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Review

Efficacy of the Vermicomposts of Different Organic Wastes as "Clean" Fertilizers: State-of-the-Art

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Abstract: Vermicomposting is a process in which earthworms are utilized to convert biodegradable organic waste into humus-like vermicast. Past work, mainly on vermicomposting of animal droppings, has shown that vermicompost is an excellent organic fertilizer and is also imbibed with pest-repellent properties. However, there is no clarity whether vermicomposts of organic wastes other than animal droppings are as plant-friendly as the manure-based vermicomposts are believed to be. It is also not clear as to whether the action of a vermicompost as a fertilizer depends on the species of plants being fertilized by it. This raises questions whether vermicomposts are beneficial (or harmful) at all levels of application or if there is a duality in their action which is a function of their rate of application. The present work is an attempt to seek answers to these questions. To that end, all hitherto published reports on the action of vermicomposts of different substrates on different species of plants have been assessed. The study reveals that, in general, vermicomposts of all animal/plant based organic wastes are highly potent fertilizers. They also possess some ability to repel plant pests. The factors that shape these properties have been assessed and the knowledge gaps that need to be bridged have been identified.

Keywords: vermicompost; organic waste; organic fertilizer; germination; seed dormancy; plant pests

1. Introduction

For sustaining soil fertility and boost crop production, organic wastes such as cattle droppings, rejects from the kitchen, sewage sludge or anaerobically digested animal manure have been used in agriculture for a long time [1–3]. These substances provide nutrients and organic carbon to the soil, but not very efficiently [4]. Moreover, some of these substances can undergo anaerobic decomposition in the soil, and generate methane, which is a major global warming gas [5–7]. Vermicomposting is believed to offer a route by which organic waste can be stabilized to a significant extent, converting it into a finished fertilizer [8]. Similar ends can be achieved with composting but composting is an energy-intensive process and the fertilizer value of the composts is known to be inferior to that of vermicomposts [9–12].

Both composting and vermicomposting involve biological decomposition of organic waste to produce a stabilized organic fertilizer. However, vermicomposting is distinguished from all other pollution control processes, including composting, in that an animal—an earthworm—facilitates the microbial action on the waste. This occurs because the waste is exposed to certain bacteria and enzymes present in the earthworm gut which are not available during composting or other biological degradation processes and which bestow special attributes to a vermicompost (VC). During ingesting bits of waste, earthworms comminute them with their gizzards, thereby enhancing their surface area manifold and making them much more amenable to microbial and enzymatic action than they otherwise were [8]. As the masticated waste passes through an earthworm's gut, it is acted upon by enzymes and microorganisms present in the gut to become extensively biodegraded [13–16]. The substrate also acquires some of the enzymes and microorganisms, as well as some of the hormones, present in the earthworm gut, as it is excreted by the earthworm in the form of vermicast. During this vermicomposting, 50 ± 10% of the organic carbon present in the parent substrate is mineralized and is emitted in the form of carbon dioxide. Due to this, the concentration of nitrogen, phosphorous, and other major, medium, and trace nutrients is enhanced in the VC relative to the parent substrate. The mineralization caused by the biodegradation also makes these nutrients more bioavailable than they were in the parent substrate.

However, even as several reports exist which have shown that VC stimulated seed germination [17–19], supported plant growth and enhanced the yield and the quality of fruits [20,21] of several plant species, there are also reports describing that VC either had no beneficial effect or had a detrimental effect [19,22–25]. Likewise, there are reports which show that VC can induce resistance in plants against pests and diseases [26–29] but it is not known whether the opposite effect also occurs.

This assessment of the state-of-the-art was performed to determine the balance of evidence for and against the virtues of VC. It is aimed to identify the different reasons advanced so far to explain the different types of impacts of VC as witnessed during different ways of VC application. Additionally, it is aimed to locate knowledge gaps that have to be filled up if we are to realize the true potential of VC as an organic fertilizer and biopesticide.

2. Methodology

We began by exploring all potential sources for material on the effect of VC derived from different substrates on different species of plants. All papers/reports available on Science Direct, Web of Science, and Google Scholar were considered. Abstracts from conferences, book reviews, editorials, letters, and news stories were excluded. The material was classified based on: (1) studies showing stimulatory effect at all levels of VC applications; (2) studies showing stimulatory effect depending on the concentrations of the VC applied; (3) studies showing no effect; and (4) studies showing inhibitory effect of VC application. The role of VC in inducing resistance in plants against pests and diseases was also assessed. The possible reasons for the differences in the nature of impacts of VC, as advanced by different authors, were then identified and classified.

When the study was initiated, we had aimed at a meta-analysis in which we would have tried to quantify cause–effect relationships, assess the weight of different influences, and carry out tests of significance. However, it was not possible because of great non-uniformity in the data that have been reported in the past. The effect of vermicomposts derived from different substrates has been assessed often in combination with other fertilizers on many different botanical species, with widely differing soils and container media, and irrigation with water of widely differing quality, under highly diverse agroclimatic conditions. This extent of variability made it impossible to quantify responses beyond computation of percentages under broad classifications.

