Original Research Article

Carbon and Zeolite based Slow Release Fertilizer Formulations Enhances Nutrient Use Efficiency and Yield in Chilli

.

ABSTRACT

Aims: To develop slow release fertilizer formulations using humic acid, charcoal and zeolite and to evaluate nutrient availability, nutrient use efficiency and yield in chilli.

Study design: This experiment was conducted through completely randomized design with 14 treatments and 3 replications.

Place and Duration of Study: The research was appraised at the Department of Soil Science, College of Agriculture, Vellayani between September 2022- December 2022.

Methods: Carbon and zeolite based slow release fertilizer formulations (SRF) containing all the major, secondary and micronutrients were prepared using compatible fertilizer materials (urea, rajphos, muriate of potash, phosphogypsum, magnesium sulphate, zinc sulphate and borax), carrier materials (zeolite, humic acid and charcoal) and the binding agent (carboxy methyl cellulose) in the ratio of 1:1 and 1: 0.5 in the form of pellets. These formulations were applied to chilli and evaluated nutrient use efficiency and yield.

Results: The pellets were highly stable and weight ranged between 4.0 and 4.5 g. The highest fruit yield of chilli observed was 581.2 g/ plant. The available nitrogen (320.86 kg ha^{-1}), phosphorus (87.15 kg ha^{-1}), potassium (214.35 kg ha^{-1}), calcium (351.13 mg kg^{-1}), magnesium (106.54 mg kg^{-1}), sulphur (9.32 mg kg^{-1}), boron (0.46 mg kg^{-1}) and zinc (4.25 mg kg^{-1}) was found to be highest in treatment receiving 75 % recommended dose of fertilizers (RDF) as humic acid based slow release formulation applied in two splits (basal and 1 MAP). The apparent recovery percentage of nitrogen 78.2 %, phosphorus 86.33 % and potassium 98.70 % and partial factor productivity of 25.98 g g^{-1} were recorded due to the application of pellets.

Conclusion: Carbon and zeolite based slow release fertilizer formulations in the form of pellets are very effective compared to conventional fertilizers due to their gradual pattern of nutrient release which better meets plant demand, minimizes leaching and therefore nutrient use efficiency and ultimately crop yield. Application of slow release formulations significantly increases the nutrient availability in soil, nutrient use

efficiency, growth and yield of chilli.

1. INTRODUCTION

Agriculture is very important for people all over the world for providing food to the massively by increased population. This, in turn, leads to significant rise in fertilizers usage to improve soil fertility and to increase yields. However, the indiscriminate and uncontrolled use of fertilizers contributes not only to the degradation of soil quality but also to the leaching loss of nutrients due to the high solubility of fertilizers. Conventional fertilizers have low nutrient uptake efficiencies and are often associated with high losses to the environment and effects negative consequences. Nutrient use efficiency of fertilizer is very low due to numerous pathways of losses such as leaching, volatilization, denitrification, microbial immobilization and runoff. The key point of crop fertilization is to avoid nutrient losses and synchronize the nutrient availability with its uptake by crop.

Smart fertilizers based on slow-/controlled-release and/ or carrier delivery system have been shown to improve crop yields, soil productivity and lower nutrient loss compared with conventional fertilizers [1]. Several materials such as clays (zeolite, bentonite, montmorillonite), carbon material like charcoal, biochar and humic acid are suitable for development of smart fertilizers acting as a carrier for nutrients. Most of the common extensively used fertilizers are highly water soluble. When such materials are used in cultivation, particularly in a state like Kerala, where rainfall is well distributed and heavy, only very low efficiency could be expected on account of several losses. Smart fertilizers like slow release fertilizer is the novel technology to enhance the nutrient use efficiency, thereby improving crop yield in sustainable manner.

Therefore, the natural materials such as clay, zeolite, humic acid, charcoal / biochar carbon and their nano sizes are suitable for development of smart fertilizers acting as carrier matrices for nutrients.. Zeolite due to their special crystalline structure, have excellent adsorption, ion exchange and catalytic properties. Zeolite have large surface area and porous and keep nutrients in porous structure and release slowly. They are negatively charged and they adsorb positively charged ions and temporally bind it and slowly release nutrients [2]. The charcoal carbon and humic acid are very strong in capacity of adsorbing and maintaining nutrients and moisture, and furthermore, has an effect of stimulating the growth of crops and a good slow-release performance for the nitrogen, phosphorus and potassium [3]. In the present study natural zeolite, humic acid and charcoal based multi nutrient slow release fertilizers which release nutrients slowly over a longer period of time were developed and evaluated in chilli.

