Micronutrient diffusion behavior of nutrient pellets in acid sulphate soils

Abstract

Nutrient bias of acid sulphate soils with overabundance of oxides and sulphates of iron and aluminum fabricates acidic nature in soil as well as inadequacy of other essential nutrients. Crop production in acid sulphate soil is found challenging due to the deteriorating nutrient status hence, this soil is deemed as problem soil. This study aims to concoct a multinutrient pellet for the enhancement of nutrient status in acid sulphate soil, using nutrient sources permitted in National Programme for Organic Production. Laboratory incubation experiment was performed to evaluate the nutrient release characteristics of pellets for 60 days in completely randomized design with 8 treatments and 3 replications. Standard procedures were employed to analyze the nutrient composition of pellets and nutrient concentration of soil samples drawn at regular intervals. 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 electrical conductivity increased with days of incubation while organic carbon decreased. Nutrient availability surged from day 1 to 60 and the maximum was observed on 60thday of incubation. The blood meal-based pellets had the strong propensity to perpetuate and enhance the nutrient release to the soil in comparison with other pellets. Hence, the replacement of conventional fertilizers by organic multinutrient pellets can optimize the nutrient cachets of acid sulphate soils.

Keywords: Problem soils**,** nutrient management**,** multi-nutrient pellets, bloodmeal, rockphosphate

Introduction

Acid sulphate soils (cat clays) are one among the poorly drained soils in the world, where pyrite levels are significantly high (Neenu and Karthika, 2020). Hence these soils are classified under the order Entisols, great group Sulfaquents and sub group Typic Sulfaquents (Beena, 2005). Fe and Al toxicity of the soil (Thampatti *et al*., 2005) along with low inflow of water into the soil during the summer months (February-May) raises the acidity, salinity and shortage of water in this region (Aparna *et al*., 2020). Amelioration of soil acidity, regulated application of lime and fertilizers has been carried out over the years. Practice of liming enhanced the physical, chemical and biological properties of acid sulphate soils (Bolan *et al*., 2003) but increased use of chemical fertilizers resulted in the excessive accumulation of agrochemical residues (Srivastav, 2020). In acid sulphate soils, organic matter has a greater alkalizing impact as well as they produce organic acids, regulate moisture levels, recycle nutrients, increase soil fertility (Yan et al., 1996; Pocknee *et al*., 1997; Srivastav, 2020), breakdown hazardous components, improve soil structure and root growth (Han *et al.*, 2016).

Plethora of studies highlighted the importance of utilization of organic multinutrient pellets in crop production. Pellets are better for long-distance transportation, durable enough without disintegration, convenient to store, handle, transport, and uncomplicated to use in the field (Hara, 200; Suppadit, *et al*., 2009). Manure pellet using concentrated organic manure can supply large amount of nitrogen, phosphorous and calcium to the soil (Jeng *et al*., 2004). The development and productivity of rice are further impacted by the soil nitrogen shift by organic manure caused and changes to the microbial populations in the field (Su *et al*., 2015). Application of organic manure with blood meal could accord high bulky carbon to the soil that could improve the soil structure and microbial biomass (Datt *et al*., 2003; Conner, 2022). 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 and it also inhibited nitrification in acidic soil, which decreased nitrogen losses (Li *et al*., 2020). Langbeinite translocate sodium in high concentrations and it contains Mg and K ions that promote flocculation, kept electrolyte concentrations high (Tian *et al*., 2017; Day *et al*., 2019). This study delved into the development of multinutrient pellets for optimizing the nutrient availability in acid sulphate soil through a laboratory incubation study conducted in a controlled environment.

Materials and Methods

Preparation and characterization of pellets

Eight cylindrical organic multinutrient pellets of 1.3 cm diameter and 2cm length were fabricated using N-P-K nutrient sources approved under the National Programme for Organic Production (NPOP) taking into account the nutritional requirement of rice (N : P_2O_5 : K_2O – 90 : 45 : 45) and the fertility status of the experimental soil, using a pelletizing machine with proper moisture to keep the shape. 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 was used as binding agent.

