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Research Article

Fermented liquid biofertilizer from banana waste: A value added product

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ABSTRACT

As a remedy to meet the current alarming situation caused by chemical fertilizers, agricultural sectors are now refocusing on organic manure production from food waste. Banana wastes have potential biomass and nutrients which could be reutilized. This study aimed to assess the potential of fermented banana waste as a biofertilizer. Banana fruit waste was fermented using cow dung and cow urine. The Physico-chemical components, total bacterial load, phosphate solubilizers count, fecal coliforms count, and germination index of the prepared fermented banana waste biofertilizer (FBW-B) was studied. pH of 6.72 and EC value of 19.41 ± 0.09 ms/cm were observed in fermented banana waste biofertilizer (FBW-B). The mineral content of FBW-B was: total nitrogen (0.26 ± 0.001 %), phosphorus (0.35 ± 0.02 %) potassium (0.04 ± 0.00 %), calcium (2096 ± 12.08, mg/kg), magnesium (595 ± 4.23 mg/kg), sulphur (169 ± 10.7 mg/kg), iron (122.6 ± 0.92 mg/kg), zinc (8.38 ± 0.9 mg/kg), copper (2.41 ± 0.1 mg/kg), lead (4.34 ± 0.02 mg/kg) and manganese (9.83 ± 0.7 mg/kg). In the bacterial population, phosphate solubilizing bacteria (PSB) in a considerable count were noted in FBW-B with the absence of fecal coliforms. Germination test shows that FBW-B has growth promotion potential after 50-fold dilution. The outcome of the study contributes to the development of organic liquid fertilizer from fruit waste and alleviates the effect of disposed of fruit waste and harmful effects of chemical fertilizers on the environment and humans.

INTRODUCTION

The growing population, change in eating habits and concern towards health has made fruits to be one of the highly produced and most utilized commodities. Food and Agricultural Organization (FAO) of the United Nations has reported that in 2019 the world trade of tropical fruits has reached 7.7 million tons with an increase of 6.4% compared to the previous year (FAO). Problems faced at farmers' level in post-harvest stages like transportation and storage, leftover in markets and households, and the perishable nature of fruits make them more vulnerable to decay. It was estimated that 42% of generated wastes are fruit and vegetable wastes from the food and food processing industries. The valuable organic biomass and bioactive nutrients, in the generated fruit waste, could be reutilized [1].

To ensure adequate production of food more amount of chemical fertilizers and pesticides were applied. The utilization of chemical fertilizers and pesticides was more in developing countries compared to developed countries. Recently more amounts of heavy metals, chemicals, and pesticides were reported in air, water, soil, food products, and very sadly in human adipose tissue and blood [2]. The overuse, mismanagement, and continuous application of chemical fertilizers have made the soil barren depleting all nutrients, destructing the soil structure and rhizomicrobes. Contamination at all levels has disturbed the human system causing adverse ill health effects like skin rashes, eye irritations, headaches, then slowly to cancer, endocrine disorders, birth defects, etc., along with ecosystem damage [2].

Organic sources like agricultural wastes, animal wastes, sewage wastes, wastes from food processing industries, etc were better potential resources when managed properly. As a step towards a Cleaner production approach, we now focus on the recovery of nutrients from organic waste and reusing them as biofertilizers. Globally, nearly one-third of the food produced for human consumption is wasted daily. The organic waste generated could be transformed into a useful product like organic fertilizers by the process of composting. The biological process that digests the organic matter into simple nutrients under optimum moisture, temperature, and aerobic conditions is composting. The inedible parts of fruits that are disposed of at various stages of food supply from farm to consumer level could be termed as fruit loss than waste [3]. The fruit loss in India accounts for 12 million tons as estimated by The Ministry of Food Processing Industries (MFPI), [4]. Banana is one of the tropical fruits consumed widely for its nutritive effect, good digestibility, flavor, and attractive color. India was the maximum producer of bananas in 2019 (30.4 million tons) and 5.1 million tons of bananas were exported from Asia in 2019 [5]. The highly decomposing nature of bananas was due to 60% and 40% of their pulp and peel respectively [6].

