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Utilization of Vermicompost as a Soil Amendment in Organic Crop Production

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ABSTRACT

The use of vermicompost (VC) has long been recognized as an effective means of increasing crop yields through improved soil physical, chemical and biological properties. Since synthetic mineral fertilizers are disallowed in organic crop production, there has been a renewed interest in recycling wastes into valuable organic fertilizer through vermicomposting and its subsequent utilization in organic crop production. This review summarizes published data on influence of VC on productivity and quality of crops and on soil properties particularly under organic management. Several researchers have reported that VC application give marginally lower or comparable crop growth and yield under organic management compared with that of mineral fertilizers. Furthermore, it has been well established that VC application significantly improves overall health of soil. Hence, VC has the potential to become a major soil amendment in organic crop production.

Keywords: chemical fertilizer, crop productivity, crop quality, earthworms, soil properties
Abbreviations: HA, humic acid; **IAA**, indole-3-acetic acid; **NPK**, nitrogen, phosphorus and potassium; **VC**, vermicompost

CONTENTS

INTRODUCTION

Agriculture and food systems have changed very much over the last 5 decades (Knudsen *et al.* 2006). Modern agriculture involving use of high yielding varieties together with synthetic fertilizers and pesticides has been of great help in alleviating hunger from the world, because the world population more than doubled itself during the last half of the 20th century; it increased from 2.5 billion in 1950 to 6 billion in 2000 (Wilson 2001). A third of the increase in world cereal production in the 1970s and 1980s has been attributed to increased fertilizer use (FAO 2003). Similarly, the global usage of pesticides has increased considerably during the second part of the 20th century. However, this development has led to a growing disparity among agricultural systems and population, where especially developing countries in Africa have seen very few improvements in food security and production. At the same time, agricultural development has contributed to environmental problems such as global warming, reductions in biodiversity and soil degradation. Furthermore, pollution of surface and groundwater with nitrates and pesticides remains a problem of most industrialized countries and will presumably become a growing problem of developing countries (Knudsen *et al.* 2006). Overuse of pesticides, especially in vegetables and fruits, have resulted in residues above safety levels (Kumari *et al.* 2003; Xu *et al.* 2008; Abhilash and Singh 2009; Osman *et al.* 2010). There is evidence that a plateau has been reached in global efforts to increase the yield per hectare through agro-chemicals. These ill-effects of modern agriculture forced people, especially in countries with high-income economies to demand food grown without fertilizers and pesticides. This paved the way for certified organic farming.

Received: 21 April, 2010. Accepted: 5 October, 2010.

Invited Review

On the contrary, a large number of farmers in developing countries produce for subsistence purposes and have little or no access to external inputs, modern technologies and product markets. For many (especially small) farmers the purchase of manufactured fertilizers and pesticides is and will continue to be constrained by their high costs relative to output prices and risks or simply by unavailability (FAO 2003). Thus many small farmers may not use agrochemicals because they cannot access them. This is often termed organic by default, but is often far from sustainable, as it uses few, if any, organic methods and is not based on an organic philosophy. Systems that depend upon sustainable use of locally available natural resources and farmers' knowledge and labour are far more likely to meet the needs and aspirations of resource-poor farmers than those which require costly or scarce external inputs. As productivity of traditional systems is often very low, organic agriculture could provide a solution to the food needs of poor farmers while relying on natural and human resources (Scialabba 2000).

DEVELOPMENT AND STATE OF (CERTIFIED) ORGANIC FARMING

Organic farming has developed rapidly worldwide during the last few years and is now practiced in approximately 120 countries. The area under organic management is continually growing. According to the latest survey (Willer and Klicher 2009), more than 32 million ha are managed organically worldwide (**Table 1**). Probably less than half of the global organic land area is dedicated to arable land, since in Australia and Argentina most of the organic land area is extensive grazing land. Global demand for organic products remains robust, with sales increasing by over five billion US$ a year. The global market for organic products is estimated to be at more than 46.1 billion US$ in 2007. North America and Europe comprise the bulk of global revenues (97%).

Consumer demand is largely confined to the industrialized world because of the price premium of organic products. Although most of the organic production in Asian and African countries will be for export markets, it is also helping regional markets to develop in which organic farmers market their organic produce to consumers in their region. This is expected to stimulate sales of organic products in many developing countries like India with a fast growing market.

Table 1 The ten countries with most organically managed land.

Country	Area (million ha)	Country	Area (million ha)
Australia	12.02	India	1.03
Argentina	2.78	Spain	0.99
Brazil	1.77	Uruguay	0.93
USA	1.64	Germany	0.87
China	1.55	World	32.2
Italy	1.15		

Source: Willer and Klicher 2009

ORGANIC FARM MANAGEMENT

Organic farm management is focused on the whole farm system and its interactions with climate, environment, social, and economic conditions, rather than considering the farm as comprised of individual enterprises. Crop production in organic systems is characterized by an increased diversity of cropping patterns in time and in space compared to intensive conventional crop production systems. The major objectives of such diversity are to i) operate a closed system for nutrients and organic matter and ii) maintain crop health.

