Current Journal of Applied Science and Technology

39(32): 10-24, 2020; Article no.CJAST.57443
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Enrichment of Organic Manures and Their Utilization in Vegetable Crops

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Authors' contributions

This work was carried out in collaboration among all authors. Author VS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors RC and GMS managed the analyses of the study. Author TS managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2020/v39i3230998
Editor(s):
(1) Dr. Nhamo Nhamo, Zimbabwe Open University, Zimbabwe.
Reviewers:
(1) Kaizzi Crammer Kayuki, National Agricultural Research Laboratories (NARL), National Agricultural Research Organization (NARO), Uganda.
(2) Mebelo Mataa, University of Zambia, Zambia.
Complete Peer review History: http://www.sdiarticle4.com/review-history/57443

Review Article

Received 29 March 2020
Accepted 04 June 2020
Published 21 October 2020

ABSTRACT

Agriculture intensification through indiscriminate and irrational use of chemical fertilizers and pesticides has resulted in reduction of crop productivity, lowered fertilizer use efficiency, accelerated environmental degradation and soil heath thus posing serious threat to the sustainability of agriculture, ecological balance and human health. However, people are gradually realizing the emerging danger and showing interest in sustainable crop production practices such increased use of organic manures to revitalize and restore soil fertility and reviving the microbial activity of the soil. Traditionally farmyard manure, animal wastes, compost, vermicompost are used as source of organic fertilizers for improving soil fertility and crop productivity. However, low nutrient content, bulkiness, handling difficulties and labour intensive application prevent the growers for larger use of these traditional organic manures. Gradually there is a decline in microbial activity of

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these organic manures which in turn leads to depletion of enzymatic activity and composition of nutrient. Manure enrichment increases the nutrient content, microbial population, enzyme activity and increase the fertility status of the soil. Enrichment of manures and composts is done by incorporation of mineral additives (rock phosphate, zinc salt etc.), bio-fertilizers (nitrogen fixing, phosphorus and potassium solubilising bacteria etc.) and bio-inoculations (*Trichoderma, Pseudomonas* etc.) have lot of benefits on crops in terms of higher yield, better quality, increased disease and pest resistance, availability of essential nutrients and increased soil microbial population and activity. Regular use of higher amount of enriched organic manures will not only reduce the amount of organic manure requirements, but will also increase the use efficiency of the applied manures. Preparation and application of enriched organic manures should be promoted to more number of vegetable growers for organic cultivation as well as for traditional crop cultivation. The present review work on enrichment of organic manure was aimed to explore the possibility of preparation and utilization of enriched organic manures on vegetable crop growth, yield and soil health. The different enrichment method and their utilization will motivate the farming community to adopt enrichment of available organic manures which in turn reduce soil pollution and environmental degradation from fossil fuels.

Keywords: Bio-fertilizers; bio-inoculants; enriched manures; vegetable crops.

1. INTRODUCTION

India is the second largest producer of vegetables just after China in the world. Nutrient demands of different vegetable crops are generally very high as they produce huge amount of biomass within very short period of time and remove lot of primary nutrients after harvest from the soil (Tables 1 and 2).To fulfil the higher nutrient demand, farmers are indiscriminately using the different chemical fertilizers. In organic farming, chemical fertilizers are not allowed but lack of availability of sufficient nutrients hampered the crop growth and productivity which fail to compete with the conventional production system. Excessive chemical fertilizers are used without sufficient organic manures, resulting in the depletion of natural soil fertility, soil become acidic and poor in nutrient use efficiency, diminishing in soil microbial diversity and tend to stagnate or decline the crop yield and productivity [1]. The conventional production system also affecting the activities of different anti-oxidants and beneficial secondary metabolites makes the plant susceptible to pests and diseases and deteriorating the quality of end produce [2]. Earthworm population in the soil is decreasing in alarming rate in conventional production system [3]. Soil microbes play vital role to regulate organic matter decomposition and nutrient cycling in soil but such chemical invasion greatly impairs the soil health by depleting soil microbial population and promoting deficiency of secondary micronutrient content of soil. In addition, the escalating gap between nutrient removal by the crop and nutrient supply has lead to nutrient depletion along with increased cost of cultivation due to high input use. The nitrite and nitrate form of nitrogenous fertilizers contaminate the surrounding water bodies and environment due to nitrate leaching posing serious environmental threats. The continuous use of large doses of nitrogenous fertilizers without addition of organic manures has resulted in humus depletion and deterioration of soil structures and drastic reduction of crop yield [4].