The fruit wastes have potential biomass and nutrients which could be reused when managed properly otherwise immature/organic waste directly added to the soil will inhibit the growth of plants. Many have reported the conversion of single fruit waste or mixed fruit waste and mixed fruit peels [7,8] into organic fertilizer. The presence of imbalanced nutrients, toxic metal ions, and pathogenic bacteria in organic waste when not treated properly may harm both the plant growth and land. Out of so many waste management strategies, composting, that occurs through microbial action in aerobic condition decompose the organic matter into a mature, stable, nutritious amendment to improve soil fertility. Cow dung was used in many indigenous fertilizer formulations to valorize organic waste.

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Olatunde et al. [7] has demonstrated the preparation of liquid fertilizer by fermenting fruit waste using cow dung.

Nearly 80% of the food products are produced by small scale farmers in developing countries. To mitigate the problems that arise from chemical fertilizers, farmers now started to refocus on organic fertilizer application. Among the organic fertilizers, liquid organic fertilizer is gaining more importance due to the easy availability of nutrients. Amudham, an antique liquid fertilizer is prepared by mixing cow dung and cow urine and fruit wastes [9]. Cow dung contains water, nitrogen, phosphorous, and potassium, as well as micro-nutrients. Cow's urine is rich in potassium and nitrogen. Animal dung and urine are very necessary to prepare good quality compost as they help to produce a high temperature so that the materials decompose easily and cow urine acts as a catalyst for decomposition [10]. Fruit waste provides moisture and nutrients to the microorganisms so that they multiply and break down the organic materials into humus. The end product was chemically stable and enriched in nutrients which can be used as a valuable soil amendment. The potential of the fermented banana waste as a biofertilizer could be assessed by phytotoxicity assay. The maturity and potential of fermented liquid after fermentation should be assessed for its fertilizing potential. Products of fermentation like acids, metals, and phenols may influence the quality of fermented fertilizer. Phytotoxicity assay is easy and quick with many advantages. Plant growth events like seed germination and root elongation were investigated by *Vigna unguiculata*, *Amaranthus* sp, *Abelmoschus esculentus* [11], *Lepidium sativum* [12] and *Vigna radiata* [13] seeds as bioindicators to determine the toxicity of fermented liquid fertilizer. The aim of the study to prepare the organic liquid fertilizer from banana fruit waste material. To analyze the nutrient components and germination potential rate of fermented banana waste biofertilizer (FBW-B).

MATERIALS AND METHODS

Preparation of fermented banana waste biofertilizer (FBW-B)

Fermented banana waste biofertilizer (FBW-B) was prepared according to the procedure described by Isa Alvares (9) with slight modifications. Cow dung (1 kg) and cow urine (1 l) were mixed well along with 10 liters of water in a plastic container. This mixture was kept aside in shade for 24 hours with the mouth of the container covered with a muslin cloth. Then smashed banana fruit waste (1 kg) along with the peels was added to the mixture and left for 5 days with daily stirring. pH, electrical conductivity, and moisture content of FBW-B were determined according to the procedure prescribed by Tandon [14].

Nutrient analysis of FBW-B

The total nitrogen, total phosphorus, potassium, calcium, magnesium, sulfur, zinc, manganese, iron, copper, lead, nickel, and C/N ratio of FBW-B were estimated [14].

Microbial analysis of FBW-B

The nutrient agar medium was used to enumerate the total bacterial count [15]. The phosphate solubilizing potential was analyzed by their ability to solubilize Pikovskaya's medium [16]. The most probable number (MPN) technique explained by Rajan and Selvi [15] was used for the enumeration of thermo-tolerant fecal coliforms. The results were expressed as the total number of colonies per ml.

Phytotoxicity assay-germination index

A phytotoxicity test was performed to assess its ability to stimulate seed germination as prescribed by Zucconi et al. [17]. Ten healthy Mung bean (Vigna radiata) seeds of identical size were surface sterilized with mercuric chloride (0.1%), washed with distilled water, and laid equispacially on the filter paper (2 layers) kept in a sterilized Petri plate. The treatment groups were: Group I - water control; Group II - 1% Urea; Group III-Fermented banana waste Biofertilizer (FBW-B), (1:25 dilution); Group IV- Fermented banana waste biofertilizer (FBW-B), (1:50 dilution); Group V- Fermented banana waste biofertilizer (FBW-B), (1:75 dilution); Group VI-Fermented banana waste biofertilizer (FBW-B), (1:100 dilution). Triplicates were maintained for each group 10 ml of the treatment solution was added to each petri plate and maintained at normal room temperature for 5 days in laboratory condition. The germination rate and germination index % were calculated for all six groups after 5 days by using the following formula

Germination rate % = (No. of seeds germinated in sample / No. of seeds germinated in Control) *100

Germination index % = ((Mean root length of the sample * No. of seeds germinated in sample) / (Mean root length of the control * No. of seeds germinated in Control)) * 100*.

