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Development and Characterization of Multi-Nutrient Formulations for Organic Farming

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study was to develop multi-nutrient formulations for organic farming containing all the essential macro and micronutrients. The experimental design selected was completely randomized design with 8 treatments and 3 replications**.** The experiment was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, Kerala between Jan 2021-May 2021. Multi-nutrient formulations were developed using various organic nutrient sources like blood meal, soybean meal, rock phosphate, steamed bone meal, potassium sulfate, langbeinite, epsom salt, and borax permitted by National Programme for Organic Production. Formulations were prepared by mixing nutrient sources considering the nutrient requirement of nendran banana

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($N:P_2O_5:K_2O$ @ 300:115:450 g plant^{-1}) and the soil fertility status. The formulations were characterized for their physical, chemical and biochemical properties. On the basis of character analysis and principal component analysis the formulation F_1 containing blood meal, rock phosphate, potassium sulfate, epsom salt and borax was found superior to other formulations. This was followed by F_3 which contains blood meal, steamed bone meal, potassium sulfate, epsom salt and borax. Formulation F_1 had 3.73 g cm^{-3} bulk density, 2.67% moisture content, 6.5 pH, 3.23 dSm^{-1} EC, 29.43% OC, 7.21% N, 2.71% P, 10.78% K, 5.98% Ca, 0.35% Mg, 4.45% S, 1174.11 mg kg^{-1} Fe, 4.53 mg kg^{-1} Mn, 13.55 mg kg^{-1} Zn, 8.65 mg kg^{-1} Cu and 93.67 mg kg^{-1} B. It also contained 45.04% crude protein, 2.95% humic acid and 3.55% fulvic acid. The formulation F_3 had 7.47 pH, 3.37 dSm^{-1} EC, 28.34% OC, 7.11% N, 2.68% P, 10.68% K, 2.05% Ca, 0.32% Mg, 4.37% S, 1163.41 mg kg^{-1} Fe, 4.87 mg kg^{-1} Mn, 14.52 mg kg^{-1} Zn, 9.05 mg kg^{-1} Cu and 96.33 mg kg^{-1} B. Hence multi-nutrient formulation F_1 based on its nutrient supplying capacity can be recommended as a nutrient source for organic farming.

Keywords: Organic farming; organic fertilizer; multi-nutrient formulation; blood meal; rock phosphate; potassium sulfate.

1. INTRODUCTION

Organic farming has gained popularity in the state of Kerala, India and the state is steadily moving forward to become an organic state [1]. The major soil type of Kerala is laterite soil which is acidic, sufficient in phosphorus, iron, zinc, copper, and manganese, and deficient in organic matter, nitrogen, potassium, calcium, magnesium, sulfur, and boron [2]. One of the most important constraints faced in the field of organic farming in the state is the inadequate availability of organic nutrient sources that are capable of providing all the essential plant nutrients in the desired quantity. Farmers mostly rely on farmyard manure, compost, and other bulky organic manure which fail to supply the entire nutrient required by the crops. This results in acute nutrient deficiencies in organically fertilized fields causing reduced yield. Organic manures available in the market are not capable of supplying the entire essential nutrient elements that are required for crops [3]. The application of multi-nutrient sources has the potential to improve crop yields by addressing multiple soil nutrient deficiencies [4].

There are nutrient sources specific to each nutrient permitted under the National Programme for Organic Production (NPOP). To complement the nutritional requirements of crops, some naturally occurring minerals like rock phosphate, potassium sulfate, gypsum, epsom salt, borax, basic slag, calcitic lime, dolomite lime, etc. are permitted in organic farming for restricted use. However, the application of a number of such sources in varying quantities is not practical from a farmer's perspective. There is a possibility of developing a multi-nutrient formulation suitable for organic farming containing all the required plant nutrients in the right quantity and form using various nutrient sources permitted in NPOP.