The aim of nutrient management within organic farming systems is to work, as far as possible within a closed system. Organic farming practices aim to maximize the efficiency of nutrient cycling within the farm ecosystem (e.g. avoidance of losses from manure heaps, optimizing mineralization of soil organic N), and maximizing the fixation of atmospheric N by legumes. Organic standards minimize or eliminate use of synthetic or manufactured inputs and encourage maximum use of local natural resources. The inputs allowed as fertilizers in organic production are generally lower and more variable in nutrient content and plant-availability than commercial fertilizers. Therefore, they have to be applied at high rates to meet all the crop needs. Furthermore, there is greater likelihood of supplying some nutrients at excess rates, which may lead to increased risk of loss and negative environmental impact. There are a number of organic sources of plant nutrition and among them green manuring, composting, biofertilizers and vermicompost (VC) are important.

VERMICOMPOST AS AN ORGANIC AMENDMENT

The use of VC has long been recognized as an effective means of increasing crop yields through improved soil physical, chemical and biological properties. Since synthetic mineral fertilizers are disallowed in organic crop production, there has been a renewed interest in recycling wastes into valuable organic fertilizer through vermicomposting and its subsequent utilization in organic crop production.

Depending on the origin, VCs differ in chemical composition (Handreck 1986); however, VCs of the same waste origin have reproducible characteristics (Tomati *et al.* 1990). VC is a nutritive 'organic fertilizer' rich in NKP (nitrogen (N) 2-3%, potassium (K) 1.85-2.25% and phosphorus (P) 1.55-2.25%), micronutrients, beneficial soil microbes like 'nitrogen-fixing bacteria' and 'mycorrhizal fungi' and plant growth hormones. Kale and Bano (1986) reports as high as 7.37% N and 19.58% P as P_2O_5 in worms' vermicast. They are scientifically proving as 'miracle plant growth promoters' much superior to conventional composts and chemical fertilizers (Sinha and Bharambe 2007; Sinha *et al.* 2009a). Suhane (2007) asserts that VC is at least 4 times more nutritive than cattle dung compost. In Argentina, farmers who use VC consider it to be seven times richer than conventional composts in nutrients and growth promoting values (Munroe 2007). Similarly, Atiyeh *et al.* (2000) found that the conventional compost was higher in 'ammonium', while the VC tended to be higher in 'nitrates', which is the more available form of nitrogen to promote better growth and yield. They also found that VC had higher N availability than the conventional compost on a weight basis and the supply of several other plant nutrients e.g. P, K, sulfur (S) and magnesium (Mg), were significantly increased by adding VC as compared to conventional compost to soil. Then VC retains nutrients for long time and while the conventional compost fails to deliver the required amount of macro- and micronutrients including the vital NKP to plants in shorter time, the VC does (Subler *et al.* 1998).

VCs have the same reported benefits as conventional composts such as a source of organic matter, increased moisture-holding characteristics, and enhanced nutrient uptake and plant hormone-like activity (Tomati *et al.* 1988; Galli *et al.* 1990; Suthar 2010).

EFFECT OF VERMICOMPOST ON GROWTH AND YIELD OF CROPS

VC plays a major role in improving growth and yield of different field crops, vegetables, flowers and fruit crops. The increases in plant growth have mostly been related to improvements in physical and chemical structure of the growth media. However, the use of VC appears to affect plant growth in ways that cannot be directly linked to physical or chemical properties. It seems likely that some growth promotion is due to plant hormone-like activity related to microflora associated with vermicomposting and to metabolites produced as a consequence of secondary metabolism (Parle 1963; Tomati *et al.* 1987; Atiyeh *et al.* 2002).

Table 2 Effect of vermicompost on yield attributes and yield of rice.

Treatment	Productive tillers hill^{-1}	Panicle length (cm)	1000-grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Recommended NPK	7.5	18.64	17.58	4090	5294
Rice straw VC[a]	8.25	20.44	18.65	5135	6203
Sugarcane trash VC[a]	9.15	20.77	19.01	5551	6898
Water hyacinth VC[a]	10.60	21.23	19.36	6315	7799
LSD 5%	0.77	0.19	0.16	494	616

[a] Vermicompost applied at 5 t ha^{-1}
Source: Sudhakar 2000

In India several farmers are being motivated to shift to 'organic farming and sustainable agriculture' through vermiculture and give up 'chemical agriculture' (Sinha 2008). A number of villages in the districts of Samastipur, Hazipur and Nalanda in Bihar have been designated as bio-villages where the farmers have completely embraced organic farming by use of earthworms and VC. They have completely given up the use of chemical fertilizers for the last four years since 2005. They are growing cereals (rice, wheat and corn), fruits (banana, guava, mango and lemons) and vegetable crops (potato, tomato, onion, brinjal, cucumber, okra, etc) on VC.

Cereals

Edwards (1998) reported that VC was an excellent source of nutrients to rice. A study conducted by Kale and Bono (1986) found that the vegetative growth like shoot weight, root weight, shoot and root length of rice were influenced by the application of worm casts in a better way than chemical fertilizer. Similarly, Sudhakar (2000) also reported that VC of various agricultural wastes significantly increased the yield attributes and yield of rice compared with recommended dose of NPK application (**Table 2**).