STATISTICAL ANALYSIS

Results are reported as Mean ± Standard error of the mean. Statistical analysis was done using SPSS Version 12.0 for the windows package.

RESULTS

The composition of organic fertilizer varies according to the nutrient content of the raw materials used in the preparation. The pH, electrical conductivity, moisture, and macronutrient content (N, P, and K) were given in Table 1. pH of 6.72 in fermented banana waste biofertilizer (FBW-B) was due to the acidic nature imparted by lactic acid or acetic acid produced by the action of microbes on sugars present in banana and cow dung. Thanaporn and Nuntavun [18] have observed acidic pH in liquid fertilizer formula prepared using distillery slop and sugarcane leaves. EC value of 19.41 ± 0.09 ms/cm obtained in FBW-B was contributed by the substrates banana waste, cow dung, and cow urine used in the preparation. FBW-B proves to be a good quality liquid biofertilizer as the value was less than 20. The C: N ratio of fermented banana waste biofertilizer was found to be 30.09. The high C/N a ratio above 30 or 35 has accelerated faster decomposition by microbes and prevents the low nitrogen loss in FBW-B (19). The mineral content of FBW-B was total nitrogen (0.26 ± 0.001 %), phosphorus (0.35 ± 0.02 %), potassium (0.04 ± 0.00 %), calcium (2096 ± 12.08 mg/kg), magnesium (595 ± 4.23 mg/kg), sulphur (169 ± 10.7 mg /kg), iron (122.6 ± 0.92 mg/kg), zinc (8.38 ± 0.9 mg/kg), copper (2.41 ± 0.1 mg/kg), lead (4.34 ± 0.02 mg/kg) and manganese (9.83 ± 0.7 mg/kg), (Table 1).

The enrichment of FBW-B with the essential minerals like nitrogen (N), phosphorus (P), potassium (K), iron (Fe), sulfur (S), magnesium (Mg), calcium (Ca), manganese (Mn), zinc (Zn), copper (Cu), are contributed by the nutrients in cow dung and cow urine (20) and banana [21]. The first essential macronutrient required by the plants for their growth is Nitrogen. Nitrogen promotes the vegetative growth of the plants by increasing the cytokinin level

[22], promoting division and enlargement of new cells resulting in expansion and a greater number of leaves and nodes. Nitrogen also increases the absorption of phosphorus and potassium Brady and Weil [23] and He et al. [24].

Table 1. Physico-chemical characterization of fermented banana waste-biofertilizer (FBW-B).

Parameter	Unit	Amount
pH		6.72 ± 0.05
Electrical conductivity	ms/cm	19.41 ± 0.09
Moisture	%	93.99 ± 1.4
Total Nitrogen	%	0.26 ± 0.001
Total Phosphates as P2O5	%	0.35 ± 0.02
Potassium	%	0.04 ± 0.00
Calcium	mg/kg	2096 ± 12.08
Magnesium	mg/kg	595 ± 4.23
Sulphur	mg/kg	169 ± 10.7
Zinc	mg/kg	8.38 ± 0.9
Manganese	mg/kg	9.83 ± 0.7
Iron	mg/kg	122.6 ± 0.92
Copper	mg/kg	2.41 ± 0.1
Lead	mg/kg	4.34 ± 0.02
Nickel	mg/kg	3.48 ± 0.03
C/N		30.09 ± 1.6

Phosphorus stimulates rhizobial symbiosis, root growth, fruit, and seed formation [23,24]. Phosphorus was responsible for an increase in stem girth, number of leaves, leaf area, chlorophyll, grain filling, number of pods, and plant height [25]. Potassium promotes meristematic growth, increases the chlorophyll and protein content [26]. Thus the presence of macronutrients like N, P, and K in FBW-B might stimulate plant growth when amended to the soil as fertilizer.