Balanced use of essential primary (nitrogen, phosphorous and potassium) and secondary (calcium, magnesium, sulphur) nutrients through sufficient organic manure encourages better nutrient availability and nutrient use efficiency. It also enhances the availability of secondary and micronutrients, improve/ increase the microbial diversity, reduce the nitrate toxicity and prevent acidity of soil. People are gradually realizing the dangerous effects of chemical based production system and recent years have witnessed a renewed interest for sustainable crop production by revitalizing and restoring the soil fertility and reviving the microbial activity to make the soil lively and healthy. Emphasis is given on liberal application of organic manures for better soil health and to sustain the crop production. Organic manures are the organic materials derived from animal, human and plant residues at various stages of decomposition used by the growers to provide food (plant nutrients) to the crop plants [5]. The commonly used organic manures are farmyard manure, compost, vermicompost, poultry manure, sheep manure, green manures, urban organic wastes, sludge, sewage waste etc. Organic manures act as a store house of plant nutrients (Table 3). They played a direct role in supplying macro and micronutrients and indirectly in improving the physical, chemical and biological properties of soil [6]. The use of organic manures is not only important in the immediate contest of economy in use of fertilizer, but also for the maintenance of soil fertility and crop productivity for a longer period [7]. Farmers gradually realizing the harmful effects of chemical fertilizers on crop growth, soil health and environmental degradation, and now they are searching for good quality organic manures to substitute the chemical fertilizers for better crop growth, soil and human health. They are increasingly adopting the use of the traditional organic manures namely cow dung manure, poultry manure compost and vermicompost as an alternative source of plant nutrients in crop production. However, nutrient concentrations of such organic manures are very low and thus required in large quantities to satisfy crop requirements. Lack of availability of these organic manures in huge amount prevents the farmers from large scale use in crop cultivation. The present review is an attempt to provide information on the method of enrichment of different available organic manures and their utilization in crop cultivation, so that more number of farmers can adopt the procedure for large scale use of enriched organic manures which will not only reduce the demand of chemical fertilizers, but also improve the microbial load of soil and subsequently better soil health and higher crop yield in a sustainable manner.

2. ROLE OF ORGANIC SOIL AMENDMENTS IN IMPROVEMENT OF SOIL PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES

The application of organic manures is gaining popularity particularly among the vegetable crop growers [9]. The carbon content in the organic manure is the source of energy for microbes which help in soil aggregation. Farmyard manure supplies essential plant nutrients, improves soil aeration and organic matter, thereby increasing the soil microbial population along with accumulation of excess humus content. Incorporation of farmyard manure was found to increase the water holding capacity and decrease the bulk density and p^H of soil [10,11,12]. It also increases the electrical conductivity of soil. It also decreases the penetration force and increased the hydraulic conductivity and the infiltration rate resulting in favourable soil condition for higher crop yield. Compost improves soil structure, soil fertility,

Table 1. General recommendation of NPK for different vegetable crops

Crop	N (kg/ha)	P (kg/ha)	K (kg/ha)
Winter eggplant	150	100	100
Summer eggplant	120	60	60
OP tomato	100	50	50
Hybrid tomato	180	90	90
Sweet pepper	100	80	80
Hot peppers	90	60	60
Okra	100	50	50
Onion	150	100	150
Garlic, turnip, carrot and beetroot	80	60	60
Radish	60	60	60
Cabbage	200	100	100
Cauliflower	150	100	100
Beans	50	60	80
OP watermelon	90	60	60
Hybrid watermelon	150	100	100
Gourds, pumpkins and cucumber	140	70	70
Pointed gourd	120	60	60
Sweet potato	80	50	100
Elephant foot yam	200	100	150
Spinach	80	60	60
Arum	150	100	150
Ginger and turmeric	120	60	80