3. State-of-the-Art

A total of 252 reports were located in primary literature. A summary is provided in Tables 1–4. The bulk of these studies have been published during the last 10 years and more studies have been published during 2011–2015 than in any eairly five-year span (Figure 1). These statistics reveal the world's increasing interest in VC. The relative proportion of studies on VC derived from manure, phytomass, manure-phytomass blends, and substrates other than manure and phytomass are presented in Figure 2. As may be seen, there is predominance of studies which involve manure, either alone or in combination with phytomass. Studies on phytomass are less than 1/3 of all, even though by far much greater quantities of waste phytomass are generated in the world than of animal manure. The reasons for much lesser utilization of phytomass than animal manure for VC until now was explained by us recently [30].

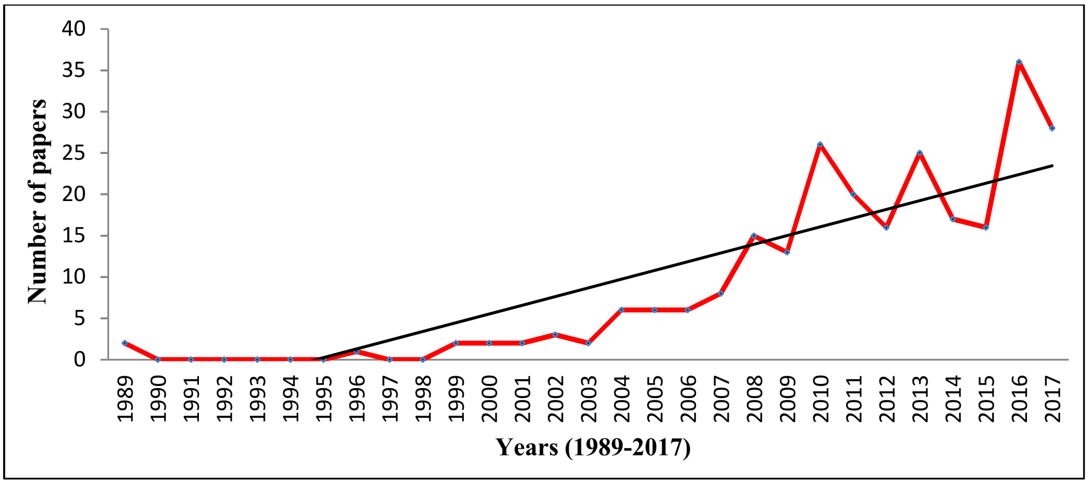

Figure 1. Number of papers published on the effect of vermicompost (VC) on germination, growth, yield, disease control and soil health, during 1989–2017.