Though micronutrients are needed in minimal quantity requirement is vital and their requirement should be within permissible [27]. Calcium maintains leaf integrity, activates enzymes, and mediates the signaling process in legumes [28]. Magnesium is essential for chlorophyll synthesis, prevents the accumulation of photosynthates in leaves and improves translocation to roots, and thus increases CO_2 fixation. Sulfur reduces the soil pH, increases the water retention capacity, and also increases the availability of the nutrients micronutrient like P, Mn, Zn, and especially Fe [29]. Zinc is required for the synthesis of chlorophyll and the metabolism of carbohydrates [30]. Biological processes like respiration, redox reactions, DNA synthesis, and chlorophyll synthesis are activated by iron [31]. Copper plays a major role in maintaining cell wall elasticity, chlorophyll formation [32]. Soil nutrient content of N, P, K, S, Fe, Zn and Mo has been found to increase after the application of seaweed [33]. Chemical fertilizers do not usually provide trace elements. The addition of fermented banana waste biofertilizer (FBW-B) to the soil will supply both macro and micronutrients which could increase both the yield and quality of crops. The liquid nature of FBW-B facilitates the effective nutrient absorption by soil and also it can be used as a foliar spray.

Microbial load

The liquid fertilizer (FBW-B) supported a high population of bacteria (4.48 x107), in which 5 x 105 are phosphate solubilizing bacteria (Table 2; Fig. 1) and no fecal coliforms were identified. The presence of nearly 60 species of bacteria reported in cow dung [34] and cow urine [35] have contributed to the microbial population in FBW-B. The mineral K in banana peel stimulate the growth of microbes in the fermentation medium, promotes soil rhizobacterial activity and solubilization of minerals [36,37].

Table 2. Microbial load of Fermented Banana Waste- Biofertilizer (FBW-B).

Organism	Total Count Colonies / ml
Total Bacteria	4.48 x 107
Phosphate Solubilizing bacteria	5 x 105
Feacal Coliforms	Nil

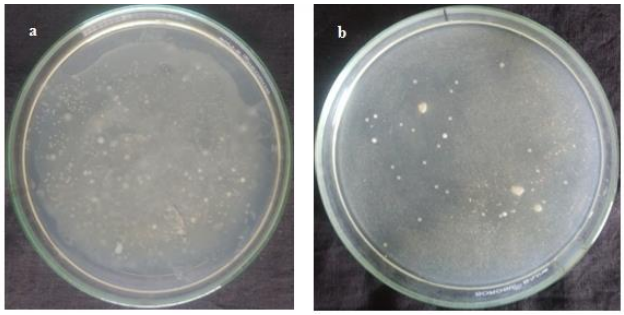

Fig. 1. (a) Total bacterial load (b) phosphate solubilisers in FBW.

Fermented banana waste when supplemented to the soil, could serve as a good source for soil microbes in the production of hormones to stimulate plant growth. Similar research by Kamala [38] has agreed to the role of bio-extract fermentation in plant growth. Fermented banana waste as a rich bio-inocula will enrich the soil nutrient status by increasing the organic matter, mobilizing the Fe [39] promoting plant growth and also protect from diseases [40].

Phosphorus solubilizing microorganisms are plant growth promoting bacteria that are mainly involved in mobilizing organic and inorganic phosphorus from soil. Phosphate solubilizers also improve the nitrogen fixing ability, protect the plants from pathogens, stimulate plant growth by phytohormones, and mobilize the trace elements like Zn and Fe [41]. Thanaporn and Nuntavun [18] have reported the production of the plant growth promoting hormone auxin by the microbes at the end of the fermentation period in the liquid fertilizer produced using waste molasses, sugarcane leaves, and distillery slop as substrates. Thus cow dung and cow urine used in the fermentation medium serve as the source of phosphate solubilizers [35] and cow dung as a soil conditioner [42].

The presence of plant growth promoting bacteria in fermented banana waste will increase the nutrient content and organic content of the soil. Thus the addition of fermented banana waste to soil promotes plant growth evidenced by stimulation of shoot and root growth, increase in length, wet and dry weight as reported by Rodríguez and Fraga [43]. The absence of pathogenic fecal coliforms in FBW-B was due to the germicidal potential of cow urine [Report, 2014]. The fermentation process releases organic molecules like amino acids and carbohydrates from the banana waste which in turn are converted to hormones, enzymes, and amino acids [44]. Fermented banana waste thus serves as a source

of nutrients and microbes that help the plants to access nutrients and improves soil health.