2. MATERIAL AND METHODS

2.1 Development and Characterization of Slow Release Fertilizer Formulations

Carbon and zeolite based slow release fertilizer formulations containing major, secondary and micro nutrients were prepared using compatible fertilizer sources (urea, rajphos, muriate of potash, phophogypsum, magnesium sulphate, zinc sulphate and borax), carrier materials (zeolite, charcoal and humic acid) and binding agents (carboxy methyl cellulose). Formulations were prepared in the ratio of 1:1 and 1: 0.5 (fertilizer mix: carrier + binding agent). Multinutrient fertilizer mix was prepared with urea (22 g), rajphos (25 g), MOP (6.0 g), Magnesium sulphate (12.0 g), phosphogypsum (25.0 g), zinc sulphate (6.0 g), borax (3.0 g) based on soil nutrient status and crop nutrient requirements. The formulations was prepared in the form of pellets using pelleting machine by compaction process, [4] with 2.5 cm height, 2 cm in diameter and 4 to 4.5 g weight. The pellets prepared are P1 (Fertilizer mix: zeolite+ carboxy methyl cellulose-1:0.5), P2 (Fertilizer mix: humic acid + carboxy methyl cellulose-1:0.5) and P3 (Fertilizer mix: charcoal+ carboxy methyl cellulose- 1:1) (plate. 1). The stability, disintegration time, nutrient content, pH, EC, moisture content and bulk density of these pellets were analysed using standard procedures.

(FM: zeolite+ CMC 1:0.5)

(FM: humic acid+ CMC 1:0.5)

(FM: charcoal+ CMC 1:1)

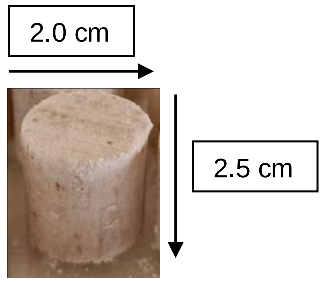

Plate 1. Prepared slow release fertilizer pellets

2.2 Evaluation of Slow Release Formulations in Chilli

A pot culture experiment was carried out at College of Agriculture, Vellayani during September 2022 with chilli variety Vellayani Athulya as test up to evaluate the effect of these pellets on nutrient availability in soil**,** nutrient use efficiency, growth and yield. Slow release fertilizer formulations were applied at 2 levels viz., 75 and 100 % of recommended dose of fertilizers and were compared with package of practice recommendation of Kerala Agricultural University, 2016 and absolute control. The design was CRD with 14 treatments and 3 replications. The required quantity of nutrients as per the levels of 75 % and 100% of recommended dose of fertilizers for each plant was satisfied with 6 and 8 pellets respectively. The pellets were placed at a depth of 5 cm and a distance of 5 cm away from the root zone. The soil samples collected from the pot experiment were analysed for pH, EC, organic carbon, nutrients such as N, P, K, Ca, Mg, S, Zn and B as per standard procedures. The biometric observations viz., plant height, number of fruits per plant and yield were recorded. The results of various parameters obtained from experiments were analysed statistically for the test of significance by standard procedures using GRAPES software.

3. RESULTS AND DISCUSSION

3.1 Pellet Characterization

3.1.1 Properties of slow release fertilizer pellets

Properties of slow release fertilizer pellets (Table 1) revealed that the pellets prepared were hard and highly stable, their disintegration time varied from 10 to 11 hours and were non hygroscopic. The pH was found to be acidic (6.4 to 6.59).The acidic nature of slow release formulation might be due to the presence of acidic ions. [5] observed that the pH of leachate from controlled release fertilizers was found to be variable but constantly acidic this might be due to the influence of fertilizers used. Electrical conductivity varied between 18.45 (P3) to 23.10 dS m^{-1}(P1). This might be attributed to the presence of soluble salts in the formulations from fertilizers used. An increased in electrical conductivity of leachates from controlled release fertilizers is reported by [5] due to the release of dissolved salts from the fertilizers. The moisture content of the pellets ranged from 8.61% (P1) to 7.35 % (P3). The bulk density varied between 0.53 and 0.57 Mg m^{-3}.