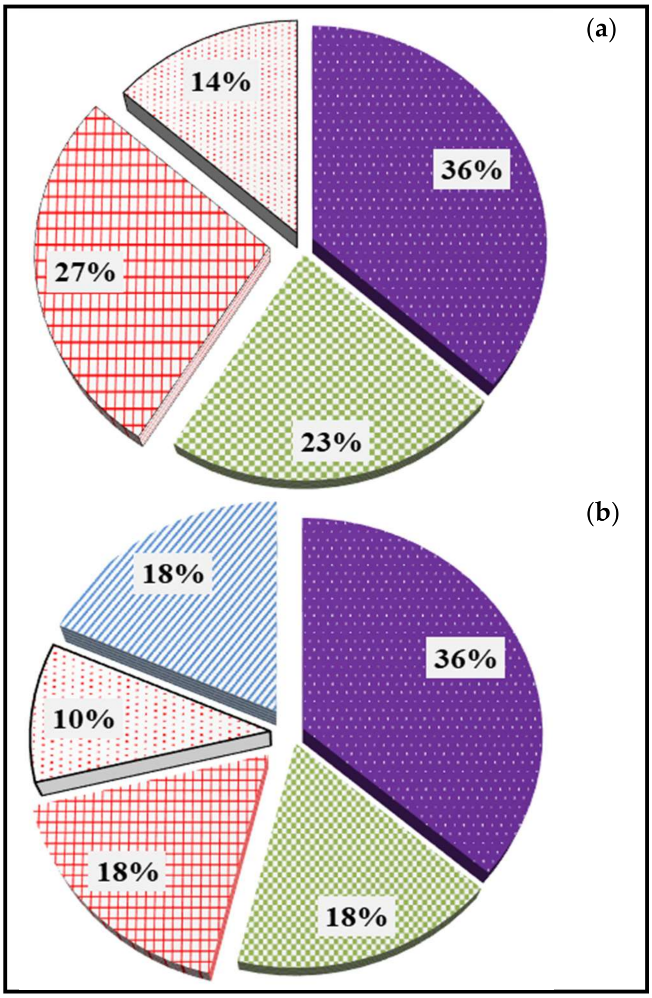

Figure 2. *Cont.*

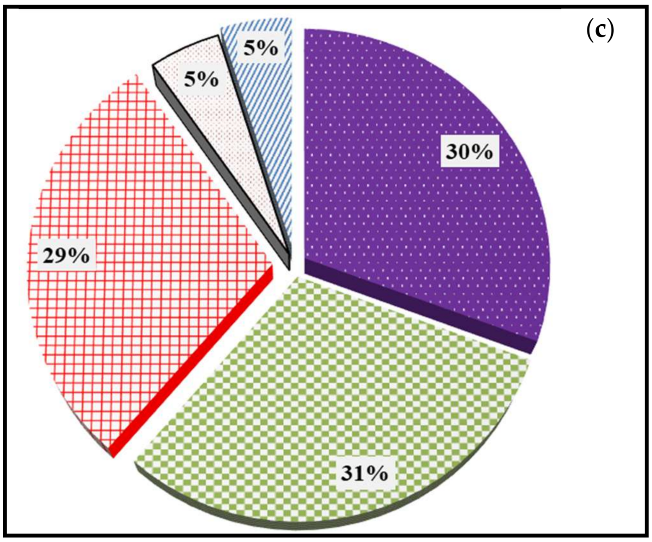

Figure 2. Fractions of studies describing impact of vermicompost derived from manure, phytomass, manure-phytomass mixture, other substrates, and with no mention of source of VC on (**a**) seed germination; (**b**) growth and yield, and (**c**) soil health.

3.1. Effect of Vermicompost on Seed Germination

As shown in Table 1, seeds of several plant species have been used to evaluate the influence of VC on their germination. The findings present a mixed picture: in the majority of cases VC was found to promote germination but no effect or negative effect was also reported. The relative proportion of studies reporting different types of impacts of VC on seed germination is reflected in Figure 3a. Enhancement was reported in 40% of the studies while 37% reported stimulation up to certain VC concentrations and inhibition beyond those concentrations. In 9% of reports, only inhibition was shown, and 14% reported no impact. Thus, 77% of studies claimed that VC facilitates seed germination, at least up to certain levels of application.

The nature of the effect VC exerts seems to depend on plant species and VC concentration. Seed germination is essentially an internally regulated process, which is influenced mainly by the genotype of plants. However, external factors such as temperature, humidity, light period, soil moisture, and presence of certain chemical compounds can also alter this process through either promotion or inhibition [31,32]. All these factors are intertwined and are facilitated by signaling through multiple hormones that either promote or inhibit seed germination [33].

The first study reporting the duality in behavior of VC—increased germination success up to certain concentrations and inhibition at higher levels—was reported by Wilson and Carlile [34]. They found that duck waste VC in the range 2–8% increased the germination success of tomato (*S. lycopersicum*), lettuce (*L. sativa*), and pepper (*Capsicum* sp.), while 10–20% VC treatments reduced the germination success significantly. In a recent series of extensive investigations, Hussain et al. [35–39] found that VC derived from salvinia (*Salvinia molesta*), lantana (*Lantana camara*), parthenium (*Parthenium hysterophorus*), and ipomoea (*Ipomoea carnea)* enhanced the germination success of ladies finger, green gram and cucumber when used in the concentration range of 2–8% but hindered it at higher levels of application. The possible reasons for the dual behavior of VC, culled from reports in Table 1, are summarized below:

(a) As mentioned in the Introduction, during vermicomposting, a substrate loses 50 ± 10% of its carbon in the form of emitted CO_2 which is produced from worm-mediated aerobic biodegradation. On the other hand, nitrogen is not lost; rather some nitrogen gets added in the form of earthworm mucus. The combined effect is a reduction in the substrate mass with the consequent enhancement in the concentration of nitrate and ammonium in the vermicast relative to that in the substrate. All other nutrients also get enriched. As both nitrate and ammonium are efficient breakers of seed dormancy [40,41], their enrichment in VC makes the latter a facilitator of germination. Indeed, nitrate and ammonium are known to be especially effective when present together. Even though several attempts have been made to explain this individual and collective action of nitrate and ammonium on germination, no clear picture has emerged yet [42,43].

(b) Breaking of seed dormancy is facilitated by several organic chemicals as well. Such compounds include relatively simple aliphatics, e.g., methanol, ethanol, acetone and ethyl ether; aromatics, e.g., phenol and hydroxyquinoline; and complex growth regulators, e.g., gibberellins and cytokines [44]. As VC is rich in organic chemicals [45–48], it is likely to contain one or more of these compounds which enhance germination success. It has already been shown that plant growth hormones that are present in VC facilitate seed germination [49,50].

(c) Most of the chemicals which promote germination up to certain concentrations are known to inhibit it when present in higher concentration [50–52]. Chemical fertilizers also display this dichotomy—facilitating germination and growth up to certain levels of application and hindering the same at higher levels [53–55].

