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Vermicomposting in organic Agriculture: Influence on the soil nutrients and plant growth

Shristi Piya, Inisa Shrestha, Dhurva P. Gauchan and Janardan Lamichhane*

Department of Biotechnology, Kathmandu University, Dhulikhel, Kavrepalanchowk, Nepal

*Corresponding Author: ljanardan@ku.edu.np; Phone: 977-011-415100; Fax: 977-011-415011

Vermicomposting is a green technology that converts organic wastes into plant available nutrient rich organic fertilizer. It has also found to reduce heavy metal concentration in contaminated feeding materials. Vermicompost (VC), when used as fertilizer, not only bears positive impact on soil quality, plant growth and yield but also enhances nutritional value of crops produced. Use of VC on soil improves its physiochemical (aggregation, stability, pH, EC, bulk density, water holding capacity (WHC), organic matter (OM), micro- and macro- nutrients.) and biological properties (microbial population, enzymes). It also increases soil structural stability and reduces vulnerability of soil to calamities like erosion. Use of VC in plant growth enhances their development in early as well as latter stages of plant growth but proper concentration of VC must be considered for optimum plant growth and production.

Keywords: *Vermicompost, soil quality, plant growth promotion, plant nutrients*

1. Introduction

"Organic Agriculture" is an sustainable alternative to conventional system as it aids in environmental protection [1], improved food quality and human health [2]-[4]. It restricts use of agro-chemicals and genetically modified organisms; rather focuses on other agricultural practices like organic manure (compost, vermicompost, green manures, animal manures), crop rotations and biological control of pests to maintain productivity. Increasing awareness on consumers has uplifted the demand of organic products in global scenario. However, the organic supply has not been competent to meet the demand. Therefore farmers are encouraged to move into organic farming.

Nutrient management of cropland is an important factor for agricultural success. Thus organic fertilizers like VC have been boon for organic agriculture and farmers. VC is an organic fertilizer produced by biological processing of organic feed by earthworms. It converts organic wastes viz. municipal waste [2]–[4], agricultural waste [5], [6], animal waste [7]–[9], industrial waste [13]-[15], sewage sludge [10]–[12], human faeces [19], anaerobic digestate [13], [14] into nutrient rich VC by help of earthworms. It is rich in micro- and macro- plant nutrients which are in plant available forms like nitrate (NO_3^-) [15], phosphate (PO_4^{3-}), sulphate (SO_4^{2-}), Potassium (K^+) etc. and aids in plant growth promotion that increases crop productivity [16], [17]. It also contains large number of microorganisms (bacteria, fungi, actinomycetes) which produce phytohormones (Indole 3acetic acid, Gibberellic acid, Kinetin) [18] and enzymes (Dehydrogenase, Urease) [26] that promote plant growth. Microorganisms isolated from VC and having potential to inhibit pathogens have also been used as bio-fertilizer or bio-pesticide. Also, its extracts like humic acid, vermin-tea are successfully being used in raising crop productivity. However, to maintain good quality of VC, type of raw materials/feed [27]- [29]; stocking density [30], types of earthworm [31], [32] and other environmental factors [19] should be taken into consideration.

Nowadays chemical fertilizers are being used in high quantities which degrade soil quality in long run [34]. Many researchers have reported positive changes in soil quality and soil productivity by application of VC compared to chemical fertilizers [20]. Many have testified significantly greater crop production through VC amendment. Kashem et al. (2015) reported higher tomato yield compared to inorganic fertilizers suggesting the significance of VC over inorganic fertilizers [21]. Crops grown with VC amended soils are also found to have additive nutrient content compared to non-amended. According to Gutiérrez et al. (2007) tomatoes produced in VC amended substrate were more suitable for juice

Table 1 Quality of vermicompost prepared from different substrates

SN	Substrate used	Earthworm used	C:N	pH	Moisture (%)	EC (ds/m)	mg/g	
							TOC	N
1	Domestic waste	*P.sansibaricus* *P. excavatus*	9.89±0.05 10.40±0.04	7.43±0.02 7.59±0.03	- -	- -	200.2±0.19 201.6±0.11	20.36±0.10 19.26±0.06
2	Cattle waste Goat waste	*E. foetida*	40.66±39b 43.34±39	6.80±0.01a 6.72±0.01b	- -	- -	521.5±0.24b 530.0±0.25a	12.8±0.01a 12.2±0.01b
3	Human faeces	*E. foetida*	6.5±0.5	8.0±0.3	43±5	0.294	175±10	28.0±0.2
4	Food industry sludge & cow dung; 1:1	*E. foetida*	-	6.0±0.02	-	1.7±0.26	310±3.5	20
5	Cow dung	*E. foetida*	26.4	-	-	-	337	12.4
6	Household solid waste		18.1	6.88	51.8	1.9	255	14.1
	Horse and rabbit manure		12.4	6.82	41.2	0.4	188	15.1
	Chicken manure		31.9	8.1	11.3	6.8	428	13.4
7	Woodchips (Quercus rubra) and lake mud	*E. foetida*	12.04	7.48		3.19	15.0.50	12.5
8	Cowdung *Azolla* *Eichorrnia*	*Eudrilus eugeniae*	20:23 26:32 27:26	6.6 6.9 6.8	- - -	1.68 2.25 2.84	124 285 224	6.2 11.2 9.6