Blood meal which is the byproduct of industrial slaughter houses is recognized as a good source to be used as nitrogen and iron fertilizer in organic farming due to its capacity to provide nitrogen and is characterized by the presence of a prosthetic group (protoporphyrin) containing iron [5]. It contains 10-13% N and 0.2-0.3% Fe [6] and plays a vital role in the growth, development as well as yield of many crops like lettuce and onion [7,8]. Soybean meal is a byproduct of soybean oil extraction. It raises the amount of nitrogen, potassium, crude protein, and gibberellic acid in plants. It also increases the yield attributing parameters like shoot length and fresh weight [9]. Substituting NPK fertilizer with soybean meal increases yield [10]. Rock phosphate is recommended in acid soil because it is slowly available and does not fix in the soil as quickly as other soluble forms of phosphate. When applied on acidic soils, soluble forms of phosphate fertilizers change into less soluble aluminum phosphate (Al-P) and iron phosphate (Fe-P) due to the high activity of Al_2O_3 and Fe_2O_3 in soil [11]. Rock phosphate promotes rooting and is a good alternative to bone meal [12]. Bone meal releases its phosphorous faster than rock phosphate [13]. Bone meal increases height and number of nodes in sugarcane. Total soluble solids content in sugarcane also increases when fertilized with bone meal [14]. Potassium sulfate decreases pH and increases EC in soil. It inhibits nitrification under low pH conditions but under higher pH levels it does not inhibit nitrification [15]. Langbeinite translocates 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, keeps electrolyte concentrations high [16]. Epsom salt does not form sulfuric acid in the soil and does not affect soil pH [17]. It shows a positive effect on vegetative growth parameters, N, Mg, chlorophyll a and b content in leaves and yield of banana [18]. Borax is water soluble and is subjected to leaching and its soil application influences the fruit yield and pulp to peel ratio in banana [19]. The application of magnesium sulfate and borax in soil reduces the NH_3 and N_2O emissions and increases the nitrogen uptake by the plant [20].

Hence the present investigation was undertaken to develop multi-nutrient formulations suitable for organic farming using various organic nutrient sources permitted in NPOP.

2. MATERIALS AND METHODS

2.1 Experimental Site

Experiments were conducted in the laboratory at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, Kerala during the month between Jan 2021 to May 2021.

2.2 Preparation of Organic Multi-Nutrient Formulations

Nutrient sources permitted in NPOP were selected for the preparation of multi-nutrient formulations. Nutrient sources taken for nitrogen - blood meal (BM) and soybean meal (SM); for phosphorus - rock phosphate (RP) and steamed bone meal (SBM); for potassium - potassium sulfate (SOP) and langbeinite (L); for magnesium - epsom salt (ES) and for boron - borax (B). Nutrient formulations were prepared using these nutrient sources considering the nutrient requirement of the nendran banana (N: P_2O_5 : K_2O @ 300:115:450 g plant^{-1}) and the fertility status of the soil of agro-ecological unit 8 of Kerala. Predetermined quantities of different N, P, and K nutrient sources for different treatment combinations were taken (Table 1) and hand mixed properly. The experimental design selected was CRD with 8 treatments and 3 replications. The formulations prepared were F_1 - BM + RP + SOP + ES + B; F_2 – BM + RP + L + ES + B; F_3 – BM + SBM + SOP + ES + B; F_4 – BM + SBM + L + ES + B; F_5 – SM + RP + SOP + ES +B; F_6 – SM + RP + L + ES + B: F_7 – SM + SBM + SOP + ES + B and F_8 – SM + SBM + L + ES + B. The multi-nutrient formulations are presented in Plate 1.