(d) Elevated salinity, caused by the higher mineral content of VC, perhaps slows down water uptake by seeds, thereby inhibiting their germination and root elongation [56–58]. Neamatollahi et al. [59] suggested that salinity may also affect germination by facilitating intake of toxic ions, which may change certain enzymatic or hormonal activities in seeds to the detriment of seed germination [60].

3.2. Effect of Vermicompost on Plant Growth and Yield

The studies are summarized in Table 2. Of these, 84% of studies reported stimulation, 11% reported stimulation or inhibition based on the rate of application, 2% reported only inhibition and 3% reported no impact (Figure 3b). In other words, 95% of the studies showed that VC exerts a beneficial influence on plants, at least up to certain concentrations. This general surmise is significant, considering the great variability in the past studies in terms of plant species tested, types of soils and other container media used, and the manner of fertilization which ranged from exclusive use of a VC to the deployment of complex mixtures of VCs, chemical fertilizers, and other amendments. The reports also cover widely varying agroclimatic regions and agricultural practices.

Given the extent of coverage of various possibilities, and the very large fraction of the studies which indicate that VC exerts beneficial influence, it can be generalized that VCs are good organic fertilizers. However, a great deal of uncertainty exists on what levels of VC applications are beneficial for which stage of plant growth. It is also not totally clear as to how a VC exerts its beneficial impacts and why it begins harming the growth of plants beyond certain concentrations—even as a good deal of understanding of the possible factors does exist. It is almost certain that VC improves the nutrient content of the soil or the container media to which it is applied [61–65]. Several other reports also suggest that the increase in the growth and yield of plants is a result of the increased nutrient levels in the VC amended soil/media [66–75].

The improvement in the physical properties of soil caused by the VC application, discussed in the following section, may also be a factor supporting plant growth and fruit yield.

A VC carries rich and diverse microbial populations, particularly fungi and bacteria [76,77]. It has been suggested that this could result in the production of significant quantities of plant growth regulators such as indole acetic acid, gibberellins and cytokinins by microorganisms [78], besides an increase in the enzymatic activities. Hussain et al. [35–39] reported an increase in the microbial biomass carbon in soil amended with the VCs derived from *L. camara*, *I. carnea*, *P. hysterophorus*, and *S. molesta*. Pointing to the importance of the role of microorganisms, Arancon et al. [49] suggested that the enhanced plant growth in the VC amended media cannot be attributed entirely to the physical and chemical amelioration by the VC. They found that plant growth was better in the VC amended media, compared to the control media, even when all the nutrients equivalent to those contained in the VC were given to the plants growing in the control media [79]. They postulated that it was the plant growth hormones and humic acids in the VC that, in conjunction with better nutrient availability, exerted the beneficial effect. Canellas et al. [80] and Zandonadi et al. [81] reported that the humic substances extracted from earthworm's compost were capable of inducing lateral root growth in maize plants by stimulation of the plasma membrane H+-ATPase activity, thus producing an effect similar to the one achieved by exogenous application of indole-3-acetic acid (IAA). Another perspective is the induction of lateral root initiation by VC-derived humic substances which has been related to the activation of the transcription of some auxin responsive genes [82]. The hypothesis of the auxin activity of the VC-based humic substances is reinforced by the presence of exchangeable auxin groups in their macrostructure [80].

The ability of VC to suppress plant pests and pathogens may also contribute to better growth and yield of the VC fertilized plants. This aspect is elaborated in Section 3.4.