3.1.2 Nutrient content of pellets

Nutrient content in the pellets are depicted in the Table 2. The pellet contains 8.38 to 8.63 % nitrogen, 5.36 to 5.84% phosphorus, 3.31 to 3.41 % potassium, 5.40 to 5.62 % calcium, 2.01 to 2.75 % magnesium, 4.20 to 5.20 % sulphur, 0.17 to 0.23% boron and 1.2 to 1.5 % zinc. The highest concentration of nitrogen was recorded in P2 (8.63 %), this might be due to presence of high nitrogen content in humic acid used in the formulation. Similar results were reported by [6] in a multinutrient fertilizer tablets which contained 8.42 % nitrogen, 4.67 % phosphorus and 2.43 % potassium content. Phosphorus content was highest in P1 (5.84 %) which might be contributed from zeolite used which contained about 2.54 % phosphorus.

Table 1. Properties of slow release fertilizer pellets

Pellets	Stability	Disintegration time (hours)	Hygroscopicity	pH	EC (dS m^{-1})	Moisture content (%)	BD (Mg m^{-3})
P1	Highly stable	11	Nil	6.40	23.10	8.61	0.57
P2	Highly stable	10	Nil	6.48	20.15	7.20	0.53
P3	Highly stable	10	Nil	6.59	18.45	7.35	0.57

**P1 (Fertilizer mix: zeolite+ carboxy methyl cellulose-1:0.5), P2 (Fertilizer mix: humic acid + carboxy methyl cellulose-1:0.5) and P3 (Fertilizer mix: charcoal+ carboxy methyl cellulose- 1:1).*
BD- Bulk density

Table 2. Nutrient content in slow release fertilizer pellets

Pellets	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (%)	B (%)
P1	8.38	5.84	3.31	5.62	2.75	5.20	1.5	0.23
P2	8.63	5.66	3.40	5.68	2.86	5.30	1.6	0.22
P3	8.42	5.36	3.41	5.40	2.01	4.20	1.2	0.17

**P1 (Fertilizer mix: zeolite+ carboxy methyl cellulose-1:0.5), P2 (Fertilizer mix: humic acid + carboxy methyl cellulose-1:0.5) and P3 (Fertilizer mix: charcoal+ carboxy methyl cellulose- 1:1).*

3.2 Evaluation of Slow Release Formulations in Chilli

3.2.1 Nutrient availability in soil

The available nutrients in soil were significantly influenced by the application of different slow release fertilizer formulations (Table 3). The available nitrogen (320.86 kg ha^{-1}), phosphorus (87.15 kg ha^{-1}), potassium (214.35 kg ha^{-1}), calcium (351.13 mg kg^{-1}), magnesium (106.54 mg kg^{-1}), sulphur (9.32 mg kg^{-1}), boron (0.46 mg kg^{-1}) and zinc (4.25 mg kg^{-1}) was found to be the highest in treatment T_8 receiving 100 % recommended dose of fertilizers as slow release containing FM : HA+CMC in the ratio 1:0.5, which was followed by T_6 receiving 100% of RDF as slow release fertilizer formulation applied in two splits (basal&1 MAP) both were found to be on par. This might be due to the gradual release of nutrients from the pellets and also to the nutrient content and adsorption capacity of carriers that gradually increased the availability in soil [7, 8, 9]. [10] reported that soil available nutrients was increased by the application of zeolite based slow release fertilizer.