2.3 Characterization of Multi-Nutrient Formulations

The multi-nutrient formulations prepared were characterized for physical properties viz. moisture content by oven dry method and bulk density by tapping method [21]. The chemical properties viz. pH and EC were determined in a 1:5 sample to water extract using pH and EC meter respectively, TOC was estimated by weight loss on ignition method. The N content was determined by micro Kjeldahl distillation after digestion in concentrated H_2SO_4 acid [22]. The P, K, Ca, Mg, S, Fe, Mn, Zn and Cu content was determined by acid digestion of the samples by nitric-perchloric (9:4) acid and later estimated by spectrophotometry using vanadomolybdate method for P [22], flamephotometry for K [22], versanate titration method for Ca and Mg [22], turbidimetry for S [23], atomic absorption spectrometry for micronutrients [22]. The B content was determined by dry ashing at 550 ℃ in silica crucibles followed by extraction of ash in 10ml 0.36 NH_2SO_4 for 1 hour at room temperature and filtration through Whatman no. 42 filter paper and then estimated by spectrophotometry [24]. The biochemical properties viz. lignin content was determined by Klason lignin method [25]. Total protein (crude) content was computed by multiplying the total

Table 1. Quantity of nutrient sources used for preparing multi-nutrient formulations

Treatment	N- source	P-source	K-source	Mg- source	B-source
F_1	2500 g BM	325 g RP	850 g SOP	160 g ES	4g B
F_2	2500 g BM	325 g RP	1900 g L	160 g ES	4g B
F_3	2500 g BM	433 g SBM	850 g SOP	160 g ES	4g B
F_4	2500 g BM	433 g SBM	1900 g L	160 g ES	4g B
F_5	4300 g SM	145 g RP	814 g SOP	160 g ES	4g B
F_6	4300 g SM	145 g RP	1800 g L	160 g ES	4g B
F_7	4300 g SM	193 g SBM	814 g SOP	160 g ES	4g B
F_8	4300 g SM	193 g SBM	1800 g L	160 g ES	4g B

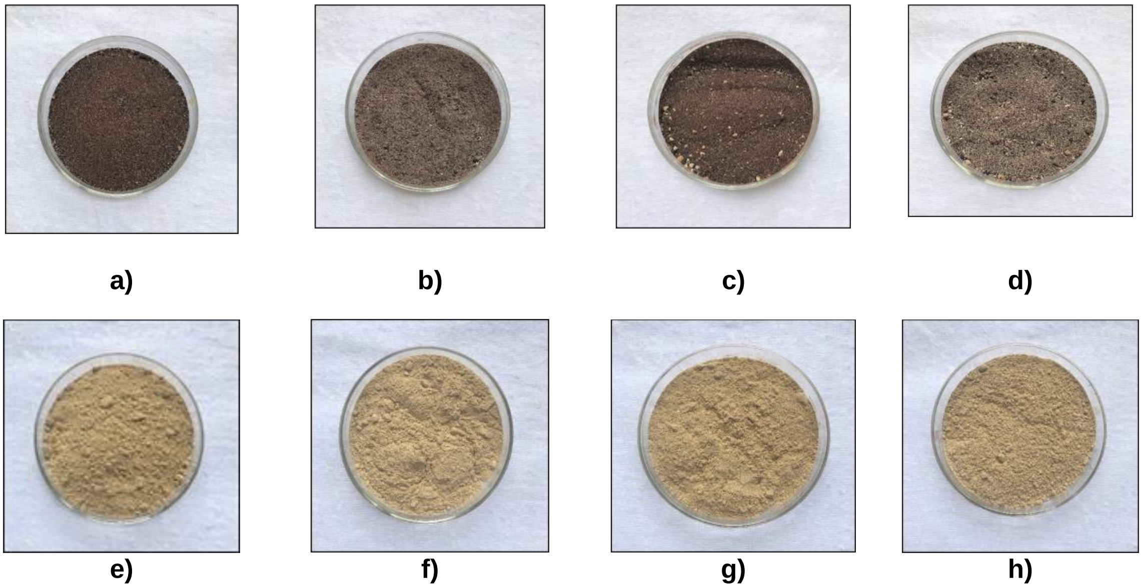

Plate 1. a) Formulation F_1 (BM + RP + SOP + ES + B), b) Formulation F_2 (BM + RP + L + ES + B), c) Formulation F_3 (BM + SBM + SOP + ES + B). d) Formulation F_4 (BM + SBM + L + ES + B), e) Formulation F_5 (SM + RP + SOP + ES +B), f) Formulation F_6 (SM + RP + L + ES + B) g) Formulation F_7 (SM + SBM + SOP + ES + B), h) Formulation F_8 (SM + SBM + L + ES + B)

nitrogen value with a conversion factor of 6.25 [26]. Crude fiber was extracted with acid and alkali followed by oven drying and ignition at 550° C [27]. Organic acids (fulvic and humic acid) were determined by using 0.1N NaOH and concentrated HCl [22].