Source: [8]

Table 2. Nutrient removal (kg/ha) by some commercial vegetables

Crop	Yield (t/ha)	N	P_2O_5	K_2O	MgO	S
Less removal						
Cucumber	40	70	50	120	60	-
Okra	20	60	25	90	35	10
Pumpkin	50	90	70	160	40	NA
Lettuce	25	60	220	120	-	-
Moderate removal						
Tomato	50	140	65	190	25	30
Onion and garlic	35	120	50	160	15	20
Spinach	25	120	45	200	35	NA
Radish	20	120	60	120	30	NA
Peas	2	125	30	75	-	-
Soybean	1.8	160	60	115	-	-
High removal						
Egg plant	60	175	40	300	30	10
Potato	40	175	80	310	40	20
Carrot	30	125	55	200	30	NA
Very high removal						
Cabbage	70	370	85	480	60	80
Cauliflower	50	250	100	350	30	NA
Sweet potato	14	312	111	701	-	-
Broccoli	50	220	100	230	-	-
Celery	30	180	80	300	-	-

Source: [23]

stimulates soil life, improves crop growth, kills weed seeds and pathogenic organisms, helps plants to tolerate pest and disease by reducing offensive odour and improves the physical, chemical and biological properties of soil [13]. Vermicompost is the product obtained during decomposition process by different worms species, generally white worms, red wigglers and earthworms for producing a mixture of decomposing food waste or vegetable waste, vermicast and bedding materials [14]. Vermicompost is rich in macro and micronutrients and having plant growth substances, nitrogen fixers and humus forming microbes [3]. Vermicompost improves plant growth, soil fertility, water holding capacity, aeration, physical and biological condition of soil [15]. It also boosts the crop productivity by 40% with 20 to 60% lower use of nutrient inputs [16,17]. Vermicompost influences the degree of soil aggregation and can reduce the bulk density. It can increase the total porosity, moisture-holding capacity, cation exchange capacity and oxidation potential of soil [18]. The humic substance present in vermicompost helps to increase the root hair proliferation, mineral nutrient release, protein synthesis and various enzymatic reactions [19]. Poultry manure is the droppings and urine of chickens used as an organic fertilizer. It contains higher amount of nitrogen, phosphorus and potassium as well as several micronutrients used by plants. Poultry manure increases microbial activity as well as increases soil/ manure stability [20,21,22]. It helps in decreasing the soil acidity and hence protects the crop from aluminum toxicity. The soil having higher organic manure content ensures greater microbial activity and higher soil nitrogen supplying power.

3. LIMITATIONS OF TRADITIONAL ORGANIC FERTILIZERS AND NEED FOR ENRICHMENT

Traditionally, different manures are incorporated into the rhizosphere (the zone most occupied by plant roots) of the soil. All manures are organic. However, this traditional technique requires huge amount of organic manures to achieve a significant effect, as most of the organic manures are bulky in nature, they have low nutrient content, labour intensive in terms of application and transport, difficulty in handling, beside the extra cost of manpower [24]. It also takes long time to decompose, hence slowly releasing the nutrients. The decomposition of organic manures also depends on the maturity and stability of the organic matter. Sometimes there will be loss of nutrients if poorly stored and promote the chance of spreading disease, pest and weeds.

Therefore, it is necessary to manufacture a modern eco-friendly organic manure source marked with high nutrient content to be able to compete with mineral sources, with a low volume to minimize the extra cost of manpower and transportation [25]. The use efficiency of different traditional manures can be enhanced by adopting certain measures before field application. Farmyard manure should be used after proper decomposition, avoid direct use of raw manures in the field, farmyard manure should be covered with plastic during rainy season to prevent nutrient leaching, two to three organic manures can be mixed together for balanced supply of nutrients, farmyard manure should be protected from termite infestation and it should be applied at least 3 weeks before transplanting of the crop for maximum efficiency. The farmyard manure can be converted to compost or vermicompost for better use efficiency and enriching of organic manures with bio-fertilizers/ bio-inoculants/ rock phosphates will be a viable option. Therefore, a good quality organic manure should contain the balanced constitutions of organic sources (rice straw and compost), eco-friendly mineral additives (rock phosphate and feldspar) and bio-inoculations (nitrogen fixing, phosphorus and potassium dissolving bacteria) to maximize the productivity potential [26].