Chemical properties such as pH and EC (Potentiometry Conductometry) organic carbon (Walkley and Black rapid titration method), total N (Macrokjeldahl distillation and titrimetry after extraction with 2 M KCl), P and K (Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using spectrophotometer for P and flame photometer for K), Ca and Mg (Diacid (HN O_3:HCl O_4 in the ratio 9:4) digestion and estimation using versanate titration method), S (Diacid (HN O_3:HCl O_4 in the ratio 9:4) digestion and turbidimetry), Fe, Mn, Zn, Cu (Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using atomic absorption spectrometry) and B (Spectrophotometry - Azomethine-H method).

Incubation experiment - nutrient release characterization

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 Kuttanad were 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. Samples were drawn at 15th, 30th, 45th, and 60thday of incubation, and analysis was done for the following parameters. Chemical parameters such as pH, EC (Potentiometry Conductometry), organic carbon (Walkley and Black rapid titration method), Available N (Alkaline potassium permanganate method- Kjelphus), Available P (Bray No.1 extraction and estimation using spectrophotometer), Available K (Neutral normal ammonium acetate extraction and estimation using flame photometer), Exchangeable Ca and Mg (Versanate titration method), available S ($CaCl_2$ extraction and estimation using spectrophotometer), B (Spectrophotometry - Azomethine-H method) and available Fe, Mn, Cu, and Zn (0.1 N HCl extraction and estimation using atomic absorption spectrometry).

Results and discussion

Experimental soil characterization

Initial characterization on physio-chemical and chemical properties conveyed that the experimental soil was strongly acidic (4.45) with meager EC (0.06 dS m^{-1}), but the soil had high OC content of 3.34% and moderate availability of N, P and K which was 362.6 Kg ha^{-1}, 25.6 Kg ha^{-1} and 184.5 Kg ha^{-1} respectively. Excess of secondary nutrients *viz.*, Ca, Mg and S and sufficiency of micronutrients *viz.*, Mn, Zn, Cu and B along with high concentration of Fe, were reported from experimental soil.

Table 1. Characterization of initial soil on physio-chemical and chemical properties

pH	EC (dS m^{-1})	OC (%)	N (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})	Ca (mg Kg^{-1})

4.45	**0.06**	**3.34**	**362.6**	**25.6**	**184.5**	**481**
Mg (mg Kg^{-1})	S (mg Kg^{-1})	B (mg Kg^{-1})	Fe (mg Kg^{-1})	Mn (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})
159	**18.4**	**0.48**	**291**	**2.68**	**1.51**	**1.17**

Pellet Characterization

Slightly acidic pH of P_1 (5.88), P_3 (5.77), P_6 (5.72), P_2 (5.67), P_7 (5.61) and P_4 (5.55) were closer to the neutrality (Table 2). Addition of organic compounds with blood meal increased the pH as the hexacoordinated Fe (III) present in blood meal coordinated by OH^- ion and by a Cl^- ion (Mavadati *et al.*, 2010; Citak *et al.*, 2011). Release of mineral salts from potassium langbeinite rooted the variations in electrical conductivity (EC) with highest in P_6 and it is followed by P_8, P_5 and P_2. Pellets were blazoned with high organic carbon in which P_1 (23.13 %) and P_2 (20.94 %) had higher concentration while total OC range managed to remain within 17.5% - 23.5%. The presence of blood meal contributed high organic matter content in pellet (Mavadati *et al.*, 2010).