2.4 Statistical Analysis

The data obtained from the characterization study were analyzed statistically by a standard procedure using GRAPE 1.0.0 (General R-shiny based Analysis Platform Empowered by Statistics) software. Means of different treatment combinations were compared based on the least significant difference (LSD) at 0.05 probability level. Principal component analysis was done to select the best multi-nutrient formulations.

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Multi-Nutrient Formulations

The multi-nutrient formulations varied significantly with respect to physical properties like bulk density and moisture content (Table 2). The bulk density was found to be the highest in formulation F_4 (4.76 Mg m^{-3}) which was found to be on par with F_2 (4.62 Mg m^{-3}) and the lowest was observed in F_7 (1.70 Mg m^{-3}). The differences in the bulkiness of individual sources like blood meal and soybean meal could be the reason behind the differences in the bulk density of formulations. The moisture content of formulations ranged between 1.02% (F_8) to 2.67% (F_1). The moisture content of individual nutrient sources influenced the moisture content of the formulations. The blood meal is a liquid byproduct of a slaughterhouse, it goes through the drying process to become powder. Whereas soybean meal is plant based product and contains less moisture than blood meal [28].

3.2 Electro-Chemical Properties of Multi-Nutrient Formulations

Significant variation was observed between different formulations with respect to electro-chemical properties like pH, EC and OC (Table 3). The pH of all the formulations was in the neutral range (6.50-7.68). The highest pH value was recorded in F_8 (7.68) which contained SM + SBM + L + ES + B followed by F_4 (7.58), F_7 (7.50) and F_3 (7.47). The lowest pH value was recorded in F_1 (6.50) which contained BM + RP + SOP + ES + B. Steamed bone meal usually has a high pH, therefore adding steamed bone meal to the formulation mixture raises the pH value. Steamed bone meal was used in the formulation of F_8, F_4, F_7, and F_3, which resulted in their higher pH levels [29]. Blood meal and soybean meal were used in F_1, F_2, F_5, and F_6 formulations and their pH was in the range of 6.50-6.96 [30].

The electrical conductivity of formulations ranged between 2.10-3.90 dS m^{-1}. The highest value was recorded in F_4 (3.90 dS m^{-1}) which contains BM + SBM + L + ES + B and the lowest was recorded in F_7 (2.10 dS m^{-1}). The highest EC in F_4 may be because of the release of mineral salts from mineral fertilizer like langbeinite [16]. The organic carbon content of the formulations was in a range of 25.47% (F_4) -38.54% (F_5). The organic carbon content of the F_5 (38.54%), F_6 (34.48%), F_7 (30.19 %) and F_8 (28.70%) formulations were found to be higher compared to F_1 (29.43%), F_2 (26.41%), F_3 (28.34%), and F_4 (25.47%). This might be because the formulations F_5, F_6, F_7, and F_8 contain soybean meal [31].