Mixing of traditional organic manure with nutrients/ bio-fertilizers/ bio-inoculants to increase the nutrient content, decomposition, mineralisation and better microbial load is referred as organic manure enrichment. With the passage of time, there is a gradual decline in microbial activity of the traditional organic manure, which in turn leads to depletion of enzymatic activity and macronutrient composition. Enrichment increases the microbial population, available nitrogen, phosphorous and potassium content, enzyme activity and increase the fertility status of soil [27,28]. The availability of nutrients in enriched organic manures become much higher as microbial decomposition slowly increase the availability of nutrients to the plant throughout the growth period. Bio-fertilizers are the substances which contains living micro-organisms that accelerate the different microbial processes in soil and enhance the availability of nutrients to growing plants. When they are applied as seed or soil inoculants, they colonize the interior of the plant and enhance nutrient cycling and growth of the plant. Biological fertilizers have the capacity to mobilize the nutritionally important elements from non-usable form to usable form through some biological processes and are known to enhance yield in different crops [29]. The commonly available beneficial soil microbes includes N fixers of the genera of *Rhizobium, Azospirillum*, *Azotobacter*; P solubilizer of the genera of *Pseudomonas*, *Bacillus*, *Enterobacter*; K solubilizerof the genera of *Burkholderia, Acidothiobacillus, Bacillus;* soil beneficial mycorrhiza includes *Acaulospora*, *Entrophospora*, *Gigaspora*, *Glomus*, *Sclerocystis*, *Scutellospora* and prominent soil bio-inoculants such as *Trichoderma* sp., *Chaetomium* sp., *Gliocladium* sp., *Pseudomonas* sp., *Bacillus* sp. etc. Most of the microbes play significant role in balancing the dynamics of decomposition of organic matter and the availability of essential plant nutrients in the soil. It provides nutrients through the action of nitrogen fixation, solubilising phosphorus and trigger growth of plant through synthesis of growth promoting essence [30]. Bio-fertilizer plays an important role in maintaining long term fertility and sustainability of soil, which may enhance crop yield by 10-30% [31].

4. METHODS OF ENRICHMENT OF ORGANIC MANURES

Traditional organic manures are mostly deficient of essential macro and micronutrients as well as beneficial microbial population. Several researchers investigated and reviewed the enrichment of organic manures through mineral additives (rock phosphate, zinc salt etc.) [32,33,34] and bio-inoculations (nitrogen fixing, phosphorus and potassium solubilizing bacteria etc.) [35,36,37,38]. Fig. 1 summarize the different methods of enrichment of organic manures. [39] studied the effect of enrichment of compost by rock phosphate on organic matter decomposition and observed that the maximum rate of decomposition with minimum loss of nitrogen was found with the enrichment by both nitrogen (C: N ratio of 30) and low grade rock phosphate (Waste: rock phosphate ratio of 4: I) at the level of 70% moisture on a dry weight basis. Unuofin et al. [33] stated that during vermicompost preparation with cow dung waste and paper mixtures, the addition of 2% phosphorus through rock phosphate was found to increase the rate of bio-transformation and humification of the resultant vermicompost and emerged as suitable organic fertilizer for organic farming. Patel et al.[34] worked on zinc and iron enrichment of farmyard manure by mixing 200 kg farmyard manure with 1.5 kg $ZnSO_4$, $7H_2O$ and 3.0 kg $FeSO_4$, $7H_2O$ for 45 days before field application.

They found that the process resulted in significant improvement in Zn and Fe content of the enriched farmyard manure and helped to convert inorganic into organically bound and naturally chelated form of Fe and Zn.