Gopinath *et al.* (2008) evaluated the impact of VC application on wheat yield during a two-year transition to organic production. VC application resulted in significantly lower crop growth and ears per plant than did the mineral fertilizer treatment. Both treatments, however, produced similar number of grains per ear and 1000-grain weight. The grain yield reduction for VC treatment ranged from 28-41% compared with mineral fertilizer treatment. Lower grain yields in the plots amended with VC may have been associated with the less readily available nutrients in the initial years of transition as nutrient cycling processes in first-year organic systems change from inorganic N fertilization to organic amendments (Harris *et al.* 1994; Reider *et al.* 2000) and slower release rates of organic materials (Liebhardt *et al.* 1989; MacRae *et al.* 1993). After one year of transition, protein content of wheat grain was significantly higher for the mineral fertilizer treatment than for the VC treatment. After the second year of transition, however, both mineral fertilizer and VC treatments had similar effect on protein content of wheat grain. The latter treatment, however, registered significantly higher P and K contents in wheat grain than with mineral fertilizer treatment. Similarly, Ramesh *et al.* (2005) also reported that the grain and straw yields of wheat were reduced by 12.6 and 10.2%, respectively due to VC application compared with mineral fertilizer treatment (**Table 3**). However, the harvest index and protein content of grain were not affected by source of plant nutrition.

On the contrary, several studies on cereal crops done in India at University of Rajasthan (1997-2001) and at Bihar Agriculture University (2007-2009) and in Australia at Griffith University (2007-2009), have revealed that application of VC in potted and field crops displayed excellent growth performances in terms of height of plants, color & texture of leaves, appearance of fruiting structures etc. as compared to chemical fertilizers and the conventional compost. There is also less incidences of pest and disease attack, and reduced demand of water for irrigation (Sinha *et al.* 2009b).

Suhane *et al.* (2008) reported that exclusive application of VC at 2.5 t ha^{-1} in farm wheat crops supported yield better than chemical fertilizers. The wheat grain yield was 4.0 t ha^{-1} from VC amended plots compared with the mineral fertilizer treatment (3.4 t ha^{-1}). The wheat yield was about 3.3 t ha^{-1} from the plots amended with cattle dung compost at 10.0 t ha^{-1} (4 times of VC). Application of VC had other agronomic benefits. It significantly reduced the demand for irrigation by nearly 30-40%. The results also indicated better availability of essential micronutrients and useful microbes in VC applied soils. Most remarkable observation was significantly less incidence of pests and disease attacks in VC applied plots. Nainawatt (1997) also found that the application of VC resulted in higher dry matter production and increased grain yield in comparison to organic manure and chemical fertilizer.

Table 3 Effect of nutrient sources on productivity and protein content of wheat.

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index	Protein content (%)
Vermicompost	3968	4990	0.44	11.44
Cattle dung manure	3890	5120	0.43	11.81
Chemical fertilizers	4544	5560	0.45	12.14
LSD 5%	322	420	NS[a]	NS

[a] non-significant
Source: Ramesh *et al.* 2005

Sinha and Bharmbe (2007), Chauhan (2009) and Valani (2009) also reported higher growth of potted corn and wheat crops on VC as compared to conventional composts and chemical fertilizers. Singh *et al.* (2007) found that the rice grain yield (4.0 t ha^{-1}) obtained under combined application of four organic amendments (blue green algae, *Azolla*, VC and farmyard manure) was at par with the yield recorded under recommended dose of chemical fertilizer application. However, application of VC alone gave about 39% lower grain yield of rice than mineral fertilizer treatment.

Some studies indicate that smaller amounts of VC in fact promote better growth performances of crops. Subler *et al.* (1998) reported that in all growth trials the best growth responses were exhibited when the VC constituted a relatively small proportion (10-20%) of the total volume of the container medium. Valani (2009) observed that 200 g of VC applied in pot soils performed better growth in wheat crops than those with 400 and 500 g of VC. Singh *et al.* (2009) found that the application rate of VC may be reduced after 3-4 years of successive application. They found that both application rates (2.0 and 2.5 t/ha) of VC produced similar wheat yields during the fourth year of field experiment.

In maize, the number of leaves, wet weight of plant, stem height and stem diameter increased 0.10-, 0.48-, 0.15- and 0.29-fold, respectively, in peat moss amended with VC (Gutierrez-Miceli *et al.* 2008). The response of maize plants grown in VC supplemented with peat moss improved with additions of *Glomus fasciculatum* and diazotrophic bacteria. VC increased the mycorrhization of maize roots at 5% but inhibited it at 10%. Water retention, nutrient supply and minor elements in VC amended soil are known to increase favoring a better plant development (Atiyeh *et al.* 2002). It is also possible that humic acids in the VC had positive effect on the growth of maize plants as has been found for peppers in laboratory and greenhouse experiments. Another factor might be that VC improved soil structure thereby

Table 4 Effect of vermicompost on growth and yield of greengram.

Treatment	Yield (g plant^{-1})	Root weight (g plant^{-1})	Nutrient in plant (%)		
			N	P	K
RDN[a] as urea	5.2	0.23	1.44	0.39	1.02
RDN as vermicompost	7.7	0.56	1.49	0.42	1.10
RDN as farmyard manure	5.7	0.35	1.38	0.39	1.06
LSD 5%	0.8	0.03	0.17	0.04	0.06

[a] recommended dose of nitrogen

Source: Rajkhowa *et al.* 2000

Table 5 Effect of organic nutrition on quality of Cowpea [*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcort].