Germination test

The germination test was found to be a very sensitive test as it combines germination ability and root length. In the present study, germination percentage and germination index (GI) of the mung bean after the application of fermented banana waste biofertilizer (FBW-B) was found to increase after 50 fold dilution (Table 3; Fig. 2). The maturity of the compost and its feasibility to be applied as fertilizer was assessed by germination index assay. If organic wastes are not properly composted, their application to the soil will rob the oxygen by increasing the microbial activity which in turn limits nitrogen availability [18]. The results of the present study confirm the non-phytotoxic nature of FBW-B after 50 fold dilution.

Table 3. Germination percentage of mung bean (*Vigna radiata*) treated with four different dilutions of fermented Banana waste-biofertilizer (FBWB).

Group/ Treatment	Germination (%)	Root Length (cm)
Group I- Water	100 ± 0.00	3.4 ± 0.03
Group II- 1% Urea	95 ± 0.00	4.3 ± 0.05
Group III - 1 :25 diluted Fermented Banana Waste - Biofertilizer (FBW-B)	60 ± 0.00	2.48 ± 0.01
Group IV -1:50 diluted Fermented Banana Waste - Biofertilizer (FBW-B)	90 ± 0.00	3.6 ± 0.08
Group V-1:75 diluted Fermented Banana Waste - Biofertilizer (FBW-B)	95 ± 0.00	4.38 ± 0.04
Group VI -1:100 Fermented Banana Waste - Biofertilizer (FBW-B)	100 ± 0.00	5.83 ± 0.03

Values are expressed as Mean ± SEM

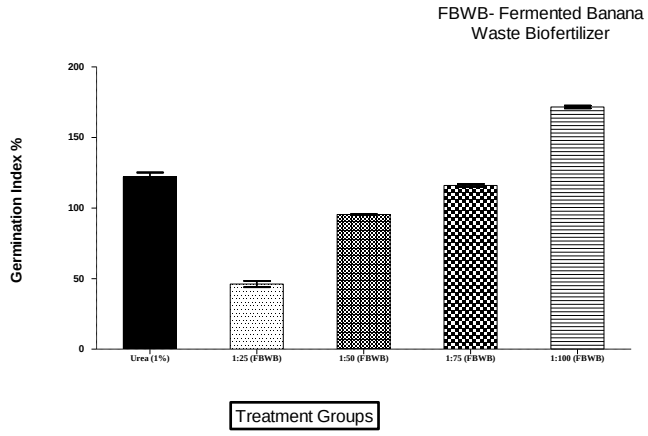

Fig. 2. Germination index values of mung bean (*Vigna radiata*) treated with four different dilution factor of fermented banana waste-biofertilizer (FBWB).

Emino and Warman [44] have reported that GI value below 50% could be considered as phytotoxic and above 125% it could be treated as biostimulant due to its phytonutrients. The GI value of FBW-B exceeds 125%, hence it can be used as a biostimulant. Thus the concept of recycling the banana waste through efficient fermentation prevents the loss of nutrients and it is a cost effective, ecofriendly and feasible technique that could be practiced even by small scale farmers. The liquid biofertilizer produced from banana waste is an indigenous preparation with a high number of macronutrients, trace elements, and beneficial microorganisms. Thus, biofertilizers with microbial inoculum will serve as a sure environmentally friendly, innovative alternative to chemical fertilizers.

CONCLUSION

Thus FBW-B produced from banana waste has a desirable amount of macronutrients, trace elements, carbon and moisture content, beneficial microbes, and proper pH. The liquid nature of FBW-B allows maximal absorption of nutrients stimulates soil rhizobacteria, increases the soil organic matter and nutrient release and supports plant growth. Thus, fermented banana waste biofertilizer (FBW-B) will serve as easy processed, low cost, biofertilizer with no side effects to ecosystem and human health.

AUTHOR CONTRIBUTIONS

Thendral Hepsibha - team member and did experimental design and statistical analysis. P. Jayanthi - lab member and supported to complete the experimental work. V Muniappan - completed the manuscript and served as supervisor.