C:N = Carbon:Nitrogen, EC= Electrical Conductivity, TOC= Total organic carbon, N= Nitrogen, P= Phosphorous, K= Potassiumproduction due to higher soluble and insoluble solids content compared to control [28].Its application has also found to increase minerals like Vitamin C and sugar in tomatoes [29].

Vermicomposting has emerged as a sustainable technology for management of organic waste, production of organic fertilizer and reduction in use of chemical fertilizers. It is at times also used incorporated with chemical fertilizers to maintain soil quality. The aim of this review paper is to discuss on nutrient quality of VC and its efficacy on plant growth promotion and soil quality enhancement.

2. Physiochemical properties of VC

Vermicomposting enhances nutrient content of feeding materials making it suitable for using in agricultural lands [23]. However, some organic materials like industrial waste and sewage, must be spiked with other bulking agents like cowdung to make suitable habitat for earthworms [19], [39]. Plant available nutrient are abundant in VC compared to normal compost. Atiyeh et al. 2000, reported that vermicomposting significantly decreased concentration of ammonium-nitrogen nitrogen, which cannot be taken by plants directly, thus increasing the quantity of nitrate-nitrogen by 28 folds. In normal composting nitrate-nitrogen increased only by 3 folds [15]. Nutrient quality of VC is highly influenced by feeding material. It has been reported that VC prepared from cattle and goat manure varied on nutrient quantity. Carbon (C), Nitrogen (N) and pH were lower and Phosphorous (P) and Potassium (K) concentrations were higher in goat manure VC than the cattle manure. This may be due to variability in nutrient uptake by earthworms [9]. Similarly, VC quality is also governed by earthworm species used. *Perionyx excavates* is more suitable and efficient than *Perionyx sansibaricus* for VC preparation of domestic waste [3]. However, several studies have cited *Eisenia fetida* as most preferred species for vermicomposting [30]. Effects of vermicomposting on organic wastes are summarized in Table 1.

3. Heavy metals (HM) and vermicomposting

Vermiconversion of HM contaminated feeding materials reduces concentration of HM in wormcast. This is accredited to accumulation of HMs in worm tissues. However, these residual contaminants may possess harmful impact on agriculture land [31]–[33]. According to Abu et al. (2015) HM concentration through vermicomposting varies according to the feed used [34]. Vermiconversion of four treatments Cowdung (CD): Spent Mushroom Compost (SMC), CD:2SMC, Goat manure (GM):SMC and GM:2SMC spiked with 2 litres of landfill leachate each for 75 days resulted in major flush out of HMs. Chromium (Cr) was removed at highest level ranging from 95-99.81%. Cadmium (Cd) and Lead (Pb) were reduced by 90% and 80% in all treatments respectively. Meanwhile, Copper (Cu) concentration increased in CD: SMC II and GM:SMC I. Zinc (Zn) also showed an increase but only in GM:SMC I (15.01%). Percentage increase in Cu and Zn was clarified by Lukkari et al. (2006), due to binding of HMs to organic matter. Moreover, the HMs concentration was found within the international compost limits given by different organizations. It has also been reported that vermicomposting reduces HM concentration in higher amount than normal composting and thus can be approached as an environmental friendly method to reduce the toxicity issue [35]. However, further justification should be made prior to claiming it.

4. Influence of VC on physiochemical properties of soil

VC imparts positive impact on physiochemical properties of soil. It helps to improve soil aggregation, stability, pH, EC, bulk density, water holding capacity (WHC), organic matter (OM), micro- and macro-nutrients. VC increases soil structural stability thus reducing the vulnerability of soil to calamities like erosion. This is reported by Tejada et al. (2009) who applied beet vinasse, VC and compost (prepared by composting beet vinasse and VC) in soil vulnerable to erosion. BV increased instability index by 7.9% however V and BVV decreased it by 11.2% and 13.2%, respectively compared to control soil. Also, VC amendment reduces large aggregate formation in soil thus increasing aggregate stability in all aggregate size fractions. This can be explained by that organic matter application may have caused changes in the exchange complex that resulted in breakdown of larger fractions [36]. Correspondingly, (Table 2) Doan et al. (2015) reported reduction on leaching and runoff at highest quantity by vermicompost compared to control [37].