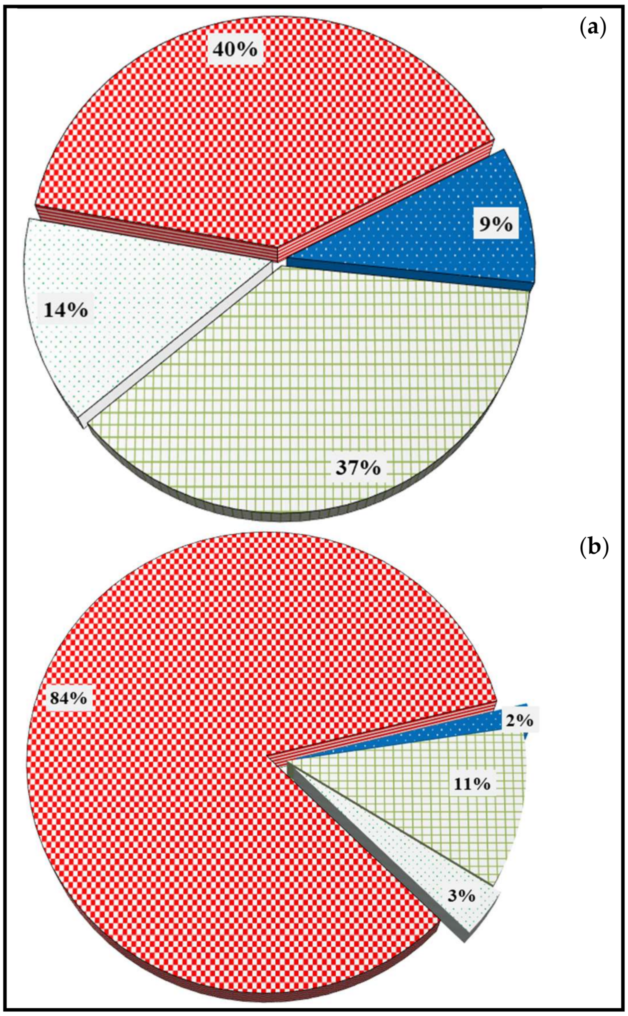

Figure 3. Relative fractions of studies on the effect of vermicompost on (**a**) seed germination; and (**b**) plant growth and yield: [no effect pattern] no effect, [stimulation pattern] stimulation, [inhibition pattern] inhibition, and [grid pattern] stimulation at lower concentrations and inhibition at higher.

3.3. Effect of Vermicompost on Soil Health

Several studies reported the positive impact of VC on soil health (Table 3). The possible ways by which VC is reported to improve soil health are:

(1) Addition of VC to the soil elevates the organic matter content in the latter. The vermicast particles, which tend to slowly dissolve in water, contribute to an increase in the overall pore space and

water holding capacity of the soil, with concomitant decrease in the soil's bulk and particle density [17,34,83].

(2) VC is known to contain high concentrations of plant-available nutrients such as nitrates, phosphates, exchangeable calcium and soluble potassium. These when supplemented to the soil enhance the nutrient content of the soil [84–86].

(3) Earthworms excrete polysaccharides, proteins and other nitrogenous compounds creating resource heterogeneity that ultimately increases microbial diversity [45–48]. During the gut transit, the pore space between organic and mineral particles is altered and packing void is created in the deposited castings. The structural rearrangement of the organic matter in the intestine of the earthworm results in more fine pores and fewer macropores in the castings. This enhances the availability of both water and nutrients to microorganisms, thus enhancing the microbial population in the soil. This, in turn, increases the activity of beneficial enzymes, hormones and plant growth regulators in the VC, and hence in the soil.

3.4. Effect of Vermicompost on Pests and Disease

As can be seen in Table 4, several studies showed that VCs can suppress a wide range of microbial diseases, insect pests and plant parasitic nematodes. Szczech [87] and Szczech and Smolinska [88] reported significant reduction in the infection caused by *Fusarium lycopersici* and *Phytophthora nicotianae* in tomato grown in VC−amended soil. Arancon et al. [89] found that tomato, pepper and cabbage plants grown in VC amended media have significantly lesser infections caused by *Myzus persicae*, *Pseudococcus* spp. and *Peiris brassicae*. Yardim et al. [26] reported reduction in the *Manduca quinquemaculata*, *Acalymma vittatum*, and *Diabotrica undecimpunctata* infestations in the cucumber and tomato plants grown in pig manure VC. Several other reports also suggest that VC amendment significantly reduces pathogen attacks on plants [90–96].

Several studies have indicated that better nutrient availability and the presence of antimicrobial compounds such as flavonoids, phenolics and humic acids in the VC may have induced resistance to pathogens in the plants [27,97–100]. According to Cardoza [93], the resistance against the diseases and pests may be influenced more by the microbial flora than the chemical compounds in the VC [39]. This premise is supported by the studies of Ershehin et al. [91] and Szczech and Smolinska [88] who found that the autoclaved vermicasts were no longer effective in suppressing the plant pathogens. Gopalakrishnan et al. [101] reported that actinomycete isolates from vermicasts were found to be effective in the biocontrol of the fusarium wilt in chick pea (*Cicer arietinum*). Out of 137 tested isolates, 33 were reported to show an antagonistic potential against fusarium wilt and, hence, could help to control it in the *C. arietinum* plant.

4. A Summary of the Nature and Causes of Different Effects

The possible reasons for the beneficial effects of VCs are summarized as:

(1) VCs have higher nutritional value than traditional composts. This is due not only to the increased mineralization but also greater degree of humification caused in them by the action of earthworms [21,102].

(2) VCs contain higher concentrations of plant-available nutrients such as nitrates, phosphates, exchangeable calcium, soluble potassium, and trace metals. When a VC is supplemented in soil, it enhances the relative proportion of these micro, semi-micro, and macro nutrients, thereby promoting pant growth and yield [84–86,103,104].

(3) VCs contain humus which plays an important role in regulating the retention and release of plant nutrients. Humus contains negatively charged components in large numbers and is thus capable of holding many cations. This gives a VC the ability to act as a slow release fertilizer [105,106].

(4) VCs are rich in organic matter, which, when added to the soil, increases the soil's porosity, aeration, and water-holding capacity, with concomitant reduction of soil's bulk and particle

density. The resulting overall improvement in the physical properties of the soil contributes significantly to better plant growth and yield [76,106–108].

(5) VCs contain large and diverse microbial population, which produces plant growth regulators, enzymes, and hormones beneficial to the plant growth [77,109,110]. There is also production of cytokinins and auxins [78,111].