Table 3. Effect of slow release fertilizer formulations on nutrient availability in soil

Treatment	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	Zn (mg kg^{-1})	B (mg kg^{-1})
T_1	304.4	78.34	192.3	302.2	99.85	6.45	4.02	0.39
T_2	317.7	84.11	210.5	342.1	104.1	7.69	4.15	0.42
T_3	303.5	76.03	190.5	301.1	98.42	5.91	3.97	0.37
T_4	314.3	82.53	209.0	325.1	103.5	7.45	4.12	0.41

T_5	311.9	81.45	206.8	320.3	102.7	7.21	4.09	0.40
T_6	318.1	85.66	213.4	346.0	105.0	8.53	4.21	0.44
T_7	308.3	81.00	205.4	317.5	101.6	6.86	4.05	0.40
T_8	320.8	87.15	214.3	351.1	106.5	9.32	4.25	0.46
T_9	286.8	69.19	177.0	282.1	96.09	5.55	3.92	0.30
T_{10}	295.4	71.22	181.9	296.4	98.00	5.83	3.85	0.34
T_{11}	254.7	69.01	176.8	276.2	96.00	5.41	3.90	0.31
T_{12}	297.2	73.59	185.7	297.5	98.00	6.42	3.95	0.35
T_{13}	307.3	80.11	205.6	303.8	99.10	5.16	3.87	0.29
T_{14}	165.6	51.12	80.10	210.0	42.58	2.12	1.00	0.11
SEm (±)	8.51	1.99	6.33	1.88	1.89	0.08	0.05	0.02
CD(0.05)	24.53	5.97	18.92	14.47	5.489	0.24	0.13	0.05

**T*$_1$ (100% RDF as FM:Z+CMC-1:0.5 applied as basal), T_2 (100% RDF as FM:Z+CMC-1:0.5 applied in two splits (basal & 1 MAP), T_3 (75% RDF as FM:Z+CMC-1:0.5 applied as basal), T_4 (75% RDF as FM:Z+CMC-1:0.5 applied in two splits (basal & 1 MAP), T_5 (100% RDF as FM:HA+CMC-1:0.5 applied as basal), T_6 (100% RDF as FM:HA+CMC-1:0.5 applied in two splits (basal & 1 MAP), T_7 (75% RDF as FM:HA+CMC-1:0.5 applied as basal), T_8 (75% RDF as FM:HA+CMC-1:0.5 applied in two splits (basal & 1 MAP), T_9 (100% RDF as FM:CHAR+CMC-1:1 applied as basal), T_{10} (100% RDF as FM:CHAR+CMC-1:1 applied in two splits (basal & 1 MAP), T_{11} —75% RDF as FM:CHAR+CMC-1:1 applied as basal), T_{12} (75% RDF as FM:CHAR+CMC-1:1 applied in two splits (basal & 1 MAP), T_{13} (Soil test based KAU POP recommendation), T_{14} (Control).*

3.2.2 Growth and yield parameters

The growth and yield of chilli was significantly influenced due to the application of slow release fertilizer formulations (Table 3). The maximum plant height (56.52 cm) and number of fruits per plant (52.70) were obtained from the treatment T_8 receiving 75 % of recommended dose of fertilizers as slow release fertilizer formulation FM:HA+CMC(1:0.5) applied in two splits (basal & 1MAP). The maximum yield of 581.2 g per plant was also recorded in the same treatment which was on par with T6 receiving 100% RDF as FM:HA+CMC-1:0.5 applied in two splits (basal & 1 MAP (506.5 g per plant) and were found to be significantly superior over all other treatments. The yield and yield attributes was significantly influenced by the slow release fertilizer formulations due to the higher nutrient use efficiency and plant growth [11]. [12] reported highest growth in maize by using humic acid based slow release fertilizer. The effect of humic acid multinutrient fertilizers on growth parameters of potato was reported by [13]. Highest yield were also reported in apple [14], soybean [15] and [16] due to application of humic acid multinutrient complex fertilizers.

Table 4. Effect of slow release fertilizer formulations on growth and yield in chilli

Treatments	Plant height (cm)	Number of fruits per plant	Yield (g per plant)
T_1	44.57	33.69	261.7
T_2	51.65	44.60	469.1
T_3	43.76	33.15	211.8
T_4	49.29	42.13	450.7
T_5	47.29	39.65	372.3
T_6	53.14	46.64	506.5
T_7	46.40	37.69	343.3
T_8	56.52	52.70	581.2

T_9	42.56	30.66	165.8
T_{10}	42.76	31.14	178.7
T_{11}	41.48	29.87	153.5
T_{12}	43.14	32.59	199.1
T_{13}	44.92	35.58	314.8
T_{14}	37.88	26.24	124.64
SEm (±)	1.15	0.86	15.10
CD(0.05)	3.333	2.59	45.31