Table 2. Chemical characterization of organic multi nutrient pellets

Pellets	**pH**	**EC (dSm^{-1})**	**B (mg kg^{-1})**	**Fe (mg kg^{-1})**	**Mn ($mgkg^{-1}$)**	**Zn ($mgkg^{-1}$)**	**Cu ($mgkg^{-1}$)**
Blood meal +Rock phosphate +Potassium sulphate (P_1)	5.88	1.41	1.18	254.03	37.37	23.62	4.38
Blood meal +Rock phosphate +Langbeinite (P_2)	5.67	1.62	1.09	325.37	32.48	19.73	3.67
Blood meal +Steamed bone meal +Potassium sulphate (P_3)	5.77	1.37	1.07	364.55	32.82	16.19	3.39
Blood meal +Steamed bone meal +Langbeinite (P_4)	5.55	1.58	1.18	265.82	19.24	18.56	4.30
Groundnut cake +Rock phosphate +Potassium sulphate (P_5)	5.38	1.49	1.12	190.77	42.22	23.23	2.67
Groundnut cake +Rock phosphate +Langbeinite (P_6)	5.72	1.79	1.08	176.00	17.82	22.79	5.84
Groundnut cake +Steamed bone meal +Potassium sulphate (P_7)	5.61	1.33	1.79	211.64	35.36	25.72	3.76
Groundnut cake +Steamed bone meal + Langbeinite (P_8)	5.49	1.69	1.88	192.82	35.50	22.83	4.44

On perusing micro nutrient content of eight pellets (Table 2), boron concentration of pellets existed in the range of 1.88 mg kg^{-1} – 1.07 mg kg^{-1}, where P_8 had the highest content. Highest Fe content was in P_3 with 364.55 mg kg^{-1} followed by P_2 (325.37 mg kg^{-1}) as these pellets fabricated with blood meal (Felipe *et al*., 2013). Slow release organic fertilizers are able to contain micronutrients in available form (Shaji *et al*., 2021), which can be appropriately applicable for Mn, Zn and Cu. Manganese content of pellets were in an order of P_5 (42.22 mg kg^{-1}) > P_1 (37.37 mg kg^{-1}) > P_8 (35.50 mg kg^{-1}) > P_7 (35.36 mg kg^{-1}) > P_3 (32.82 mg kg^{-1}) > P_2 (32.48 mg kg^{-1}) > P_4 (19.24 mg kg^{-1}) > P_6 (17.82 mg kg^{-1}), while Zn content in pellets occurred in the range of 25.72 mg kg^{-1} (P_7) to 16.19 mg kg^{-1} (P_3) and Cu content was found in the range of 5.84 mg kg^{-1} (P_6) - 2.67 mg kg^{-1} (P_5).

Nutrient release pattern of pellets

Soil pH and EC:

Soil pH was found to increase during the incubation days (Table 3), where P_1 reduced more acidity followed by pellets P_2 and P_6. Combined application of organic compounds elevates soil pH along the incubation period in acid soils, which is associated with the organic acid content of the manure (Pocknee *et al.*, 1997) and basic cation concentration availability in pellets and its slow release characters which is found consistent with other studies (Whalen *et al.*, 2000; Grybos *et al*., 2009; Stumm *et al.*, 2012).

Significant influence of organic multinutrient pellets on electrical conductivity was in shortfall until the 45^{th} day of incubation (Table 3). Higher concentration of dissolved solutes in an organically improvised soil - P_1 (0.187 dSm^{-1}) was able to create an influence on EC on the 60^{th} day and it was followed by P_4 (0.183) (Materechera and Mkhabela, 2002). Application of blood meal can influence the electrical conductivity of soil due to the presence of inorganic nitrogen (Conner, 2022). Similar trends in EC has observed by Fernandez-Sanjurjo *et al*. (2014) in a study with NPK fertilizer tablet.

Soil Organic Carbon:

Organic carbon benefactions from multinutrient pellets was found non-significant till 45^{th} day (Table 3), which causes minor fall in OC content on 60^{th} day, within a scale of 3.79% (P_1) to 3.59% (P_6). Utilization of manure along with blood meal contribute soil C due to inflated concentration of water-soluble carbon with days (Yunta *et al*., 2013; Fernandez-Sanjurjo *et al.*, 2014; Conner, 2022).