VC application reduced bulk density of soil in comparison to farm yard manure and chemical fertilizer due to increasing concentration of organic matter which in turn decreases bulk density [48]. Conversely, soil pH is found to increase due to application of VC. But, some researches assure that addition of VC to soil did not change the pH [28]. Contradictorily, VC has also been found to decrease pH of soil. These discrepancies are attributed to nutrient content of

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Table 2 Changes on physico-chemical parameters of soil due to application of vermicompost and other fertilizers

SN	Feedstock used	Treatment	pH	EC	OC (%)	TN (%)	P (ppm)	K (ppm)	Reference
1	No fertilizer, C	0 t/ha	7.17	0.66	-	0.095	-	-	[25]
	Household solid waste (HSW)	HSW 10 t/ha	7.07	0.98	-	0.011	-	-	
	Horse and rabbit manure (HRM)	HRM 10 t/ha	7.21	0.94	-	0.01	-	-	
	chicken manure (CM)	CM 10 t/ha	7.17	0.076	-	0.011	-	-	
	Household solid waste (HSW)	HSW 20 t/ha	7.3	0.9	-	0.012	-	-	
	horse and rabbit manure (HRM)	HRM 20 t/ha	7.09	0.66	-	0.011	-	-	
	chicken manure (CM)	CM 20 t/ha	7.19	0.83	-	0.011	-	-	
2	No fertilizer, To	0 t/ha	5.3 (0.1)	-	0.31(0.07)	0.15(0.01)	3.8 (0.02)	76.8(1.4)	[37]
	urea, %N=46.3%, 40 g m−2), potash, %K=60%, 16 gm−2) and phosphate, %P=16%, 50 gm−2)	Minerals (M) only	4.8 (0.1)	-	1.15 (0.25)	0.20 (0.01)	114.9 (1.04)	249.7 (4.5)	
		M + Biochar (B) (7t/ha)	5.5 (0.1)	-	1.29 (0.22)	0.21 (0.01)	163.0 (1.99)	216.5 (5.20	
		Buffalo manure, BM (20t/ha)	6.4 (0.1)	-	2.61 (0.17)	0.31 (0.02)	181.1 (1.95)	285.7 (5.2)	
	BM	Compost (2ot/ha)	6.4 (0.20	-	3.17 (0.22)	0.30 (0.04)	199.4 (1.54)	229.8 (3.1)	
	BM	Vermicompost (V) only (20t/ha)	6.5 (0.2)	-	3.02 (0.28)	0.29 (0.04)	202.0 (1.21)	251.9(3.4)	
		V (20t/ha) +B (7t/ha)	6.5 (0.2)	-	3.10 (0.25)	0.35 (0.03)	220.7 (2.31)	303.3 (3.5)	

EC= Electrical Conductivity, OC= Organic carbon, TN= Total Nitrogen, P= Phosphorous, K= Potassium soil and VC, base content aiding to buffering capacity of soil and capacity to absorb free protons (H+) in the soil [49], [50]. Electrical conductivity increases with VC application [28]. It helps to inhibit toxicity due to saline water and rather enhances plant growth [38]. Soil WHC also increases with amendment of VC. This is because VC has high WHC and increases porosity when mixed with soil making pore spaces available for storing water [50]. Also this is related to a higher proportion of hydrophilic/hydrophobic groups of the humic substances in VC compared to that in control soil [39].

It is justified that amendment of VC and its extract on soil increases organic carbon percentage compared to chemical fertilizer which rather reduces it. This is because chemical fertilizer do not contain carbon whereas organic content of VC is slowly released into soil making it plant available [20], [40].Application of organic as well as inorganic fertilizes upsurge nutrient content in soil. Nevertheless, VC has found to raise available N, P and Kin soil at higher levels compared to them [41] and further increases with increasing rate of application [42]. Similarly, sheep manure VC is also found to increase soil nutrients and can be raised further by increasing rate of application. When soil was treated with 5, 10 and 15 t/ha of VC, the soil quality as in pH, EC, bulk density, porosity, N, P, K was best at highest rate of application [42]. On the other hand, Sangwan et al. (2010) reported loss of mineral elements in soil after harvest of marigold which has been accounted due to leaching or being taken up by the plants. Nevertheless, concentration of this loss in VC amended soil was found lesser than the control; 55% in control, 7.3% in cowdung VC and 7.2% in filter cake VC [43]. VC amendment also increases micronutrients like Copper (Cu), Zinc (Zn), Iron (Fe) and Manganese (Mn) in soil butat suitable concentration [43]–[45].