**T_1 (100% RDF as FM:Z+CMC-1:0.5 applied as basal), T_2 (100% RDF as FM:Z+CMC-1:0.5 applied in two splits (basal & 1 MAP), T_3 (75% RDF as FM:Z+CMC-1:0.5 applied as basal), T_4 (75% RDF as FM:Z+CMC-1:0.5 applied in two splits (basal & 1 MAP), T_5 (100% RDF as FM:HA+CMC-1:0.5 applied as basal), T_6 (100% RDF as FM:HA+CMC-1:0.5 applied in two splits (basal & 1 MAP), T_7 (75% RDF as FM:HA+CMC-1:0.5 applied as basal), T_8 (75% RDF as FM:HA+CMC-1:0.5 applied in two splits (basal & 1 MAP), T_9 (100% RDF as FM:CHAR+CMC-1:1 applied as basal), T_{10} (100% RDF as FM:CHAR+CMC-1:1 applied in two splits (basal & 1 MAP), T_{11} —75% RDF as FM:CHAR+CMC-1:1 applied as basal), T_{12} (75% RDF as FM:CHAR+CMC-1:1 applied in two splits (basal & 1 MAP), T_{13} (Soil test based KAU POP recommendation), T_{14} (Control).*

3.2.3 Nutrient use efficiency

The nutrient use efficiency of slow release fertilizer formulations are given in figure 1 and 2. The treatment T_8 receiving 75% of recommended dose of fertilizers as slow release fertilizer formulation FM:HA+CMC-1:0.*5* applied in two splits (basal+1MAP) recorded the highest agronomic efficiency for nitrogen (32.86 g g^{-1}), phosphorus (61.61 g g^{-1}) and potassium (98.58 g g^{-1}) which was found to be on par with T_6. With respect to apparent nutrient recovery the highest recovery percentage was recorded by T_6 for N (78.2 %), P (86.33 %) and K (98.70 %). Application of slow release fertilizer formulations in the form of pellets might have enhanced the nutrient use efficiencies due to the high adsorption and sustained release capacity of carrier materials used [13, 17, 18].

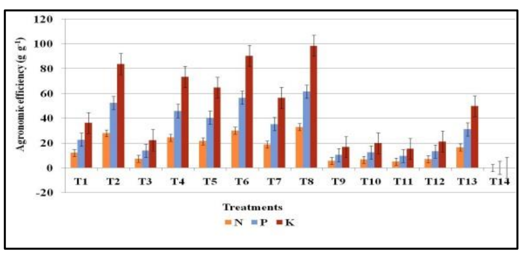

Fig 1. Effect of slow release fertilizer formulation on agronomic efficiency

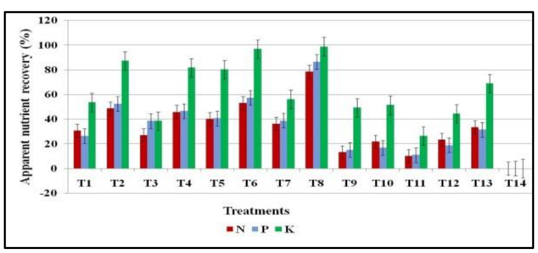

Fig 2. Effect of slow release fertilizer formulation on apparent recovery

4. CONCLUSION

Carbon and zeolite based slow release fertilizer formulations in the form of pellets are very effective compared to conventional fertilizers due to their gradual release pattern of nutrients which better meets plant demand, minimizes leaching and therefore fertilizer use efficiency and ultimately crop yield. Application of slow release formulations prepared with fertilizer mix: humic acid + CMC in the ratio 1:0.5 significantly increased the nutrient availability in soil, NUE, growth and yield of chilli.