Similarly, a study was made by [41] on the enrichment of farmyard manure, poultry manure and sugar press mud by mixing rock phosphate and effective micro-organisms. They observed a slight reduction in pH (7.34), EC (3.29) and narrowing of C: N ratio (18.32), and there was gradual increase in macro (total NPK) and micronutrient content (Fe and Zn) of the enriched organic manures. Chandra [35] reported that enrichment of compost for nitrogen can be achieved by mixing the compost with N-fixing bacteria- *Azotobacter* and *Azospirillum* each 2 kg per ton of solid wastes just after the thermophillic phase of the composting process. It will

Table 3. Nutrient composition of different organic manures

Organic manures	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Bulky organic manures			
Cattle dung	0.40	0.20	0.20
Cattle urine	1.00	-	1.35
Sheep and goat manure	3.00	1.00	2.00
Sheep and goat dung	0.75	0.50	0.45
Sheep and goat urine	1.35	0.05	2.10
Vermicompost	3.00	1.00	1.50
Poultry manure	3.03	2.63	1.40
Pig dung	0.60	0.50	0.40
Pig urine	1.10	0.10	0.45
Horse manure	2.00	1.50	1.50
Horse urine	1.35	-	1.25
Farm litter compost	0.50	0.15	0.50
Town compost	1.40	1.00	1.40
Sugarcane trash	2.73	1.81	1.31
Rural compost	1.22	1.08	1.47
Water hyacinth compost	2.00	1.00	2.30
Night soil	5.50	4.00	2.00
Sewage sludge	1.5-3.5	0.75-4.00	0.3-0.6
Paddy straw	1.50	1.34	3.37
Concentrated organic manures			
Groundnut cake	6.5-7.5	1.3	1.5
Neem cake	5.2-5.6	1.1	1.5
Castor cake	4.0-4.4	1.9	1.4
Linseed cake	5.6	1.4	1.3
Coconut cake	3.4	1.9	1.9
Cotton seed cake (decorticated)	6.9	3.1	1.6
Cotton seed cake (undecorticated)	3.6	2.5	1.6
Safflower cake (decorticated)	7.9	2.2	1.9
Safflower cake (undecorticated)	4.9	1.4	1.2
Niger cake	4.7	1.8	1.3
Sesamum cake	4.7-6.2	2.1	1.3
Pongamia cake	4.0	1.0	1.3
Mahua cake	2.5	0.8	1.9
Raw bone meal	4.0	20-25	-
Steamed bone meal	4.7	25-30	-
Blood meal	10-12	1-2	1.0
Fish meal	4-10	3-9	1.5
Meat meal	9-11	3.5	-
Horn and hoof meal	10-15	1.0	-
Basic slag	4.0	1.0	1.3
Guano (Peruvian bird)	11-16	8-12	2-3
Press mud	1-1.5	4-5	2-7

Source: [40]

accelerate the decomposition during the composting process. For phosphorus enrichment, P-solubilizing bacteria- *Bacillus polymixa* at 4 kg should be mixed with one ton of solid wastes. Potassium rich compost can be prepared by mixing K-mobilizing bacteria- *Fraturia aurantia* at 4 kg per ton of solid wastes [35]. Chandra [35] reported that bio-inoculant rich compost can be made by inoculating the substrates with cellulolytic and lignolytic micro-organisms *like Trichoderma viride* and *Pseudomonas fluorescens* at 2 kg per ton of solid wastes. They further suggested that if bio-fertilizers are not mixed with the substrates during composting process, then enrichment can be done by mixing the bio-fertilizers with the harvested compost and heaping the treated compost in shed for at least two weeks before field application. Kaushik et al. [36] studied the effect of inoculation of nitrogen fixing strains *Azotobacter chroococcum*, *Azospirillum brasilense* strain and phosphate solubilizing bacteria *Pseudomonas maltophila*, on nitrogen and phosphorous content of vermicomposts prepared from cow dung textile mill sludge. They found that nitrogen enrichment of vermicompost varied with the different inoculated microbes and *Azotobacter chroococcum* treated vermicompost contained maximum nitrogen followed by the inoculation of *Azospirillum brasilense*. Nilay et al. [37] reported that during the enrichment of vermicompost and farmyard manure with different beneficial microbes like *Azotobacter*, *Azospirillum* and phosphate solubilizing bacteria (PSB), the population of microbes significantly increased in the final compost from about 35 to 133% during the 30 days incubation period. Vermicompost enriched with *Azospirillum lipoferum* increased the nitrogen content and solubilised phosphorous of soil, as the bacterial strains proliferated rapidly, fixed nitrogen and *Pseudomonas striata* solubilised the native phosphorous of the soil [42]. The potassium solubilising micro-organisms are the rhizospheric micro-organisms which solubilise the insoluble potassium (K) to soluble forms of K for plant growth and yield [38]. These potassium solubilising microorganisms were found to solubilise potassium, silicon and aluminium from insoluble K-rich minerals such as micas, illite and orthoclases, by excreting organic acids which either directly dissolves rock potassium or chelated silicon ions to bring potassium into the solution. Shruthi et al. [43] studied different organic manure based carrier to support the maximum microbial population for longer storage life. The result reported that press mud was the best carrier material for the beneficial microbes namely *Rhizobium phaseoli*, *Bacillus megaterium* and *Glomus fasciculatum* (AM fungi) for their prolonged storage followed by vermicompost. The consortium of *Rhizobium phaseoli*, *Bacillus megaterium* and *Glomus fasciculatum* (AM fungi) in press mud as carrier has resulted in higher yield than their individual application in French bean.