VC also has been reported to remediate metal contaminated soil. It effects concentration of HM in metal contaminated soils. Angelova et al. (2013) reported decrease in available Zn, Cd, Cu, Mn and Pb from the soil due to VC application except Fe, while application of compost further increased Zn, Cd, Fe and Mn. This increase in HM through compost was subjected to decrease in pH which make metals ions more soluble whereas reduction of HM are attributed to conversion of OM to stable form by binding with the HMs [46]. Thus addition of VC in metal contaminated soil may help in soil remediation and improving its quality.

5. Influence of VC on biological properties of soil

Microbial population and its activities in soil are enhanced by addition of VC. On the contrary, they are reduced in chemical amended soils [44]. Tejada et al. (2009) found that VC increased soil microbial biomass and respiration by 59.1% and 69% respectively compared to control soil. Dehydrogenase, Urease, β-glucosidase, phosphatase and aryl sulfatase activities in soil was also significantly enthused with VC application compared to control. These enzyme activities were more enhanced with increasing rate of VC application [47].Similarly, these enzymes responsible for carbon and phosphorous cycles were found to increase with VC application during celery production in alkaline soil [48].

6. Effect of VC on plant growth

VC is also found to have positive effect on early as well as later stages of plant life cycle. Arancon et al. (2008) reported that seedling emergence of petunias seeds grown in mixture of VC (produced from cattle manure, food waste and paper waste) and MM360, increased compared to control (100% MM360). However, different rate of VC application exhibited different impact. It also significantly increased dry shoot/root weight but at lower rates than higher ones [49].Similar results are demonstrated by Manh et al (2014) who reported that application of VC with rice hulls ash and coconut husk gave higher germination, plant height, leaf biomass and leaf area [50]. It is also stated that VC enriched with beneficial organisms like *Trichoderma* further enhances germination and seedling quality [51]. Conversely, VC is found to inhibit germination and plant growth, these were recorded lowest at highest rate of application and highest in control sphagnum peat [52].Similarly, rosemary grown in control peat was better than that in VC amended substrates[53].

VC is found to have positive influence on crop productivity and quality in wide range of crops such as tomato [21], [28], [29], [45], [54]–[56], eggplant [27], [57], okra [20], lettuce [58], cabbage [35], coriander [59], cucumber [60], strawberry [61] and pistachio [62]. It also enhances growth of ornamental plants like marigold [43]. It greatly enhances crop productivity than inorganic fertilizers. According to Ansari (2010), leaf number, stem circumference and marketable yield was found maximum in chemical amended soil rather than VC amended soil. But, biochemical (protein, fats) properties of crops harvested were enhanced in VC or VC extracts amended soil. Similarly, It is also reported that higher rate of application increases crop yield. When VC was applied at 3 rates, 4 t/ha, 5t/ha and 6t/ha highest production was observed at 6t/ha application rate. VC when applied along with chemical fertilizers produces high quality vegetable like *Solanum melongena*. VC produced from Cowdung, *Azolla* and *Eichorrnia* substituted with 50% of NPK increase plant height, number of leaves per plant, number of fruits per plant, length and width of fruit. It also shortened number of days for flowering. Among all Azolla VC greatly enhanced growth and yield parameters of *S. melongena* [27].

Amount of VC required differs according to type of crops, leafy vegetable require minor VC quantity than for tuber crops [40]. Similarly, it has been reported that quality and quantity of production largely depend on rate of VC applied [63]. In an experiment where VC and soil was added in ratio of 1:1, 1:2, 1:3 and 1:4; maximum yield was recorded in 1:1 while , maximum crop nutrient like Vitamin C, total sugar, soluble solids, insoluble solids and nitrites were witnessed in higher ratios [29]. However, some has reported that application of VC at lowest rates can have similar yield to higher application rates thus can be cost effective [54], [64].

7. Conclusion

The literatures cited verify that VC can be used as an organic fertilizer alternative to in organics as it improves soil quality as well as plant growth and production. It can also be used for bioremediation of HV contaminated soil. It is thus found to improve soil physio-chemical and biological properties. However its efficacy on soil quality and PGP greatly depends on raw materials used for its production and have suggested spiking of earthworm friendly wastes to few probable toxic wastes like sewage during vermiconversion. It is found that increasing soil quality due to VC application is reflected in plant growth and production. The review also suggests that VC should be used at appropriate rate depending on type of crops grown and its nutrient requirement for cost effectiveness. Overall, VC is boon to organic farming.

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