3.3 Nutrient Content of Multi-Nutrient Formulations

Significant variation was observed with respect to nutrient content (N, P, K, Ca, Mg, S, Fe, Zn, Mn, Cu and B) of multi-nutrient formulations (Table 4). The highest nitrogen content was found in formulation F_1 (7.21%) followed by F_3 (7.11%). The lowest N content was recorded in formulation F_7 (4.01%). The higher N content in blood meal and steamed bone meal contributes to the highest N% in F_1 and F_3. The high nitrogen content in blood meal and steamed bone meal is due to high amino acid content [32]. The total phosphorus content in formulations ranged from 1.41-2.71%. The phosphorus content of the formulation F_1, F_2, F_3, F_4, F_5, F_6, F_7 and F_8 was 2.71%, 2.11%, 2.68%, 2.08%, 1.42%, 1.56%, 1.41% and 1.54% respectively. Formulation F_1 (2.71%) had the highest phosphorus content which was on par with F_3 (2.68%) while F_7 had the lowest phosphorus content. The P content was higher in the formulations containing rock phosphorus compared to steamed bone meal. Formulation F_1 (10.78%) had the highest total potassium content which contains BM + SBM + SOP + ES + B which was on par with F_3 (10.68%). Formulation F_7 (5.50%) had the lowest total potassium content. This may be because of the higher potassium concentration in potassium sulfate compared to langbeinite [33]. The highest calcium content was in formulation F_5 (5.98%) and the lowest was in formulation F_8 (1.15%). The formulations having rock phosphate had higher calcium content. The highest total magnesium content was observed in formulation F_2 (4.20%) which was on par with formulation F_8 (4.14%). The variations in the magnesium content among the formulations may be because

Table 2. Physical properties of multi-nutrient formulations

Treatment	BD (Mg m^{-3})	Moisture content (%)
F_1 (BM + RP + SOP + ES + B)	3.73^{c}	2.67^{a}
F_2 (BM + RP + L + ES + B)	4.62^{a}	2.28^{ab}
F_3 (BM + SBM + SOP + ES + B)	4.34^{b}	2.28^{ab}
F_4 (BM + SBM + L + ES + B)	4.76^{a}	1.71^{abc}
F_5 (SM + RP + SOP + ES +B)	1.87^{de}	1.34^{bc}
F_6 (SM + RP + L + ES + B)	2.05^{d}	1.05^{c}
F_7 (SM + SBM + SOP + ES + B)	1.70^{e}	1.14^{bc}
F_8 (SM + SBM + L + ES + B)	1.78^{e}	1.02^{c}
SE(m)	0.06	0.39
CD(0.05%)	0.18	1.17

Table 3. Electro-chemical properties of multi-nutrient formulations

Treatment	pH	EC (dSm^{-1})	OC (%)
F_1 (BM + RP + SOP + ES + B)	6.50^{d}	3.23^{cd}	29.43^{cd}
F_2 (BM + RP + L + ES + B)	6.86^{c}	3.73^{ab}	26.41^{de}
F_3 (BM + SBM + SOP + ES + B)	7.47^{b}	3.37^{bc}	28.34^{cde}
F_4 (BM + SBM + L + ES + B)	7.58^{ab}	3.90^{a}	25.47^{e}
F_5 (SM + RP + SOP + ES +B)	6.90^{c}	2.23^{e}	38.54^{a}
F_6 (SM + RP + L + ES + B)	6.96^{c}	2.83^{d}	34.48^{b}
F_7 (SM + SBM + SOP + ES + B)	7.50^{b}	2.10^{e}	30.19^{c}
F_8 (SM + SBM + L + ES + B)	7.68^{a}	2.77^{d}	28.70^{cd}
SE(m)	0.06	0.16	1.08
CD (0.05%)	0.17	0.49	3.22

of the presence of magnesium in langbeinite, which raised the magnesium content of langbeinite containing formulations [33]. The total sulfur content in all formulations ranged from 3.10 to 9.06%. The formulation F_2 had the highest sulfur content (9.06%) which was significantly higher than all other formulations. The formulation F_7 had the lowest total sulfur (3.10%). The sulfur supply was provided by the sulfate content of potassium sulfate and langbeinite. The langbeinite containing formulations F_2, F_4, F_6 and F_8 had higher sulfur content compared to potassium sulfate containing formulations F_1, F_3, F_5 and F_7.