Soil available micronutrients:

Boron content was found increasing on each stage of incubation with the application of organic fertilizer (Fig 1). P_8 was having significantly higher value throughout the incubation intervals as readily available B continuously increases for more than 12 weeks (Ajayan and KC, 2021). The influence of pellet on Fe, Mn, Zn and Cu content in soil was crucial. Following the incubation phase, the Fe concentration steadily increased (Fig 2) where P_1 indicated a higher level of iron from the 15^{th} (324.94 mg kg^{-1}) to the 60^{th} (347.07 mg kg^{-1}) day of incubation. Application of organic fertilizers and blood meal containing organic compounds added more Fe to the soil (Ciavatta *et al*., 1997; Shaji *et al.*, 2021). Mn release was found higher in P_7, with 4.04 mg kg^{-1} on 15^{th} day and at the end of incubation, it was 5.57 mg kg^{-1} (Fig 3). According to Zinc, P_1 had significantly superior values during incubation phases and the inferior effect was expressed by P_7 (Fig 4). On the 15^{th} day available Cu was within a range of 1.64 mg kg^{-1} (P_6) to 1.35 mg kg^{-1} (P_5) which was gradually grown towards the 60^{th} day (Fig 5). On the application of organic fertilizers, the content of Mn, Zn and Cu exhibited gradual increase over time (Radhakrishnan and Suja, 2019; Wan *et al.*, 2020; Ramos *et al*., 2021).

Table 3. Impact of organic multinutrient pellets on pH, EC and Organic Carbon in soil

Treatment	**Period of Incubation (days)**							
	pH				**EC (dSm^{-1})**			
	15	**30**	**45**	**60**	**15**	**30**	**45**	**60**
Blood meal +Rock phosphate +Potassium sulphate (P_1)	5.1	5.21	5.33	5.4	0.123	0.163	0.207	0.187
Blood meal +Rock phosphate +Langbeinite (P_2)	5.13	5.27	5.32	5.39	0.143	0.153	0.193	0.173
Blood meal +Steamed bone meal +Potassium sulphate (P_3)	5.06	5.2	5.3	5.38	0.137	0.153	0.193	0.173
Blood meal +Steamed bone meal +Langbeinite (P_4)	5.1	5.24	5.3	5.37	0.133	0.167	0.203	0.183
Groundnut cake +Rock phosphate +Potassium sulphate (P_5)	5.05	5.19	5.29	5.36	0.133	0.137	0.177	0.147
Groundnut cake +Rock phosphate +Langbeinite (P_6)	5.14	5.28	5.33	5.37	0.117	0.153	0.193	0.163
Groundnut cake +Steamed bone meal +Potassium sulphate (P_7)	5.06	5.21	5.29	5.39	0.12	0.143	0.183	0.153
Groundnut cake +Steamed bone meal + Langbeinite (P_8)	5.1	5.24	5.32	5.36	0.123	0.14	0.18	0.15
SEm (±)	0.015	0.01	0.008	0.008	0.008	0.008	0.008	0.008
CD (0.05)	0.031	0.029	0.025	0.024	NS	NS	NS	0.023