The possible reasons why VCs exert a negative effect when applied at higher-than-desirable concentrations can be summarized as:

(1) As happens with germination, the growth of plants is adversely affected if nutrients are supplied in excess of the plant's needs [35,112,113].
(2) If VC application is excessive, the resulting salinity may also inhibit plant growth [114–116]. Elevated salinity slows down water uptake by the seeds, thereby inhibiting their germination and root elongation as well as subsequent plant growth [56–60].
(3) High levels of active substances of both phenolic and humic nature may suppress plant growth [115,117]. Phenolic compounds are among the secondary metabolites implicated in plant allelopathy and affect the plants in the following ways:

    (a) They increase the permeability of cell membranes, causing the cell contents to spill out leading to increased lipid peroxidation. Consequently, the growth of cells slows down and causes the death of the plant tissues. In addition, excessive phenolic compounds interfere with the absorption of the nutrients by the plants, thereby restricting the growth of the plants.
    (b) They are also known to impede the elongation of roots, plant cell division, and disturb the cell ultra-structure. In this manner, they interfere with the normal growth and development of the entire plant.
    (c) They tend to weaken the oxygen absorption capacity of plants, causing hindrance in the respiratory process. In addition, phenolic compounds adversely affect photosynthesis by reducing the chlorophyll content of the leaves. Consequently, the rate of photosynthesis is slowed down. Patterson [118] reported that caffeic acid, coumaric acid, ferulic acid, cinnamic acid, and vanillic acid in the concentration range 10–30 μmol/L could significantly inhibit the growth of soybean *(Glycine max)*. Photosynthetic products and chlorophyll content of *G. max* were also strongly reduced.
    (d) They enter the plants through the plant's cell membrane and change the activity and function of certain enzymes. Rice [119] demonstrated that chlorogenic acid, caffeic acid and catechol can inhibit activities of phosphorylase, while cinnamic acid and its derivatives can inhibit the hydrolysis activities of ATPase.
    (e) Phenolic compounds can hinder, even stop, the physiological activity of plant hormones, in turn inhibiting the normal physiological processes in the plants. Hydroxyl benzoic acid, polyphenols, and other compounds have been shown to suppress the decomposition of indole acetic acid and gibberellin.
    (f) While some phenolics (i.e., ferulic acid and cinnamic acid) have been seen to inhibit protein synthesis [120], all phenolics have the potential to reduce integrity of DNA and RNA [121–123].

(4) Elevated concentrations of heavy metals alongside the elevated salinity and nutrient contents may also be the cause of suppression of plant growth when excessive levels of VC are applied [17]. Heavy metals induce growth inhibition, structure damage, and a decline in physiological and biochemical activity when present above certain concentrations [122].

The possible reason why some authors found no impact of VC on plant growth and yield may be due to the use of such doses of VCs which may not have been sufficient to satisfy the nutrient demand of plant species studied, leading to no impact on growth and yield [124].

Table 1. Effect of vermicompost (VC) on seed germination.

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of seed germination		
Cattle dung	Flax (*Linum usitassimum* var LC-54 and LC-2063)	In commercial potting media (perlite, peat and coconut coir) VC was mixed in proportions 0%, 20%, 40%, 60%, 80%, and 100% (*v*/*v*). In addition, the effect of vermiwash and inorganic fertilizers was also explored.	Substituting soil with 60% VC in LC-54 and with 40% VC in LC-2063 improved the performance of seeds. Further increase in the VC concentration had no significant effect.	[125]
Salvinia (*Salvinia molesta*)	Ladies finger (*Abelmoschus esculentus*)	Seeds were sown in soil fortified with VC to the extent of 2.5, 3.75 and 5 t/ha. Unamended soil served as control.	An increase in the germination success was recorded in plants grown in VC amended soil.	[126]
Parthenium (*Parthenium hysterophorus*)	Ladies finger (*A. esculentus*)	Plants were germinated and grown in soil fortified with VC to the extent of 2.5, 3.75 and 5 t/ha. Unamended soil served as control.	VC stimulated the germination success compared with the controls. Higher the VC concentration in the soil better was the performance.	[127]
Cow dung and agriculture residue	Asparagus (*Asparagus Officinalis*)	In separate treatments, VC and cow manure were supplemented alone or in combination with Nitroxin in the sand and soil mixture to the extent of 0%, 15% and 30%.	VC treatments have shown higher germination rate and mean germination time then controls and cow manure treatments.	[128]
Rice waste	Tomato (*Solanum* spp.)	VC, rice hush ash (RHS) and coconut fiber (CF) were mixed in the following proportions (*v*/*v*): 3/3 VC (control treatment) (T1), 2/3 VC: 1/3 RHS (T2), 2/3 VC: 1/3 CF (T3), 1/3 VC: 2/3 RHS (T4), 1/3 VC: 2/3 CF (T5), and 1/3 VC: 1/3 RHS: 1/3 CF (T6).	Mixture containing equal proportions of VC, rice hush ash and coir fiber significantly influenced the seedling emergence.	[129]
Macrophytes and cow dung	Brinjal (*Solanum melongena*)	Macrophyte based VC was applied to the soil at the rate of 0 (control), 2, 4, and 6 t/ha.	Incorporation of VC increased the germination success compared to the controls. Maximum germination was reported in 6 t/ha followed by 4 and 2 t/ha treatments.	[32]
Lantana leaves	Cluster bean (*Cyamopsis tetragonoloba*)	Seeds were sown in soil amended with VC at concentration 0, 5, 7.5, and 10 t ha^{-1}.	VC substitution enhanced the germination percentage.	[106]
Tendu leaves	French bean (*P. vulgaris*)	VC was supplemented in soil at the concentration equivalent of 0%, 50%, 75% and 100% of recommended dose of nitrogen and in combination with urea.	VC amendments enhanced the germination percentage significantly over the controls.	[130]