Treatment	% protein	% fiber	Shelf life (days)	Palatability score (4 point scale)
20 kg N ha^{-1} as farmyard manure (FYM)	23.1	10.2	5.7	2.7
20 kg N ha^{-1} as FYM + P solubilizing microorganisms (PSM)	23.1	10.0	5.3	2.7
20 kg N ha^{-1} as vermicompost (VC)	26.7	8.7	6.3	3.3
20 kg N ha^{-1} as VC + PSM	26.7	8.5	6.3	3.7
Mineral fertilizer	17.1	15.67	4.3	1.7
LSD 5%	0.72	1.04	0.27	0.31

Source: Bhaskaran *et al.* 2009

Table 6 Effect of vermicompost application on yield attributes, seed yield and protein content of pigeonpea.

Treatment	Pods plant^{-1}	Seeds pod^{-1}	100-seed weight (g)	Seed yield (kg ha^{-1})	Protein (%)
Chemical fertilizers	195	3.77	9.60	2438	20.30
Vermicompost	192	3.85	9.58	2400	20.68
Control	131	3.35	8.66	1247	19.98
LSD 5%	8.0	0.31	0.52	212	NS[a]

[a] non-significant

Source: Ramesh *et al.* 2006

favoring plant growth (André *et al.* 2003). On contrary, Ramesh *et al.* (2008) reported that VC application gave significantly lower grain yield and protein content of maize compared with chemical fertilizers treatment.

Legumes

The application of VC gave higher germination (93%) of greengram (*Vigna radiata*) compared to the control (84%). Further, the growth and yield of greengram was also significantly higher with VC application (Nagavallemma *et al.* 2004). Similarly, Rajkhowa *et al.* (2000) reported that application of VC showed positive effect on yield, dry matter production and nutrient content in plant (**Table 4**).

Likewise, in another pot experiment, the fresh and dry matter yields of cowpea (*Vigna unguiculata*) were higher when soil was amended with VC than with biodigested slurry (Karmegam *et al.* 1999; Karmegam and Daniel 2000). Similarly, plots amended with VC + P-solubilizing microorganisms (mixture of *Pseudomonas*, *Aspergillus* and *Azospirillum*) produced comparable pod yields (3606 kg ha^{-1}) of cowpea [*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcort] as that of inorganically grown crop (Bhaskaran *et al.* 2009). They also observed that there was an increase of 56.14% for protein in cowpea pods from VC treated plots compared to inorganic treatment (**Table 5**). The highest protein content (26.7%), lowest fibre content (8.5%), highest keeping quality (shelf life – 6.3 days) and best taste (palatability – score 3.7) were recorded due to VC application.

In another experiment on cowpea, Sailaja Kumari and Ushakumari (2002) also reported that application of VC enriched with rock phosphate resulted in significantly higher yields of cowpea and nutrient uptake by the crop compared with treatments involving farmyard manure at 20 t ha^{-1}, VC at 20 t ha^{-1} applied either alone or with mineral P fertilizer.

In pigeonpea (*Cajanus cajan* L.), all the yield attributes, seed yield and protein content from the plots under VC treatment were similar with that of chemical fertilizer treatment (**Table 6**; Ramesh *et al.* 2006).

Sugarcane

VC application has been found to have a favourable influence on all yield attributes, yield and quality of sugarcane compared with chemical fertilizer (**Table 7**; Ismail 1995). Similarly, Singh *et al.* (2007) reported that application of organic amendments (farmyard manure and VC) produced yield parameters and cane yields in both planted and ratoon crop statistically similar to those with recommended NPK (**Table 8**).

Vegetables

Application of VC at 5 t ha^{-1} significantly increased yield of tomato (*Lycopersicon esculentum*) (5.8 t ha^{-1}) in farmers' fields in Adarsha watershed, Kothapally, Andhra Pradesh compared to control (Nagavallemma *et al.* 2004). Similarly, Gutiérrez-Miceli *et al.* (2007) evaluated five treatments combining VC and soil in proportions of 0: 1, 1: 1, 1: 2, 1: 3, 1: 4 and 1: 5 (v/v) on the growth, productivity and chemical characteristics of tomato. The addition of VC increased plant sizes significantly in response to all mixtures. The largest increase in tomato plant heights and stem diameters were obtained in the 1: 4 VC: soil treatment. The yields of marketable fruits were significantly greater in the 1: 1 and 1: 2 VC: soil treatments compared to those in the 1: 4, 1: 5 and control treatments. The yields of marketable fruits per plant increased 1.8-times in response to a 1: 1 VC to soil mixture compared to the control treatment.

The addition of VC increased amounts of soluble and insoluble solids in tomatoes significantly compared to those

Table 7 Effect of vermicompost on yield attributes, yield and quality of sugarcane.

Parameters	Chemical fertilizer	Vermicompost
Number of canes hill^{-1}	6.00	6.66
Cane diameter (cm)	3.26	3.05
Shoot length (m)	1.79	1.57
Cane yield (t ha^{-1})	135.0	143.08
Brix (%)	15.05	17.17
Pol (%)	12.22	14.66
Purity (%)	81.20	85.38

Source: Ismail 1995

Table 8 Yield parameters and yield of sugarcane plant and ratoon crop as influenced by different organic amendments.