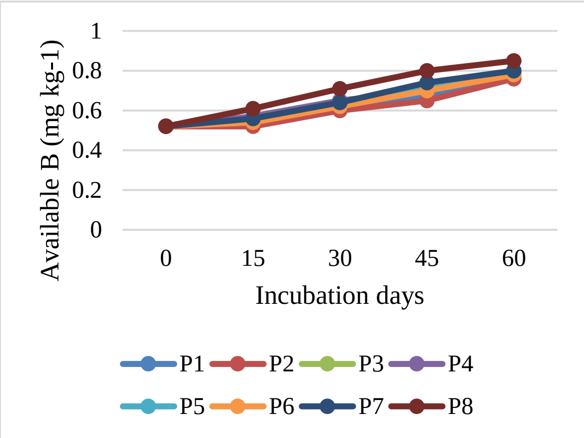

Fig 1. Release pattern of organic multinutrient pellets on available B in soil

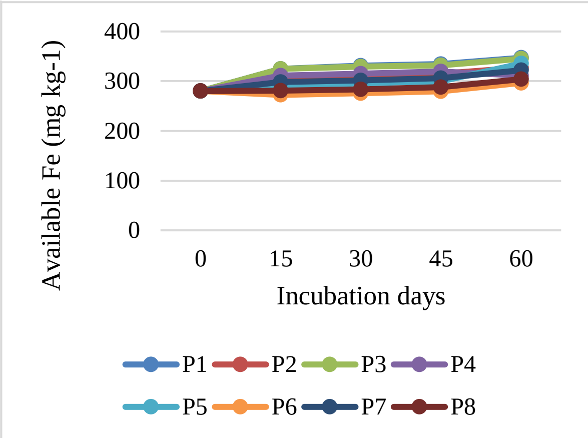

Fig 2. Release pattern of organic multinutrient pellets on available Fe in soil

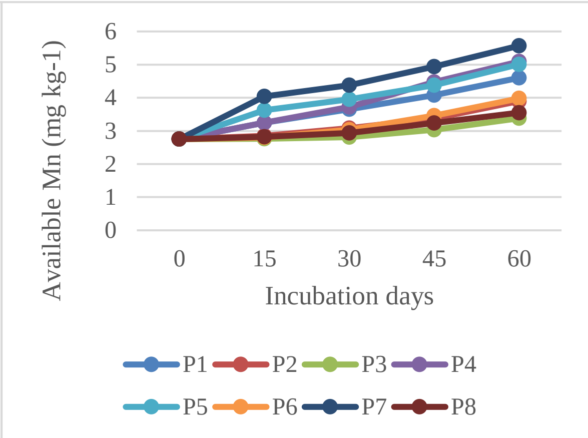

Fig 3. Release pattern of organic multinutrient pellets on available Mn in soil

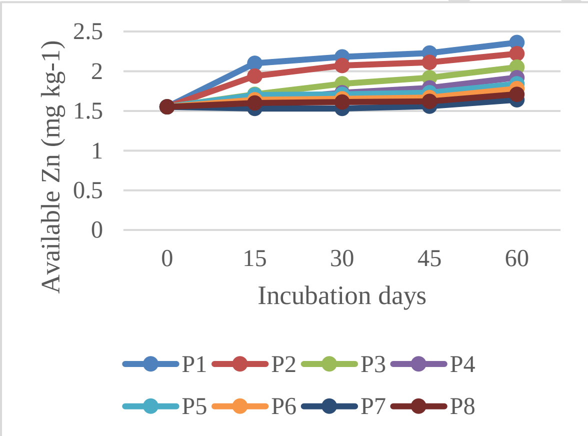

Fig 4. Release pattern of organic multinutrient pellets on available Zn in soil

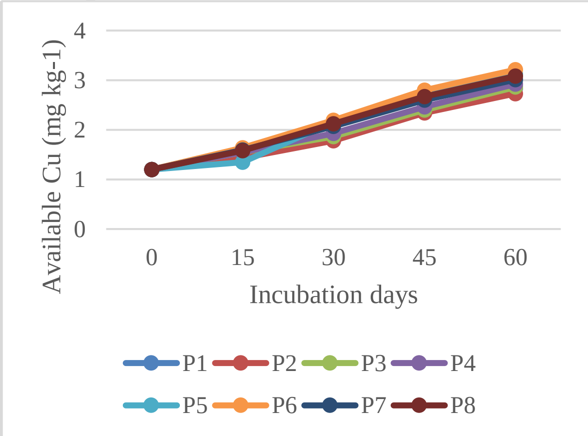

Fig 5. Effect of organic multinutrient pellets on available Cu in soil

Conclusion

The application of organic multinutrient pellets, particularly formulations P_1(Blood meal +Rock phosphate +Potassium sulphate), P_2 (Blood meal +Rock phosphate + Lanbeinite), and P_6 (Groundnut cake +Rock phosphate +Langbeinite), significantly influenced the availability of essential micronutrients in the soil during the incubation period. The observed increase in soil pH indicates that these pellets effectively reduced acidity, enhancing the overall nutrient composition, which is critical for plant growth in acid sulfate soils. The steady rise in iron (Fe) content was most pronounced in P_1 suggesting that organic compounds and blood meal within the pellets contributed to enhanced Fe availability. Manganese (Mn) levels were higher in P_7 (Groundnut cake +Steamed bone meal +Potassium sulphate) indicating its efficient release from organic sources during the incubation. Additionally, P_1 exhibited superior zinc (Zn) concentrations, while copper (Cu) content showed a gradual increase across treatments, with P_6. Furthermore, the observed increase in bioavailable sulfur (S) and boron (B) content underscores the synergistic effects of these organic multinutrient pellets in optimizing nutrient composition. Overall, the relationship between organic pellet formulations and soil parameters highlights their critical role in improving micronutrient availability, which is essential for sustainable agricultural practices and soil health in acid sulfate environments.

References

Ajayan A S and KC M T. 2021. Boron dynamics in red loam soil amended with different organic fertilizers. *International Collegiate Journal of Science*. 9(1): 1071-1076.