The highest iron content was found in formulation F_1 (1174.11 mg kg^{-1}) which was on par with F_3 (1163.41 mg kg^{-1}). The lowest iron content was found in F_7 (283.18 mg kg^{-1}). Iron content in formulation F_1, F_2, F_3 and F_4 were higher than F_5, F_6, F_7 and F_8. This can be attributed to the presence of iron containing blood meal in these formulations [5]. The highest manganese content was in formulation F_3 (4.87 mg kg^{-1}) and the lowest manganese was recorded in F_6 (1.13 mg kg^{-1}). The highest zinc content was in formulation F_3 (14.52 mg kg^{-1}) and the lowest was in F_6 (3.67 mg kg^{-1}). The addition of blood meal during vermicomposting enriched the compost in Fe, Mn, and Zn [34]. The highest copper content was found in formulation F_3 (9.05 mg kg^{-1}) which was significantly higher than all other formulations. The lowest copper content was found in F_6 (2.98 mg kg^{-1}). Fertilization with meat and bone meal improves the quality of grain of wheat by increasing the content of Cu, Fe, Mn, and Zn [35]. The boron content in the formulation was the highest in F_3 (96.33 mg kg^{-1}) and the lowest in formulation F_6 (51.33 mg kg^{-1}).

3.4 Biochemical Properties of Multi-Nutrient Formulations

The results of biochemical properties like lignin, crude fiber, crude protein, and organic acid (humic acid and fulvic acid) of multi-nutrient formulations shared significant variation (Table 5). The lignin and crude fiber content was not found in the formulations F_1, F_2, F_3, and F_4 because there was no plant-based nutrient source used in these formulations. Because soybean meal was used in the formulations F_5, F_6, F_7, and F_8, the lignin and crude fiber content in those formulations were high in the range of 15.85-23.23% and 7.08-9.15% respectively. The formulation F_5 had the highest lignin concentration (23.23%), while F_8 had the lowest (15.85%) [36]. The highest crude fiber content was in the formulation F_5 (9.15%) and the lowest in F_8 (7.08%) [37]. The highest crude protein was in formulation F_1 (45.04%) and the lowest was in formulation F_7 (25.08%). Crude protein content in F_1, F_2, F_3, and F_4 formulations ranged from 33.85% to 45.04% which was higher than in F_5, F_6, F_7, and F_8 formulations (25.08% to 25.96%). This can be attributed to the presence of low nitrogen content soybean meal in the later formulations. The humic acid content was the highest in formulation F_1 (2.95%) which was on par with F_3 (2.83%). This was followed by F_4 (2.73%), and F_2 (2.67%). The lowest humic acid was in F_8 (1.72%). Similarly, the highest fulvic acid content was recorded in formulation F_1 (3.55%) which was on par with F_3 (3.46%). This was followed by F_4 (3.36%), and F_2 (3.30%) and the lowest was in F_8 (2.42%). This could be due to the higher organic carbon content in F_1, F_2, F_3, and F_4 formulations compared to F_5, F_6, F_7 and F_8 formulations. Biodegrading organic sources contain a wide range of organic compounds, such as proteins, lipids, carbohydrates, and pigments. On decomposition, these molecules create complex organics like humic acids, fulvic acid, and other compounds.

3.5 Principal Component Analysis

The results of laboratory analysis of multi-nutrient formulations were subjected to principal component analysis (PCA) (Table 6, Plate 2) in order to find out the best formulations. The parameters used for PCA were the content of N, P, K, Ca, Mg and S of formulations. The PCA extracted 6 principal components.

The index values were calculated using the variables and PC 1 followed by the one-way analysis (completely randomized design) of the index values (Table 7). Among the formulations, F_1 has the highest mean value of 13.07 which was significantly higher than the other formulations. The formulation F_7 has the lowest mean value of 6.48. This indicates that the formulation F_1 (BM + RP + SOP + ES + B) is the best formulation among the 8 formulations with higher nutrient content while formulation F_7 (SM + SBM + SOP + ES + B) is the least favorable one with the lowest nutrient content.