Treatment	Millable cane (thousand ha^{-1})		Cane length (cm)		Cane thickness (cm)		Cane yield (t ha^{-1})	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
Control	77.4	70.0	184.1	173.0	2.2	2.0	53.0	46.3
NPK^{a}	95.2	98.5	221.0	216.5	2.4	2.3	76.1	78.1
Vermicompost^{b}	95.4	98.6	223.8	207.8	2.4	2.2	76.7	77.7
Farmyard manure^{c}	94.2	97.0	220.6	204.5	2.2	2.2	70.9	70.7
LSD 5%	1.9	5.3	10.3	11.4	0.2	0.11	6.2	9.5

^{a} 150-60-60 kg ha^{-1}

^{b,c}10 t ha^{-1}

Source: Singh *et al.* 2007

in the control treatment. Soluble solids and carbohydrate contents were correlated positively and these are important parameters of fruit quality (Wang and Liu 2002). The total N contents of tomatoes were not affected by additions of VC. The pH and titratable acidity were not significantly different between treatments, but was significantly lower than those from in the control treatment. Tomatoes from plants grown in soil, mixed with sheep-manure VC, were ideal for juice production because soluble solids > 4.5%, titratable acidity < 2% and pH < 4.4. Similarly, Vadiraj *et al.* (1998) reported that application of VC produced herbage yields of coriander cultivars that were comparable to those obtained with chemical fertilizers.

Padmavathiamma *et al.* (2008) reported that VC application had a significant effect on plant height of chilli crop (*Capsicum annum*) with a maximum height of 75 cm recorded after application of VC enriched with *Azospirillum* and P-solubilising organisms at 95 days after planting. Other biometric indicators like number of leaves/plant and shoot/root ratio also benefited from the application of enriched compost (**Table 9**).

The highest chilli yield was recorded implants which had received VC, *Azospirillum* and P-solubilising organisms. More than N-fixation activity, the ability of producing growth-promoting substances may explain the increased yields due to *Azotobacter* inoculation (Subba Rao 1982). The authors also reported that the N-uptake by the plants which had received VC inoculated with *Azospirillum* and P-solublising organisms was 66 kg ha^{-1}, whereas the N-uptake was only 41 kg ha^{-1} by plants that had received conventional compost inoculated with *Azospirillum* and P-solublising organisms. The increase in N-uptake may be attributed to a small increase in N input from biological nitrogen fixation by *Azospirillum* and increased nitrate reductase activity with the enhancement in uptake of nitrate and ammonical form of N. A high portion of non-available N in organic matter could be made available to plants through vermicomposting and microbial activity. Similarly, Syres and Springett (1984) and Padmavathiamma *et al.* (2008) also reported increased P availability and uptake by crop due to the increase in solubility of P by higher phosphatase activity by VC application.

On the contrary, Ali *et al.* (2007) reported that lettuce biomass production was optimal with a 20/80 (v/v) blend of VC and green waste compost, whilst pure VC and green waste compost yielded poor growth. Leaf chlorophyll content indicated that pure VC inhibited plant growth and depressed N content, whereas plant grown with the other treatments contained similar amounts of chlorophyll. In general, the vermicomposting process did not result in an increased availability of nutrients or potentially toxic elements, the only exception being Zn.

Table 9 Biometric indicators of chili (*Capsicum annum*) (95 days after planting) as influenced by application of enriched vermicompost.

Treatment	Plant height (cm)	No. of leaves per plant	Shoot/ root ratio
Conventional compost (CC)	52	307	1.8
CC + P-solubilizing organisms (PS)	59.5	385	2.9
CC + *Azotobacter*	53.5	341	1.7
CC + PS + *Azotobacter*	61.5	493	2.4
Vermicompost (VC)	54	392	1.9
VC + PS	66	539	3.0
VC + *Azotobacter*	56	502	1.7
VC + PS + *Azotobacter*	75	743	2.7

Source: Padmavathiamma *et al.* 2008

Karmegam and Daniel (2008) observed that application of VC either alone or in combination with 50% of recommended dose of chemical fertilizers was able to produce results constantly equal to an exclusive application of chemical fertilizers as observed through growth and yield of hyacinth bean, *Lablab purpureous* (L.) Sweet.

Fruits

Arancon *et al.* (2004) studied the agronomic impacts of VC and inorganic (chemical) fertilizers on strawberries when applied separately and also in combination. VC was applied at 10 tons ha^{-1} while the inorganic fertilizers (nitrogen, phosphorus, potassium) at 85 (N)-155 (P)-125 (K) kg ha^{-1}. While there was not much difference in the dry shoot weight of strawberries, the yield of marketable strawberries and the weight of the largest fruit was greater on plants in plots grown on VC as compared to inorganic fertilizers 220 days after transplanting. Also there were more runners and flowers on plants grown on VC. In papaya (*Carica papaya*), however, VC application resulted in about 25% reduction in fruit yield compared to mineral fertilizer treatment (Ray *et al.* 2008). However, both VC and mineral fertilizer treatments had similar effect on other parameters like fruit length, fruit weight, fruit breadth and total soluble solids.

VC has the potential to become a useful soil amendment in the Australian and New Zealand wine industries. Field trials carried out by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) with VCs made from mixtures of grape marc waste, animal manure and other agricultural wastes have shown significant increases in yield without decreases in fruit quality (Buckerfield and Webster 1998). In another study, VC was used as mulch under the vines, applied about two inches deep and covered with a thick layer of straw. When VC was applied alone, there was no significant increase in yield; however, when the VC applied was covered with straw, there was a 56% increase in yield. The straw is thought to protect the microorganisms in the VC from UV radiation and desiccation. The following fruit quality factors were measured: Brix (% sugar content), pH and titratable acidity, none of which was adversely affected by VC treatments. The effects of the VC and straw combination were still measurable two years after the original application, which enhanced the economic return for the grower (Buckerfield and Webster 2000).