Aparna B, Gladis R, Aryanath V and Thampatti K C M. 2020. Studies on the Acid Sulphate Soils of Kuttanad of Kerala. *Indian Journal of Pure & Applied Biosciences*. 8(2): 421-428.

Beena,V I. 2005 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. 207p.

Bolan N S, Adriano D C and Curtin D. 2003. Soil acidification and liming interactions. In: Donald L. Sparks (ed.) *Advances. in Agronomy*. 78: 215-72.

Ciavatta C, Govi, M, Sitti L and Gessa C. 1997. Influence of blood meal organic fertilizer on soil organic matter: A laboratory study. *Journal of plant nutrition*. 20:1573-1591.

Citak S and Sahriye S. 2011. Effects of chemical fertilizer and different organic manure application on soil pH, EC and organic matter content. *Journal of Food, Agriculture and Environment*. *9*(3): 739-741.

Conner J P. 2022. The Effects of Biochar and Reactive Iron Additions on Soil Carbon and Nitrogen Retention (Doctoral dissertation, Virginia Tech). 94

Datt N, Sharma R P and Sharma G D. 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 Journal of Agricultural Sciences*. 73: 266-268.

Day S J, Norton J, Strom C F, Kelleners T J and Aboukila EF. 2019. Gypsum, langbeinite, sulfur, and compost for reclamation of drastically disturbed calcareous saline–sodic soils. *International journal of environmental science and technology*. 16(1): 295-304.

Felipe Y, Violeta B D, Manuel M C, Paola T, Sandra L R, Anna T, Krisztina K, Zoltán K, Ferenc F and Domenico R A. 2013. Blood Meal-Based Compound. Good Choice as Iron Fertilizer for Organic Farming. *Journal of Agricultural and Food Chemistry*. 61(17): 3995-4003.

Fernandez-Sanjurjo M J, Alvarez-Rodriguez E, Nunez-Delgado A, Fernandez-Marcos,M L and Romar-Gasalla A. 2014. Nitrogen, phosphorus, potassium, calcium and magnesium release from two compressed fertilizers: column experiments. *Solid Earth*. 5(2): 1351-1360.

Grybos M, Davranche M, Gruau G, Petitjean P and Pédrot M. 2009. Increasing pH drives organic matter solubilization from wetland soils under reducing conditions. *Geoderma*. 154(1-2):13-9.

Han S H, A J Y, Hwang J, Kim S B and Park B B. 2016 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 Technolnology*.12(3):137-143.

Hara M. Fertilizer pellets made from composted livestock manure. 2001. Food and Fertilizer Technology Center for the Asian and Pacific Region. 506: 1-12.