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REFERENCES

1. Major Tropical Fruits Market Review.2019 (a). Rome, Italy: Food and Agriculture Organization of the United Nations;
2. Alvarez A, Saez JM, Davila Costa JS, Colin VL, Fuentes MS, Cuozzo SA, et al. Actinobacteria: Current research and perspectives for bioremediation of pesticides and heavy metals. Chemosphere 2017;166:41–62. http://dx.doi.org/10.1016/j.chemosphere.2016.09.070
3. Panda SK, Mishra SS, Kayitesi E, Ray RC. Microbial-processing of fruit and vegetable wastes for production of vital enzymes and organic acids: Biotechnology and scopes. Environ Res. 2016;146:161–72. http://dx.doi.org/10.1016/j.envres.2015.12.035
4. Segre A, Falasconi L, Politano A, Vittuari M. Background paper on the economics of food loss and waste. Rome, Italy; 2014.
5. Publication preview page [Internet]. FAO Documents. [cited 2023 May 29]. Available from: https://www.fao.org/documents/card/en/c/CC3421en
6. Sharma R, Oberoi HS, Dhillon GS. Fruit and Vegetable Processing Waste: Renewable Feed Stocks for Enzyme Production. In: Agro-Industrial Wastes as Feedstock for Enzyme Production. Cambridge, MA, USA: Academic Press; 2016. p. 23–59.
7. Ademola Ezra Adeleke O, Monsur Sanusi Bayode J, Olorunfemi Y. Bioconversion of mixed fruit waste as a potential source of biogas and organic fertilizer. Inter J Inte Eng. 2018;10(8):153–9.