5. BENEFICIAL ROLE OF ENRICHED ORGANIC MANURES ON VEGETABLE CROPS

Tables 4, 5 and 6 summarize the beneficial effect of different bio-fertilizers and bio-inoculants on nutrient enrichment and management of plant diseases in different vegetable crops. Inoculation of nitrogen fixing micro-organisms plays an important role in enhancing yield of vegetable crops by converting atmospheric nitrogen into organic forms which are usable by the plants. Inoculation of *Rhizobium* bacteria (mutually associated with legumes) helps to increase the nodule formation of root, encourages plant growth and produces higher pod yield in legume vegetables [30]. Kumari and Ushakumari [44] reported that vermicompost enriched with rock phosphate showed best results compared to other treatments in vegetable cowpea for yield and uptake of major nutrients like N, P, K, Ca and Mg. Singh et al. [45] found that integrated application of farmyard manure (25 t/ha) and bio-fertilizer (PSB + *Azotobacter*/ *Rhizobium*) increased the yield of okra, cowpea and bottle gourd during summer by 27.5, 40.1 and 8.33% while in rabi season integrated application of NADEP compost at 25 t/ha and bio-fertilizer (PSB+ *Azatobacter*/ *Rhizobium*) increased the yield of cabbage (*Brassica oleracea* var. *capitata*) and pea (*Pisum sativum*) by 12.8 and 23.5% respectively over conventional inorganic system. Naidu et al. [46] reported that most of the morphological parameters of okra were significantly increased by the application of different combinations of organic manures and bio-fertilizers, as the availability of essential nutrients enhanced the cell division and cell elongation and affect the growth and development of plant [47]. Inoculation of potato plants with microbes either *Azospirillum* or *Azotobacter* or their mixture increased the tuber yield [48]. Jacob and Banerjee [49] prepared an enriched bio-manure by mixing cow dung slurry with the mixture of cyanobacteria and free living nitrogen fixing bacteria and applied in the okra field at 10 t/ha. The result showed that the soil supplemented with enriched manure was found superior for fruit quality than the control and almost comparable to that chemical (urea) amended soil. Chaterjee et al.[50] showed that application of *Azotobacter*, phosphate solubilizer and potash mobilizer microbes enriched poultry manure produced cauliflower curds with highest chlorophyll, ascorbic acid and reducing sugar. Zinc enriched farmyard manure showed higher turmeric rhizome yield increase of 21.6% [51]. Promotion of plant growth by bio-fertilizers in different vegetable crops was also reported by [52], [53] and [47]. Increased yield by the phosphorous solubilizing bacteria could be due to the increased availability of nutrients in the soil and better nodulation resulting in improved growth and development which might be attributed to better phosphorus mobilization and also hormonal balance on the plant system [54]. Gamliel and Stapleton [55] reported that *Pseudomonads fluorescens* and *Bacillus spp.* colonized rhizospheric soil significantly suppressed the occurrence of harmful *P. ultimum* and other fungi in lettuce field. Maity and Tripathy [56] stated that apart from nutrient mobilization, the bio-fertilizers like *Azospirillum*, *Azotobacter* and phosphorus solubilizing micro-organisms also have anti-fungal activities without any toxic or residual effect, leading to sustainable production of quality vegetables. Vegetable crop grown with inoculation of mycorrhizal fungi have increased resistance to *Fusarium oxysporum* and *Rhizoctonia solani*. Inoculation of mycorrhiza in tomato plants resulted in increased resistance to nematode infestation. Damping off disease of tomato can also be prevented by using these bio-fertilizers.