In another study in Australia, Webster (2006) found that VC increased yield of cherries for three years after single application. Yield was much higher when the VC was covered by mulch. At the first harvest, trees with 5 and 20 mm VC plus mulch yielded cherries of the value of AU$ 63.92 and 70.42, respectively. After three harvests, yield per tree were AU$ 110.73 and 142.21, respectively for the 5 mm and 20 mm VC with mulch. With VC alone (without mulch), trees yielded cherries of AU$ 36.46 per tree with 20 mm VC in the first harvest and after three harvest

AU$ 40.48 per tree. Webster (2006) also studied the agronomic impacts of compost in vineyards and found that the treated vines produced 23% more grapes due to 18% increase in bunch numbers. The yield in grapes was worth additional AU$ 3,400/ha.

EFFECT OF HUMIC ACID EXTRACTS FROM VERMICOMPOST ON CROPS

Apart from nutrient supply, VC is reported to have hormone-like activity, and this has been hypothesized to result in greater root initiation, increased root biomass, enhanced plant growth and development, and altered morphology of plants grown in VC amended media (Grapelli *et al.* 1985; Tomati *et al.* 1988; Muscolo *et al.* 2009). Using phytohormone bioassays, compounds with gibberellin, cytokinin and auxin-like activity have been detected in vermicomposted urban and sewage waste (Grapelli *et al.* 1985; Canellas *et al.* 2002).

Humic acids (HA) extracted from VC have been shown to promote plant growth (Atiyeh *et al.* 2002) as well as physiological changes in plant roots including a greater number of sites of lateral root emergence and greater total root area (Canellas *et al.* 2002). One of the ways that HA are thought to enhance plant growth is by binding plant-growth hormones present in the soil.

Arancon *et al.* (2006) evaluated the effects of HA extracted from VC and compared them with the action of commercial HA in combination with a commercial plant growth hormone, indole-3-acetic acid (IAA) which is commonly found in VCs. Substitution of HA into soil-less MM360 at rates ranging from 250 to 1000 mg kg^{-1} planting medium (MM360) increased root dry weights of marigolds, peppers and number of fruits of strawberries significantly ($P \leq 0.05$). The same range of HA substituted into MM360 (250–1000 mg kg^{-1}) increased the fruit weights of tomatoes significantly ($P \leq 0.05$). In the second series of experiments, HA extracted from food waste VCs increased the numbers of flowers and fruits of peppers significantly ($P \leq 0.05$) compared with peppers planted in MM360 only. However, the numbers of flowers and fruits did not differ significantly from those treated with IAA only demonstrating clearly that HA had an effect on pepper plants similar to the effects of a plant growth regulator such as IAA. This research provides clues as to how VCs influence plant germination, growth flowering and yields so dramatically, over and above their content of readily available nutrients (Atiyeh *et al.* 2000a, 2000b).

VERMICOMPOST LEACHATES (VERMIWASH)

Vermicomposting process produces leachate due to the activities of micro-organism and draining of leachates is important to prevent saturation of the vermicomposting unit. Leachates thus derived from vermicomposting are regarded as beneficial and can be used as liquid fertilizer due to high concentration of plant nutrients (Jarecki *et al.* 2005; Gutierrez-Miceli *et al.* 2008; Tejada *et al.* 2008). Apart from its high nutrient content, VC leachates also contribute to plant development due to presence of HA (Atiyeh *et al.* 2002; Arancon *et al.* 2004; Ordoñez *et al.* 2006) which regulate many processes of plant development including macro and micronutrients absorption. Gutierrez-Miceli *et al.* (2008) reported the use of VC leachates as liquid fertilizer in sorghum. Similarly, many researchers have reported the beneficial use of VC leachates for production of good quality tomatoes (Tejada *et al.* 2008) and strawberry (Singh *et al.* 2010) and recommended that these leachates can effectively be utilized for agricultural purposes. Farmers from Bihar in North India have reported growth promoting and pesticidal properties of this liquid. They have been using it on brinjal (egg plant) and tomato with excellent results. Spray of vermiwash effectively controlled all incidences of pests and diseases, significantly reduced the use of chemical pesticides and insecticides on vegetable crops and the products were significantly different from others with high market value. These farmers are using VC and vermiwash in all their crops since last 4 years completely giving up the use of chemical fertilizers and pesticides (Sinha *et al.* 2009b).

SOIL PROPERTIES

Physical properties

Organic matter is the major component that stimulates the formation and stabilization of granular and crumb type of aggregates. As organic residues decompose in soil, organic acids, sugars, mucilaginous substances, and other viscous microbial byproducts are evolved which, along with associated fungi and bacteria, encourage the crumb formation and net effect of these activities will decrease bulk density and increase porosity (Loganathan 1990). VC has very high porosity, aeration, drainage and water holding capacity. It has a vast surface area, providing strong absorbability and retention of nutrients. It appears to retain more nutrients for longer period of time. Increase in porosity has been attributed to increased number of pores in the 30-50 µm and 50-500 size ranges and decrease in number of pores greater than 500 µm (Nighawan and Kanwar 1952; Lunt and Jacobson 1994). Similarly, Marinari *et al.* (2000) also reported that VC application increased macropore space ranging from 50 to 500 µm, resulting in improved air-water relationship in the soil which favorably affected plant growth. Application of VC reduced particle and bulk density and increased pore space and water holding capacity of clay loam, sandy loam and red soils (Parthasarathy *et al.* 2008).