8. Dayarathna S. Effect of different fruit peel powders as natural fertilizers on growth of Okra (*Abelmoschus esculentus* L). J Agri Sci Sri Lanka. 2021;16(1):67–79.
9. Alvares I. A how to do it manual of soil nutrition and maintenance. The Organic Farming Association of India, Goa. India Soil Recipe. 2014;1–13.
10. Edwards S. How to make and use Compost? Climate Change and Food Systems Resilience in Sub-Saharan Africa. 2011;1–32.
11. Sudharmaidevi CR, Thampatti KCM, Saifudeen N. Rapid production of organic fertilizer from degradable waste by thermochemical processing. Int J Recycl Org Wast Agricult. 2017;6:1–11.
12. Buss W, Masek O. Mobile organic compounds in biochar-A potential source of contamination-phytotoxic effects on cress seed (*Lepidium sativum*) germination. J Environ Manage. 2014;137:111–9.
13. Hasnain A, Mahmood S, Saeed A, Malik N. Tolerance and toxicity levels of boron in Mungbean (*Vigna radiata*) cultivars at early growth stages. Pak J Bot. 2011;43(2):1119–25.
14. Tandon HLS. Methods of analysis of soils, plants, water, fertilizers & organic manures, FDCO, New Delhi. 2009;144–54.
15. Rajan S, Christy R. Experiments in Microbiology. Exp Microbiol. 2018;1–560.
16. Pikovskaya's Broth (medium), Granulated [Internet]. Himedialabs.com. [cited 2023 May 29]. Available from: https://www.himedialabs.com/in/gm1719-pikovskayas-broth-medium-granulated.html
17. Zucconi F. Evaluating toxicity of immature compost. Biocycle. 1981;54–7.
18. Phibunwatthanawong T, Riddech N. Liquid organic fertilizer production for growing vegetables under hydroponic condition. Int J Recycl Org Waste Agric. 2019;8(4):369–80. http://dx.doi.org/10.1007/s40093-019-0257-7
19. Rodale JI, editor. The Complete Book of Composting. Emmaus, Pa: Rodale Books Inc; 1960.
20. Randhawa GK, Kullar JS. Bioremediation of pharmaceuticals, pesticides, and petrochemicals with gomeya/cow dung. International Scholarly Research Notices. 2011.
21. Prabhu M, Mutnuri S. Cow urine as a potential source for struvite production. Int J Recycl Org Waste Agric. 2014;3(1). http://dx.doi.org/10.1007/s40093-014-0049-z
22. Arnold JB, Frensch J, Taylor AR. Influence of inorganic nitrogen and pH on the elongation of maize seminal roots. Ann Bot. 2006;97:867–73.
23. Brady NC, Weil RR. The nitrogen economy of soils. Elements of the nature and properties of soils. London, UK: Prentice-Hall, Inc; 2000.
24. He ZL, Calvert DV, Alva AK, Banks DJ, Li YC. Thresholds of leaf nitrogen for optimum fruit production and quality in grapefruit. Soil Sci Soc Am J. 2003;67(2):583–8. http://dx.doi.org/10.2136/sssaj2003.5830
25. Rudresh D, Shivaprakash M, Prasad R. Effect of combined application of *Rhizobium*, Phosphate Solubilizing Bacterium and *Trichoderma* spp. on growth, nutrient uptake and yield of chickpea (*Cicer aritenium* L.). App Soi Ecol. 2005;28:139–46.
26. Amtmann A, Hammond JP, Armengaud P, White PJ. Nutrient sensing and signalling in plants: Potassium and phosphorus. In: Advances in Botanical Research. Elsevier; 2005. p. 209–57.
27. Evans I. Minerals for Plants, Animals and Man. Agri Fax. Alberta Agriculture, Food and Rural Development. Agdex. 1988;531–3.
28. Lhuissier F. Time course of cell biological events evoked in legume root hairs by Rhizobium nod factors: State of the art. Ann Bot. 2001;87(3):289–302. http://dx.doi.org/10.1006/anbo.2000.1333
29. Martin MH, Marschner H. The mineral nutrition of higher plants. J Ecol. 1988;76(4):1250. http://dx.doi.org/10.2307/2260650
30. Ali S, Riaz KA, Mairaj G, Arif M, Fida M, Bibi S. Assessment of different crop nutrient management practices for yield improvement. Aust J Cr Sci. 2008;2(3):150–7.
31. Balk J, Schaedler TA, Dressler H, Dawson CR. On the nature and mode of action of the copper protein, tyrosinase. I and II. Biochim Biophys Acta. 1960;65:508–14.
32. Dressler H, Dawson CR. On the nature and mode of action of the copper protein, tyrosinase: I. Exchange experiments with radioactive copper and the resting enzyme. Biochimica et Biophysica Acta. 1960;45:508–14.
33. Abhay M, Bishun D. Seaweed-An Eco-friendly Alternative of Agrochemicals in Sustainable Agriculture. Cur J App Sci Tech. 2020;39(27):71–8.
34. Bhatt K, Maheshwari DK. Decoding multifarious role of cow dung bacteria in mobilization of zinc fractions along with growth promotion of *Capsium annuum* L. L Sci Rep. 2019;9(1):1–10.
35. Swain MR, Laxminarayana K, Ray RC. Phosphorus solubilization by thermotolerant Bacillus subtilis isolated from cow dung microflora. Agric Res. 2012;1(3):273–9. http://dx.doi.org/10.1007/s40003-012-0022-x
36. Essien JP, Akpan EJ, Essien EP. Studies on mould growth and biomass production using waste banana peel. Bioresour Technol. 2005;96(13):1451–6. http://dx.doi.org/10.1016/j.biortech.2004.12.004
37. Cercioglu M, Okur B, Delibacak S, Ongun AR. Changes in physical conditions of a coarse textured soil by addition of organic wastes. Eurasian J Soil Sci. 2014;3(1):7. http://dx.doi.org/10.18393/ejss.47968
38. Kamla N, Limpinuntana V, Ruaysoongnern S, Bell RW. Role of microorganisms, soluble N and C compounds in fermented bio-extract on microbial biomass C, N and cowpea growth. Khon Kaen Agri J. 2007;35(4):477–86.
39. Owen D, Williams A, Griffith P, Withers GW. Use of commercial bio-inoculants to increase agricultural production through improved phosphorus acquisition. Appl Soil Ecol. 2015;86:41–54.
40. Khan AG. Role of soil microbes in the rhizospheres of plants growing on trace metal contaminated soils in phytoremediation. J Trace Elem Med Biol. 2005;18(4):355–64. http://dx.doi.org/10.1016/j.jtemb.2005.02.006
41. Wani PA, Khan MS, Zaidi A. Co-inoculation of nitrogen fixing and phosphate solubilizing bacteria to promote growth, yield and nutrient uptake in chickpea. Acta Agron Hung. 2007;55:315–23.
42. Bélanger G, Rochette P, Chantigny M, Ziadi N, Angers D, Charbonneau É, et al. Nitrogen availability from dairy cow dung and urine applied to forage grasses in eastern Canada. Can J Plant Sci. 2015;95(1):55–65. http://dx.doi.org/10.4141/cjps-2014-039
43. Rodríguez H, Fraga R. Phosphate solubilizing bacteria and their role in plant growth promotion. Biotechnol Adv. 1999;17(4–5):319–39. http://dx.doi.org/10.1016/s0734-9750(99)00014-2
44. Emino ER, Warman PR. Biological assay for compost quality. Compost Sci Util. 2004;12(4):342–8. http://dx.doi.org/10.1080/1065657x.2004.10702203