Control) Order, 1985 [On-line]. 2017; Available: <http://www.astapice.org/food-safety/astas-analytical-methods-manual> [2 Feb. 2019].
26. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*. 1934;37(1):29-38.
27. Hesse PR. *A Textbook of Soil Chemical Analysis*. William Clowes & Sons. London, UK. 1971;153
28. Jackson ML. *Soil chemical analysis*, pentice hall of India Pvt. Ltd., New Delhi, India. 1973;498:151-4.
29. Massoumi A, Cornfield AH. A rapid method for determining sulphate in water extracts of soils. *Analyst*. 1963;88(1045):321-2.
30. Roig A, Cayuela ML, Sánchez-Monedero MA. The use of elemental sulphur as organic alternative to control pH during composting of olive mill wastes. *Chemosphere*. 2004;57(9):1099-105.
31. Subbiah BV. A rapid procedure for the determination of available nitrogen in soils. *Current Science*. 1956;25:259-60.
32. Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. *Soil science*. 1945 Jan 1;59(1):39-46.
33. Sims JT, Johnson GV. Micronutrient soil tests. *Micronutrients in agriculture*. 1991 Jan 1;4:427-76.
34. Casida Jr LE, Klein DA, Santoro T. Soil dehydrogenase activity. *Soil science*. 1964 Dec 1;98(6):371-6.

35. Ahmad S, Ghafoor A, Akhtar ME, Khan MZ. Ionic displacement and reclamation of saline-sodic soils using chemical amendments and crop rotation. *Land Degrad Dev.* 2013; 24:170–178
36. Mavadati S, Kianmehr MH, Alahdadi I, Chegini GR. Preparation of pellets by urban waste compost; 2010
37. Citak, Sedat, Sahriye Sonmez. Effects of chemical fertilizer and different organic manure application on soil pH, EC and organic matter content." *Journal of Food, Agriculture and Environment* 2011; 739-741.
38. Yunta F, Di Foggia M, Bellido-Díaz V, Morales-Calderón M, Tessarin P, López-Rayó S, Tinti A, Kovács K, Klencsár Z, Fodor F, Rombolà AD. Blood meal-based compound. Good choice as iron fertilizer for organic farming. *Journal of Agricultural and Food Chemistry.* 2013;61(17):3995-4003.
39. Ciavatta C, Govi, M, Sitti L. Gessa C. Influence of blood meal organic fertilizer on soil organic matter: A laboratory study. *Journal of plant nutrition.* 1997; 20: pp.1573-1591.
40. Cassity-Duffey K, Cabrera M, Gaskin J, Franklin D, Kissel D, Saha U. Nitrogen mineralization from organic materials and fertilizers: Predicting N release. *Soil Science Society of America Journal.* 2020; 84(2): 522-533.
41. Biswas DR, Narayanasamy G. Rock phosphate enriched compost: an approach to improve low-grade Indian rock phosphate. *Bioresource Technology.* 2006; 97(18): 2243-2251.
42. Kasno A, Sutriadi MT. Indonesian rock-phosphate effectivity for maize crop on ultisols soils. *AGRIVITA, Journal of Agricultural Science.* 2012;34(1):14-21.
43. Mugambi SM. Manure and fertiliser requirements of potatoes on acid soils. *East African Agricultural and Forestry Journal.* 1979;44(4):278-84.
44. Shaji H, Chandran V, Mathew L. Organic fertilizers as a route to controlled release of nutrients. In *Controlled release fertilizers for sustainable agriculture* Academic Press. 2021; 231-245.
45. Mikula K, Izydorczyk G, Skrzypczak D, Mironiuk M, Moustakas K, Witek-Krowiak A, Chojnacka K. Controlled release micronutrient fertilizers for precision agriculture—A review. *Science of the Total Environment.* 2020;712:136365.
46. Stumm W, Morgan JJ. *Aquatic chemistry: chemical equilibria and rates in natural waters.* John Wiley & Sons; 2012.
47. Hue NV. Correcting soil acidity of a highly weathered Ultisol with chicken manure and sewage sludge. *Communications in Soil Science and Plant Analysis.* 1992; 23(3-4): 241-264.
48. Whalen JK, Chang C, Clayton GW, Carefoot JP. Cattle manure amendments can increase the pH of acid soils. *Soil Science Society of America Journal.* 2000;64(3):962-6.
49. Materechera SA, Mkhabela TS. The effectiveness of lime, chicken manure and leaf litter ash in ameliorating acidity in a soil previously under black wattle (*Acacia mearnsii*) plantation. *Bioresource technology.* 2002;85(1):9-16.