Gopinath *et al.* (2008) reported that VC application resulted in lower bulk density of soil (1.14 Mg m^{-3}) than with mineral fertilizer check (1.27 Mg m^{-3}). Similarly, González *et al.* (2010) found that a single application of VC (2 kg m^{-2}) was enough to significantly reduce soil bulk density. Singh *et al.* (2007) observed improvement in soil physical properties such as bulk density and water infiltration rate due to addition of VC compared with mineral fertilizer and control checks. Earthworm casts are usually considered to be responsible for a good soil structure and improve soil physical properties such as infiltration, water retention and resistance to erosion (Rose and Wood 1980). Lee (1985) reported that the hydraulic conductivity increased by 8% and water infiltration by 6-fold due to VC application.

Chemical properties

The transition from conventional to organic and low-input farming is accompanied by changes in an array of soil chemical properties and processes that affect soil fertility. Fundamental differences, both qualitative and quantitative, in the flow and processing of nutrients result from the use of cover crops, manure or compost applications, and reduction or elimination of synthetic fertilizers and pesticides. These changes affect nutrient availability to crops either directly by contributing to nutrient pools or indirectly by influencing the soil chemical and physical environment. Because these soil properties are critical in determining the fertility of agricultural soils, the ability to predict and manage their dynamics and intensity in time and space will facilitate the transition to organic and low-input farming practices.

Changes in soil pH over time occur by the displacement of cat-ions or by additions of sources of acidity like hydrogen and aluminum ions. Chemical fertilizers are highly reactive and can cause extreme pH fluctuations in localized areas such as those near the fertilizer band. In contrast, organic manures can increase the buffering capacity of soils, preventing swings in pH, because of the additional organic matter (Arden-Clarke and Hodges 1988).

The soil pH increased significantly in VC-amended plots compared with mineral fertilizer treatment (Gopinath *et al.* 2008). These results are similar to those in earlier reports (Reganold *et al.* 1993; Drinkwater *et al.* 1995; Werner

Table 10 Effect of organic amendments on different soil properties.

Treatment	pH	Organic C (%)	Available nutrients (kg ha^{-1})		
			N	P	K
Composted farmyard manure (FYMC) 20 t ha^{-1} + biofertilizers (BF)	7.1^{a}	1.3^{a}	452.6^{b}	21.8^{ab}	252.0^{a}
Poultry manure (PM) 5 t ha^{-1} + BF	7.0^{ab}	1.2^{ab}	450.4^{b}	20.7^{ab}	231.8^{bc}
Vermicompost (VC) 7.5 t ha^{-1} + BF	7.0^{ab}	1.1^{b}	440.9^{b}	19.2^{bc}	223.8^{cd}
FYMC 10 t ha^{-1} + PM & VC each 1.5 t ha^{-1} + BF	7.1^{a}	1.2^{ab}	449.3^{b}	21.4^{ab}	247.1^{ab}
FYMC 10 t ha^{-1} + mineral fertilizer	6.9^{b}	1.1^{b}	483.5^{a}	23.4^{a}	260.9^{a}
Unamended control	6.7^{c}	0.9^{c}	408.1^{c}	16.9^{c}	210.4^{d}

Means in the same column with different letters are significantly ($P < 0.05$) different

Source: Gopinath *et al.* 2009

Table 11 Effect of vermicompost application on soil chemical properties.

Treatment	pH	Organic C (%)	Available nutrients (kg ha^{-1})		
			N	P	K
20 kg N ha^{-1} as farmyard manure (FYM)	5.51	0.66	241	30	144
20 kg N ha^{-1} as FYM + P solubilizing microorganisms (PSM)	5.51	0.67	261	33	149
20 kg N ha^{-1} as vermicompost (VC)	6.31	0.78	296	37	175
20 kg N ha^{-1} as VC + PSM	6.33	0.78	308	39	171
Mineral fertilizer	5.30	0.50	188	22	122
LSD 5%	0.13	0.05	23.9	1.8	11.8

Source: Bhaskaran *et al.* 2009

Table 12 Effect of organic amendments on soil microbial activity.

Treatment	Soil microbial population (×10^{3} CFU g^{-1} soil)				Dehydrogenase
	Actinomycetes	Bacteria	Fungi	Blue green algae	(µg TPE g^{-1} soil 24h^{-1})
Farmyard manure (F)	261	322	51	61	110
Vermicompost (V)	276	365	43	48	108
Azolla+BGA+F+V	301	334	61	87	125
Mineral fertilizer	164	332	69	23	101
Unamended control	160	312	29	12	101

Source: Singh *et al.* 2007

1997; Clark *et al.* 1998) where organic systems had higher pH levels in mildly acidic soils than their conventional counterparts. This illustrates the important role that organic manures and other organic matter inputs can have in buffering the pH of the soil (Stroo and Alexander 1986; Arden-Clarke and Hodges 1988).