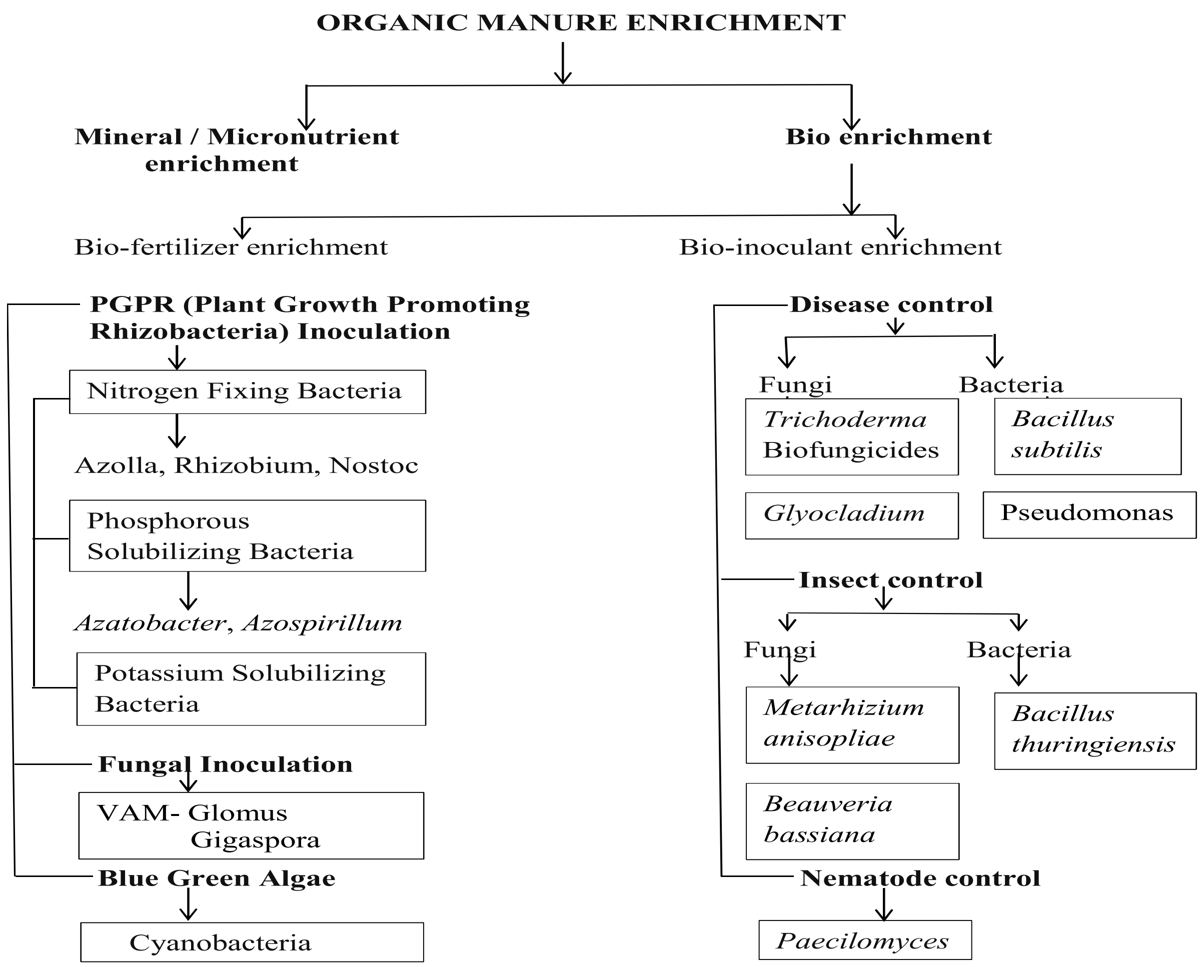

Fig. 1. Different methods of organic manure enrichment

Table 4. Response of vegetable crops to nitrogen bio- inoculations

Added microorganism (Bio-fertilizer)	Crop	Increase in yield (%)	Nitrogen economy*(%)	References
Azotobacter	Tomato	13.60	50	[57]
	Onion	18.00	-	[58]
	Garlic	14.80	25	[59]
	Garlic	14.23	25	[60]
	Cabbage	26.45	-	[61]
	Cabbage	24.30	25	[62]
	Knolkhol	9.60	25	[63]
Rhizobium	Pea	13.38	-	[64]
	Pea	5.10	-	[65]
	Cowpea	4.09	-	[66]
Azospirillum	Chilli	26.70	25	[67]
	Chilli	15.10	25	[68]
	Capsicum	9.98	25	[69]
	Okra	9.00	25	[70]
	Onion	21.68	25	[69]
	Onion	9.60	25	[71]
	Onion	6.20	25	[72]
	Garlic	6.42	25	[60]
	Cabbage	11.87	25	[62]
	Cabbage	7.00	25	[73]
	Knolkhol	14.90	25	[63]
	Sweet potato	8.50	-	[74]
	Radish	9.00	-	[75]

**Substitution of recommended nitrogen fertilizer*

Table 5. Response of vegetable crops to phosphorus bio- inoculations

Added micro organism (Bio-fertilizer)	Crop	Increase in yield (%)	Phosphorus economy* (%)	References
PSM (Phosphorus Solubilizing Microorganisms)	Potato	30.50	-	[76]
	Potato	20.00	-	[77]
	Chilli	14.29	-	[77]
	Pumpkin	51.00	25	[78]
	Onion	9.60	25	[71]
	Garlic	14.23	25	[60]
	Onion	4.70	25	[72]

Table 6. Beneficial effects of bio-inoculants in disease reduction

Bio-fertilizer	Crop	Diseases that showed reduction	References
Pseudomonas fluorescens	French bean	*Colletotrichum lindemuthianum*	[79]
	Tomato	Stem rot (*Sclerotium rolfsii*), Fruit rot, Leaf blight	[80], [81], [82]
	Chilli	Seedling damping off	[83]
	Bell pepper	Seedling damping off	[84]