Table 4. Nutrient content of multi-nutrient formulations

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})
F_1 (BM + RP + SOP + ES + B)	7.21^{a}	2.71^{a}	10.78^{a}	5.98^{a}	0.35^{c}	4.45^{d}	1174.11^{a}	4.53^{b}	13.55^{b}	8.65^{b}	93.67^{a}
F_2 (BM + RP + L + ES + B)	5.50^{c}	2.11^{b}	8.30^{b}	4.92^{b}	4.20^{a}	9.06^{a}	1079.71^{b}	3.72^{d}	11.71^{d}	7.71^{d}	71.00^{b}
F_3 (BM + SBM + SOP + ES + B)	7.11^{b}	2.68^{a}	10.68^{a}	2.05^{e}	0.32^{c}	4.37^{d}	1163.41^{a}	4.87^{a}	14.52^{a}	9.05^{a}	96.33^{a}
F_4 (BM + SBM + L + ES + B)	5.42^{d}	2.08^{b}	8.18^{c}	1.58^{f}	4.14^{a}	8.59^{b}	1023.04^{c}	4.02^{c}	12.71^{c}	8.08^{c}	73.33^{b}
F_5 (SM + RP + SOP + ES +B)	4.08^{fg}	1.42^{d}	5.58^{e}	4.46^{c}	0.23^{d}	3.14^{e}	294.46^{f}	1.72^{f}	4.26^{f}	3.93^{f}	63.00^{c}
F_6 (SM + RP + L + ES + B)	4.15^{e}	1.56^{c}	6.23^{d}	3.66^{d}	3.15^{b}	6.41^{c}	388.00^{d}	1.13^{g}	3.67^{g}	2.98^{h}	51.33^{d}
F_7 (SM + SBM + SOP + ES + B)	4.01^{g}	1.41^{d}	5.50^{e}	1.45^{f}	0.20^{d}	3.10^{e}	283.18^{f}	1.88^{e}	4.62^{e}	4.29^{e}	65.67^{c}
F_8 (SM + SBM + L + ES + B)	4.11^{ef}	1.54^{c}	6.19^{d}	1.15^{g}	3.10^{b}	6.35^{c}	336.52^{e}	1.24^{g}	3.94^{fg}	3.46^{g}	54.67^{d}
SE(m)	0.02	0.03	0.04	0.06	0.03	0.04	5.38	0.05	0.11	0.08	1.44
CD (0.05%)	0.07	0.08	0.11	0.17	0.08	0.11	16.14	0.14	0.33	0.24	4.33

Table 5. Biochemical properties of multi-nutrient formulations

Treatment	Lignin (%)	Crude fiber (%)	Crude protein (%)	Humic acid (%)	Fulvic acid (%)
F_1 (BM + RP + SOP + ES + B)	-	-	45.04^{a}	2.95^{a}	3.55^{a}
F_2 (BM + RP + L + ES + B)	-	-	34.35^{c}	2.67^{c}	3.30^{c}
F_3 (BM + SBM + SOP + ES + B)	-	-	44.44^{b}	2.83^{ab}	3.46^{ab}
F_4 (BM + SBM + L + ES + B)	-	-	33.85^{d}	2.73^{bc}	3.36^{bc}
F_5 (SM + RP + SOP + ES +B)	23.23^{a}	9.15^{a}	25.50^{fg}	1.91^{d}	2.61^{d}
F_6 (SM + RP + L + ES + B)	17.50^{c}	7.40^{c}	25.96^{e}	1.75^{e}	2.55^{de}
F_7 (SM + SBM + SOP + ES + B)	20.33^{b}	8.53^{b}	25.08^{g}	1.85^{de}	2.62^{d}
F_8 (SM + SBM + L + ES + B)	15.85^{d}	7.08^{c}	25.69^{ef}	1.72^{e}	2.42^{e}
SE(m)	0.36	0.19	0.15	0.05	0.04
CD(0.05%)	1.08	0.58	0.45	0.14	0.13

Table 6. Principal component analysis

Variables	PC1	PC2	PC3	PC4	PC5	PC6
N	-0.555	0.005	-0.14	0.223	-0.538	0.576
P	-0.552	0.069	-0.148	-0.039	-0.242	-0.78
K	-0.552	0.069	-0.152	-0.342	0.707	0.223
Ca	-0.259	-0.059	0.964	-0.026	0	-0.004
Mg	0.119	0.695	0.058	-0.635	-0.298	0.09
S	-0.027	0.71	0.054	0.654	0.251	-0.038