Table 1. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of seed germination		
Cow dung and lantana leaves	Maize (*Z. mays*)	Seeds were germinated in soil amended with 75 g of VC derived from mixture of cow dung (CD) and lantana leaves (LL) in proportions 0%, 20%, 40%, 60%, and 80% lantana leaves. Unamended garden soil acted as control.	The germination index was highest in VC containing a proportion of 80:20 (LL: CD), followed by VC having 40, 60 and 20% LL.	[131]
Domestic waste, goat and cow manure	Bhendi (*A. esculentus*)	VC and compost were added to the soil in 1:1 ratio.	Seed germination was higher in VC treatments then in composts.	[11]
Leaves of cassia and leucaena mixed with cow dung	Cowpea (*Vigna unguiculata*)	VC generated by using earthworm species *Eudrilus eugenia* and *Eisenia foetida* was used.	VC derived from *E. fetida* showed more germination success in comparison to the VC derived by using *E. eugenia*.	[132]
Rice straw and chick weed residues and cow dung	Maize (*Zea mays*), beans (*P. vulgaris*) and okra (*A. esculentus*)	Seeds were germinated in soil, amended with VC to the extent of 1 t/ha.	VC substitution enhanced the germination success of all the species studied.	[133]
Rabbit manure	Maritime pine (*Pinus pinaster*)	Seeds were sown in pots, containing perlite with a layer of sand, amended with VC to the extent of 50% (*v*/*v*). Unamended potting media was set as control.	Amalgamation of VC in the growing media increased the germination by 16%, compared with controls.	[19]
Cattle manure, food and paper waste	Petunias (*Petunia hybrida*)	Seeds were sown in soilless commercial bedding plant container medium (Metro-Mix 360) substituted with VC to the extent of 0, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% or 100% (*v*/*v*).	VC substitutions at all the concentrations enhanced the germination success of petunias.	[83]
Food and cotton waste	Tomato (*L. esculentum*)	VC was added to the commercial peat substrate at the rate of 0%, 20%, 40%, 60%, 80%, and 100% (*v*/*v*).	VC substitution enhanced the germination success of tomato.	[18]
Manures	Tomatoes (*L. esculentum*)	VC was added to peat-based compost at rates 0%, 10%, 20%, 40%, and 100% (*v*/*v*).	VC increased germination rates to the extent of 176%.	[134]
Pig manure	Tomato (*L. esculentum*), pepper (*Capsicum* sp.), lettuce (*L. sativa*) and marigold (*Calendula officinalis*)	Seeds were sown in standard commercial soilless plant growth medium (Metro-Mix 360), and in coir/perlite and peat/perlite-based container media substituted with 10% or 20% (*v*/*v*) of VC.	VC substitution enhanced the germination percentage of all the species studied.	[135]