	Cauliflower	Wilt (*F. moniliformae*)	[85]
	Cucumber	*Fusarium* root rot	[86]
	Potato	Bacterial wilt (*Pseudomonas solanacearum*)	[87]
	Radish	Fusarium wilt	[88]
	Beet root	Seedling damping off (*Pythium debaryanum* and *P. ultimum*)	[89]

6. CONCLUSION

The present review suggested that traditional organic manures like farmyard manure, vermicompost, poultry manure can be enriched by inoculating the manure with rock phosphate as well as nitrogen, phosphorous and potassium solubilising bio-fertilizers. Again, microbial inoculant enrichment through *Trichoderma* and *Pseudomonas* microbes can provide the vegetable crops from different disease infestation. Application of enriched organic manures will benefit the vegetable crops in terms of more yield, better quality, disease and pest resistance, availability of essential nutrients and overall microbial population of the vegetable field, which will not only reduce the amount of organic manure requirement but also increase the use efficiency of the applied manure. The practice will gradually reduce the excessive use of chemical fertilizers in vegetable production. Recent research outcome pointed that bio-inoculants enriched organic manures can be emerged as a viable tool for non-chemical based disease and insect suppression in crop field. More efforts will be required for scaling up preparation and application of enriched organic manures in vegetable crops to achieve sustainability in production system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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