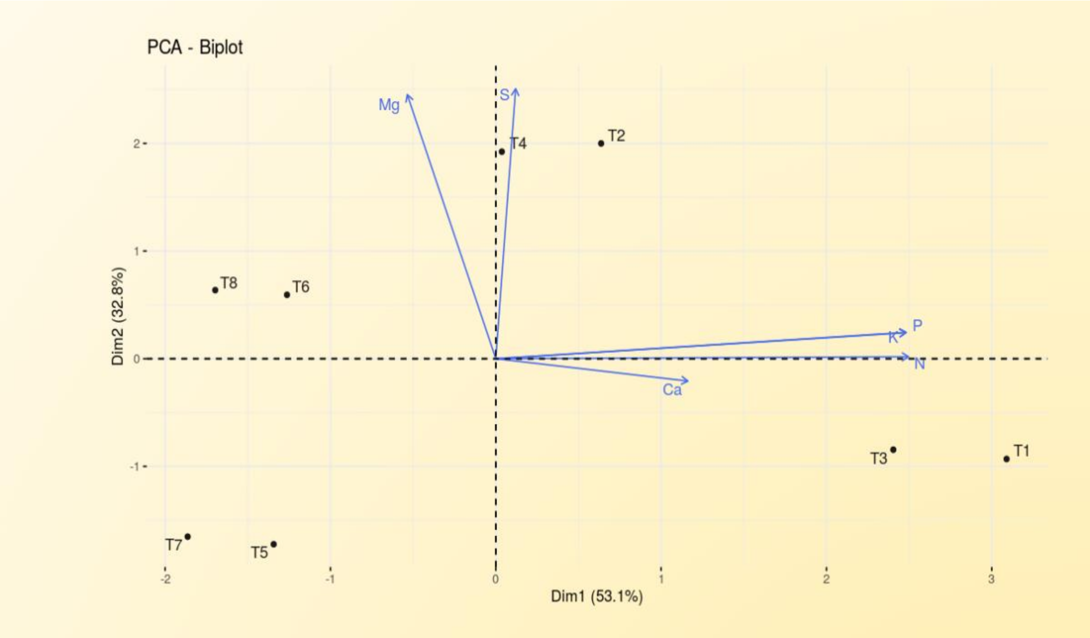

Plate 2. Principal component analysis biplot with nutrient content of organic multi-nutrient formulations

Table 7. One-way ANOVA of index values

Treatment	Mean
F_1	13.07^a
F_2	9.82^c
F_3	11.93^b
F_4	8.82^d
F_5	7.34^f
F_6	7.35^e
F_7	6.48^h
F_8	6.64^g
SE(m)	0.05
CD(0.05%)	0.16

4. CONCLUSION

The results of the characterization study have shown that all the multi-nutrient formulations prepared using organic nutrient sources permitted by NPOP have the ability to provide the essential major nutrients and micronutrients for plant growth and are suitable to use as nutrient sources in organic farming. However, after the conduct of PCA formulation F_1 containing blood meal + rock phosphate + potassium sulfate + epsom salt + borax was found to have superior quality followed by F_3 containing blood meal + steamed bone meal + potassium sulfate + epsom salt + borax. Formulation F_1 has optimum bulk density (3.73

Mg m^{-3}) and moisture content (2.67%). It has desirable electro-chemical properties with 6.5 pH, 3.23 dSm^{-1} EC and 29.43% organic carbon. It contains sufficient amount of nutrients with 7.21% N, 2.71% P, 10.78% K, 5.98% Ca, 0.35% Mg, 4.45% S,1174.11 mg kg^{-1} Fe, 4.53 mg kg^{-1} Mn, 13.55 mg kg^{-1} Zn, 8.65 mg kg^{-1} Cu and 93.67 mg kg^{-1} B. It also recorded the highest crude protein (45.04%), humic acid (2.95%) and fulvic acid (3.55%) content. The results indicate that multi-nutrient formulation F_1 can be recommended for nutrient management in organic farming.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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