Jeng A, Haraldsen T and Vagstad N. 2004. Meat and bone meal as nitrogen fertilizer to cereals in Norway. *Agricultural and Food Science*. 13(3):268-75.

Klencsár Z, Fodor F and Rombolà A D. 2013. Blood meal-based compound. Good choice as iron fertilizer for organic farming. *Journal of Agricultural and Food Chemistry*. 61(17): 3995-4003.

Li Z, Xia S, Zhang R, Zhang R, Chen F, Liu Y. N_2O emissions and product ratios of nitrification and denitrification are altered by K fertilizer in acidic agricultural soils. *Environmental Pollution*. 265:115065.

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): 1-10.

Materechera S A and Mkhabela T S. 2002. 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*. 85(1): 9-16.

Mavadati S, Kianmehr M H, Alahdadi I, Chegini G R. 2010. Preparation of pellets by urban waste compost. *International Journal of Environmental Research*. 4(4): 665-672.

Neenu S and Karthika K S. 2020. Kuttanad soils: the potential acid sulphate soils of Kerala. *Harit Dhara* .3(2):19-23.

Pocknee S and Sumner M E 1997 Cation and nitrogen contents of organic matter determine its soil liming potential. *Soil Science Society of America Journal*. 61(1):86-92.

Radhakrishnan A R S and Suja G. 2019. Nutrient release pattern of organic and inorganic resources used in cassava production (*Manihot esculenta* Crantz). *Journal of Plant Nutrition*. 42(11-12):1301-15.

Ramos M L, Moscuzza C H and Fernández-Cirelli A. 2021. Zinc and copper plant uptake in soils amended with feedlot manure or soluble salts. *Journal of Applied Biological Sciences*. 15(1):37-52.

Shaji H, Chandran V and Mathew L. 2021. Organic fertilizers as a route to controlled release of nutrients. In Controlled release fertilizers for sustainable agriculture Academic Press. 231-245.

Srivastav A L. 2020. Chemical fertilizers and pesticides: role in groundwater contamination. In Agrochemicals detection, treatment and remediation. Butterworth-Heinemann. 143-159.

Stumm W and Morgan J J. 2012. Aquatic chemistry: Chemical equilibria and rates in natural waters. *John Wiley & Sons*. 625p

Su J Q, Ding L J, Xue K, Yao H Y, Quensen J, Bai S J, Wei W X, Wu J S, Zhou J, Tiedje J M and Zhu YG. 2015. Long-term balanced fertilization increases the soil microbial functional diversity in a phosphorus-limited paddy soil. *Molecular ecology*. 24(1):136-50.

Suppadit, T. 2009. Effect of pelleting process on fertilizing values of broiler litter. *International Society for Southeast Asian Agricultural Sciences*. 15(2): 136-146.

Thampatti K C M, Cherian S, Iyer M S. 2005. Managing iron toxicity in acid sulphate soils by integrating genetic tolerance and nutrition. *International Rice Research Notes*. 30:37-39.

Tian X F, Li C L, Zhang M, Lu Y Y, Guo Y L, Liu L F. 2017. Effects of controlled-release potassium fertilizer on available potassium, photosynthetic performance, and yield of cotton. *Journal of Plant Nutrition and Soil Science*.180 (5):505-15.

Wan Y, Huang Q, Wang Q, Ma Y, Su D, Qiao Y, Jiang R and Li H. 2020. Ecological risk of copper and zinc and their different bioavailability change in soil-rice system as affected by biowaste application. *Ecotoxicology and Environmental Safety*. 192:110301.

Whalen J K, Chang C, Clayton G W, Carefoot J P. 2000. Cattle manure amendments can increase the pH of acid soils. *Soil Science Society of America Journal*. 64(3): 962-6.

Yan F, Schubert S, Mengel K. 1996. Soil pH changes during legume growth and application of plant material. *Biology and Fertility of Soils*. 23:236-42.