An important feature of environmental benefit due to a change in agricultural practice is the soil carbon content (Carter *et al.* 1997). Depending on soil type, climate, management, and the capacity of a soil to store organic matter, SOC levels may increase linearly with the amount of organic matter input (Carter 2002). During the transition years from conventional to organic farming systems, soils show a very slow but important increase in organic matter (Kuo *et al.* 1997; Clark *et al.* 1998). Soil organic carbon was higher in VC-amended plots than in those under mineral fertilizer treatment (Gopinath *et al.* 2008). Plots that had mineral fertilizer applied, however, had higher levels of available N and P than did those under VC. However, plots under both mineral fertilizer and VC treatments had similar K levels. Gopinath *et al.* (2009) also reported similar results (**Table 10**).

On the contrary, Bhaskaran *et al.* (2009) reported that the treatments with VC application registered superior values for all the soil chemical properties like pH, cation exchange capacity, organic carbon, and C/N ratio (**Table 11**). Similarly, Ansari and Sukhraj (2010) observed that application of VC either alone or in combination with vermiwash had significant effect on the biochemical properties of soil with marked improvement in soil micronutrients. The increased level of organic carbon is a good indication of better carbon sequestration in soil by reducing the amount of CO_2 released to the atmosphere. Available N, P and K in soil were also increased by VC application. The observed pH increase was due to the suppression of the activity of Fe and Al oxides and hydroxides, which played a vital role in protonation-deprotonation mechanism, controlling H^+ ion concentration in soil solution.

Biological properties

Soil organic matter is an important source of nutrients and can help increase microbial biodiversity, which provides vital ecological services, including crop protection. Organic amendments including VC can foster beneficial microorganisms, which in turn facilitate soil enzymatic activities (Drinkwater *et al.* 1995; Sinha *et al.* 2010). The incorporation of organic amendments into the soil influences the soil's enzymatic activities because the added material may contain intra- and extracellular enzymes and may also stimulate microbial activity in the soil (Pascual *et al.* 1998). Dehydrogenase activity has been commonly used as indicator of biological activity in soils because of its occurrence only within living cells, unlike other enzymes which can occur in an extra cellular state. The change in dehydrogenase activity corresponds more closely to microbial biomass generated through an enhanced microbial activity rather than direct nutritional or amendment effect (Burns 1982).

Application of VC resulted in higher populations of actinomycetes and bacteria in soil compared with other treatments except combined application of four organic amendments (**Table 12**; Singh *et al.* 2007). Among the treatments involving farmyard manure and VC, the former had higher populations of fungi, blue green algae, and dehydrogenase activity. Earthworm casts are rich in ammonia and partially digested organic matter and provide good substrate for the growth of microorganisms. Therefore, VC can be effectively utilized as a carrier medium for *Azospirillum*, *Rhizobium* and phosphate solubilizers. There will be an increase in cellulolytic, hemicellulolytic and nitrifying bacteria in earthworm casts compared to the surrounding soil (Kale 1998).

The addition of VC at 10 t ha^{-1} in sugarcane growing soils resulted highest soil microbial biomass C and soil microbial nitrogen compared with treatments involving farmyard manure at 10 t ha^{-1}, sulphitation pressmud cake at 10 t ha^{-1}, mineral fertilizer and control (Singh *et al.* 2007).

Organic nutrition particularly VC application enhanced the soil enzyme activities like dehydrogenase and phosphatase (Singh *et al.* 2008; Bhaskaran *et al.* 2009). The superiority of VC from other organic amendments in exhibiting a higher phosphatase activity was due to the higher microbial load that VC supports. The amounts of total extractable nitrogen, orthophosphates, dehydrogenase and the microbial biomass were usually greater in the soils from the VC treated tomato plots (Arancon *et al.* 2003). Similarly, Gopinath *et al.* (2008) also reported that VC-amended plots had significantly higher dehydrogenase activity than did mineral fertilizer treatment and unamended checks. The dehydrogenase activity increased with increase in application rates of VC. The greater dehydrogenase activity noted at the high dosage (150 kg N ha^{-1}) suggests that the added amendments did not include compounds that were toxic for this activity (Pascual *et al.* 1998). Plots treated with VC also showed higher activities of β-glucosidase, acid phosphatase and urease compared with mineral fertilizer and control plots (Saha *et al.* 2008; Tajeda *et al.* 2009).

CONCLUSION

Vermiculture was practiced by traditional and ancient farmers with enormous benefits accruing for them and their farmlands. However, with the introduction of high yielding varieties together with agro-chemicals, there was marked decline in the use organic manures particularly VC for crop production during second-half of the 20th century. Recently, there has been a renewed interest in recycling wastes into valuable organic fertilizer through vermicomposting and its subsequent utilization in organic crop production. A number of studies have been conducted comparing the effect of VC *vis-à-vis* chemical fertilizers on crop production and soil quality. The response to VC application depends on type of crop and its nutrient requirement and initial soil fertility levels among many factors. Several researchers have reported that application of VC gave marginally lower or comparable crop growth and yields with that of mineral fertilizer application. In addition to the direct effects of VC as a source of plant nutrients, some of the more interesting effects of VC on plants are non-nutrient related and point to the possibility that using composts may be a sustainable way to increase biological health of soil . The nutrient release pattern in VCs prepared from different organic residues, and the relative composition and effect of HA, plant growth regulators, hormones, etc. on crop growth and development require further research.

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