50. Brady N, Weil R. *The Nature and Properties of Soils*, 12th ed. Prentice, New jersey, USA; 1996
51. Fernandez-Sanjurjo MJ, Alvarez-Rodriguez E, Nunez-Delgado A, Fernandez-Marcos, ML Romar-Gasalla A. Nitrogen, phosphorus, potassium, calcium and magnesium release from two compressed fertilizers: column experiments. *Solid Earth.* 2014; 5(2): 1351-1360.
52. Cayuela ML, Sinicco T and Mondini C. Mineralization dynamics and biochemical properties during initial decomposition of plant and animal residues in soil. *Applied soil ecology.* 2009; 41(1):118-127.
53. Hirzel J, Donnay D, Fernández C, Meier S, Lagos O, Mejias-Barrera P, Rodríguez F. Controlled experiment to determine nitrogen availability for seven organic fertilizers in three contrasting soils. *Biological Agriculture & Horticulture.* 2019; 35(3):197-213.
54. Hartz TK and Johnstone P R. Nitrogen availability from high-nitrogen-containing organic fertilizers. *HortTechnology.* 2006; 16: 39–42. <https://doi.org/10.21273/HORTTECH.16.1.0039>.
55. Mahawar, N., Tagore, G.S., Vishwakarma, M., Bangre, J., Nayak, J.K., Agarwal, S. and Yadav, S., 2022. Study of Release Pattern of Phosphorus in Soils: Incubated with Organic Acids and Different Origin of Rock Phosphate. *International Journal of Plant & Soil Science*, 34(16), pp.1-10.

56. SanthoshKumar VC. Suitability of Tunisia rock phosphate for direct application in acid rice soils of Kerala (Doctoral dissertation, Department of Soil Science and Agricultural Chemistry, College of Horticulture, Vellanikara).1997.
57. Jalali M, Ranjbar F. Rates of decomposition and phosphorus release from organic residues related to residue composition. *Journal of Plant Nutrition and Soil Science*. 2009;172(3):353-9.
58. Bloukounon-Goubalan A Y, Saïdou A, Obognon N, Amadji GL, Igue, AM, Clottey VA, Kenis M. Decomposition and nutrient release pattern of animal manures biodegraded by fly larvae in Acrisols. *Canadian Journal of Soil Science*. 2018; 99(1): 60-69.
59. Olowoake AA. Nutrient release pattern from compost supplemented with *Jatropha* cake on Alfisol of Ilorin, Nigeria. *International Journal of Plant & Soil Science*. 2017;15(5):1-1.
60. Broschat TK. Release rates of controlled-release and soluble magnesium fertilizers. *Horticulture Technology*. 1997; 7(1): 58-60.
61. Broschat TK, Moore KK. Release rates of ammonium-nitrogen, nitrate-nitrogen, phosphorus, potassium, magnesium, iron, and manganese from seven controlled-release fertilizers. *Communications in Soil Science and Plant Analysis*. 2007; 38(7-8): 843-850.
62. Islam MR, Bilkis S, Hoque TS, Uddin S, Jahiruddin M, Rahman MM, Siddique AB, Hossain MA, Danso Marfo T, Danish S, Datta R. Mineralization of Farm Manures and Slurries under Aerobic and Anaerobic Conditions for Subsequent Release of Phosphorus and Sulphur in Soil. *Sustainability*. 2021 Aug 2;13(15):8605.
63. Moharana PC, Biswas DR, Datta SC. Mineralization of nitrogen, phosphorus and sulphur in soil as influenced by rock phosphate enriched compost and chemical fertilizers. *Journal of the Indian Society of Soil Science*. 2015;63(3):283-93.
64. Ajayan AS, KC MT. Boron dynamics in red loam soil amended with different organic fertilizers. *International Collegiate Journal of Science*. 2021; 9(1): 1071-1076.
65. Follett RH, Lindsa WL. Changes in DTPA-extractable zinc, iron, manganese, and copper in soils following fertilization. *Soil Science Society of America Journal* 1971; 5(4):600-602.
66. Radhakrishnan AR S, Suja G. Nutrient release pattern of organic and inorganic resources used in cassava production (*Manihot esculenta* Crantz). *Journal of Plant Nutrition*. 2019;42(11-12):1301-15.
67. Wolinska A, Stępniewska Z. Dehydrogenase activity in the soil environment. *Dehydrogenases*. 2012;10:183-210.
68. Utomo M. Effect of rock phosphate on soil properties and apparent phosphorus recovery in acid soil of Sumatra. In *Plant-Soil Interactions at Low pH: Principles and Management: Proceedings of the Third International Symposium on Plant-Soil Interactions at Low pH*, Brisbane, Queensland, Australia, 1993, 1995;653-656.
69. Rendana M, Idris WM, Rahim SA, Rahman ZA, Lihan T, Jamil H. Reclamation of acid sulphate soils in paddy cultivation area with organic amendments. *AIMS Agriculture and Food*. 2018;3(3):358-71.