REFERENCES

1. Karthik A, Maheswari MU. Smart fertilizer strategy for better crop production. Agricultural Reviews. 2021;42(1):12-21.
2. Mihok F, Macko J, Oriňak A, Oriňaková R, Kovaľ K, Sisáková K, Petruš O, Kostecká Z. Controlled nitrogen release fertilizer based on zeolite clinoptilolite: Study of preparation process and release properties using molecular dynamics. Current Research in Green and Sustainable Chemistry. 2020;3:200-209.
3. Yu L, Lu X, He Y, Brookes PC, Liao H, Xu J. Combined biochar and nitrogen fertilizer reduces soil acidity and promotes nutrient use efficiency by soybean crop. Journal of Soils and Sediments. 2017;17:599-610.
4. Agustina TE, Rizky I, Utama ME, Amal MI. Characterization and utilization of zeolite for NPK slow release fertilizer (research note). International Journal of Engineering. 2018;31(4):622-8.
5. Merhaut DJ, Blythe EK, Newman JP, Albano JP. Nutrient release from controlled-release fertilizers in acid substrate in a greenhouse environment: leachate electrical conductivity, pH, and nitrogen, phosphorus, and potassium concentrations. Hort. Science. 2006;41(3):780-7.
6. Navya M. P. Development of multinutrient fertilizer tablet and evaluation in chilli. Department of Soil Science and Agricultural Chemistry. Kerala Agricultural University. 2019.
7. Budiono MN, Rif'an M. The effects of zeolite-based slow-release nitrogen fertilizer and sulfur on the dynamics of N, P, K, and s soil nutrients, growth and yield of shallot (Allium Cepa L.). In 2nd and 3rd International Conference on Food Security Innovation (Icfsi 2018-2019) 2021(Pp. 288-292). Atlantis Press.
8. Kharisun K, Rif'an M, Budiono MN, Kurniawan RE. Development and testing of zeolite-based slow release fertilizer nzeo-sr in water and soil media. Sains Tanah-Journal of Soil Science and Agroclimatology. 2017;14(2):72-82.
9. Bansiwal AK, Rayalu SS, Labhasetwar NK, Juwarkar AA, Devotta S. Surfactant-modified zeolite as a slow release fertilizer for phosphorus. Journal of Agricultural and Food Chemistry. 2006;54(13):4773-9.
10. Soltys L, Myronyuk I, Tatarchuk T, Tsinurchyn V. Zeolite-based composites as slow release fertilizers. Physics and Chemistry of Solid State. 2020;21(1):89-104.
11. Morgan KT, Cushman KE, Sato S. Release mechanisms for slow-and controlled-release fertilizers and strategies for their use in vegetable production. Hort. technology. 2009;19(1):10-2.
12. Guo Y, Ma Z, Ren B, Zhao B, Liu P, Zhang J. Effects of humic acid added to controlled-release fertilizer on summer maize yield, nitrogen use efficiency and greenhouse gas emission. Agriculture. 2022;12(4):448.
13. Selladurai R, Purakayastha TJ. Effect of humic acid multinutrient fertilizers on yield and nutrient use efficiency of potato. Journal of Plant Nutrition. 2016;39(7):949-56.
14. Guo B, Yang J, Lu R,Yu S. Effects of Komix of growth and fruiting of 'Red Fuj'Apple. Journal of Fruit Science. 2000;17: 73-75.
15. Shuixiu, H, Ruizhen, W. A study on the effect of komix humic-acids-containing organic fertilizer on spring soybean. Jiangxi Agricultural University Journal 2001;23: 463-466.
16. Du H, Xue S, Sun Z. Effects of different application rates of humic acid compound fertilizer on leave nutrient accumulation and physiological mechanism of grape. Chinese Journal of Eco-Agriculture. 2007; 15: 49- 51.

17. Urrutia O, Erro J, Guardado I, San Francisco S, Mandado M, Baigorri R, Claude Yvin J, Ma Garcia-Mina J. Physico-chemical characterization of humic-metal-phosphate complexes and their potential application to the manufacture of new types of phosphate-based fertilizers. Journal of Plant Nutrition and Soil Science. 2014;177(2):128-36.
18. Tian C, Zhou X, Liu Q, Peng JW, Wang WM, Zhang ZH, Yang Y, Song HX, Guan Cy. Effects of a controlled-release fertilizer on yield, nutrient uptake, and fertilizer usage efficiency in early ripening rapeseed (Brassica napus l.). Journal of Zhejiang University. Science. B. 2016;17(10):775.