Table 1. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the inhibition of seed germination		
Municipal sewage sludge	Winter rye (*Secale cereale*)	Pure sand or mineral-enriched sand was substituted with VC to the extent of 0% (control), 10%, 20%, 30%, 40%, 50% (*v*/*v*).	VC inhibited the seed germination at all the concentrations. Maximum germination success was observed in controls.	[136]
Cow manure	Garden beans (*Phaseolus vulgaris*), peas (*Pisum sativum*), beet root (*Beta vulgaris*), radish (*R. sativus*), cabbage (*Brassica oleracea*) and Swedish turnip (*Brassica napobrassica*)	Sphagnum peat was substituted with VC at the rates 0, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% (*v*/*v*), successively.	In case of cabbage, onion and Swedish turnip seeds, 10–20% VC did not produce any effect, however 30–50% VC treatment reduced the germination percentage up to 50%. Contradictorily, 5–10% VC treatment inhibited the seed germination in beetroot, beans, and peas, whereas higher VC concentrations boosted the germination.	[117]
Cow manure	Bristle grass (*Setaria viridis*)	Seeds were germinated in pots, containing iron mine tailings amended with 0% (control), 10%, 20% and 30% VC (*v*/*v*).	With increasing VC concentration, the germination rate reduced. Maximum germination was recorded in controls.	[137]
Cattle manure	Radish (*R. sativus*), marigold (*C. officinalis*), and upland cress (*Barbarea verna*)	VC was mixed in Pugwash sandy loam soil to the extent of 5% and 10% compost–soil combinations.	The percent germination of all three species was depressed in soil mixes with 5% or 10% VC compared to the control soil.	[138]
		Studies showing no effect of VC on seed germination		
Cow dung	Chickpea (*Cicer arietinum*)	Seeds were germinated in soil fortified with 0% (control), 10% and 20% VC.	VC fortification had no significant impact on seed germination.	[103]
Dairy manure	Lettuce (*L. sativa*)	VC was supplemented in coconut coir to the extent of 20%, 40% and 60% (*v*/*v*). Coconut coir without fertilization was set as control.	VC supplementation had no impact on seed germination.	[139]
Tomato crop waste	Marigold (*C. officinalis*), and horned pansy (*Viola cornuta*)	VC was mixed with sphagnum peat in proportions 100:0, 75:25, 50:50, 25:75, and 0:100 (peat control) by volume.	VC supplementation did not affect seed germination.	[110]
Coconut coir dust and pepper remains	Tomato (*S. lycopersicum*)	In separate treatments, mixture of commercial blonde sphagnum peat, coconut coir dust, perlite and VC were studied. The proportion of VC was 0%, 25%, and 50%.	VC supplementation had no impact on the seed germination.	[140]
Pig manure	Tomato (*L. esculentum*), marigold (*Tagetes patula*, and pepper (*Capsicum annuum*)	Seeds were sown in commercial potting substrate (Metro Mix 360), amended with VC to the extent of 0%, 10%, and 20% (*v*/*v*).	VC supplementation had no impact on the germination of any of the species studied.	[141]
Green waste	Sunflower (*Helianthus annuus*), garden cosmos (*Cosmos bipinnatus*) and golden poppy (*Eschscholzia californica*)	VC was supplemented in peat based growing media to the extent of 0%, 20%, 40%, 60%, 80% and 100% (*v*/*v*).	VC addition had no significant effect on the germination rates within individual species groups.	[22]

Table 1. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
Studies showing the stimulation at lower concentration and inhibition at higher				
Fly ash	Marigold (*Tagetes* spp.)	Seeds were sown in media composed of pine bark compost and VC. The proportion of VC was 0%, 25%, 50%, 75%, and 100%. Additionally, in one set of treatments chemical fertilizers were added, while keeping another treatment without fertilizer fortification.	VC treatments up to 75% significantly enhanced the germination percentage, while inhibiting at 100%.	[142]
Ipomoea	Green gram (*Vigna radiata*), ladies finger (*A. esculentus*) and cucumber (*Cucumis sativus*)	Seedlings were germinated and grown in soil amended with VC at the rates 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (by weight).	When supplemented to soil in the range of 2–4%, VC enhanced the germination. Further increase in VC concentration inhibited the germination success.	[37]
Salvinia	Green gram (*V. radiata*), ladies finger (*A. esculentus*) and cucumber (*C. sativus*)	Seedlings were germinated and grown in soil amended with VC at the rates 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (by weight).	VC concentration in the range of 4–20% enhanced the germination. Further increase in VC concentration inhibited the germination success.	[38]
Cow solids	Thyme (*Thymus vulgaris*)	Seeds were germinated and grown in soil amended with VC at the rate 0, 25, 50, and 75%.	VC enhanced the seedling germination indices when added to the extent of 25%; with further increase in VC proportion, the impact was reversed.	[143]
Fly ash and cow dung	Marigold (*Tagetes* spp.)	Mixture of VC and pine bark compost was used as media, with VC added to the extent of 0%, 25%, 50%, 75%, and 100%. Seeds were sown in media with or without fertilizer.	VC treatment up to 75% of the media composition enhanced the germination percentage significantly. Further increase in VC proportion reduced the germination success.	[142]
Parthenium leaves	Green gram (*V. radiata*), ladies finger (*A. esculentus*) and cucumber (*C. sativus*)	Seedlings were germinated and grown in soil amended with VC at the rates 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (by weight).	VC enhanced the germination of all the species when used up to 2% and inhibited germination thereafter.	[36]
Lantana leaves	Green gram (*V. radiata*), ladies finger (*A. esculentus*) and cucumber (*C. sativus*)	In separate treatments seeds were sown in plastic trays containing soil, amended with 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (by weight) VC.	In all cases lantana VC enabled greater success in seed germination compared to control when used in concentration range 0.75–2%. At VC concentrations above 2%, germination was inhibited in comparison to controls.	[35]
Temple floral waste, yard waste, cow dung	Chickpea (*Cicer arietinum*)	Seed germination test was conducted by substituting the VC of each of the three substrates at concentrations 5%, 10%, and 25% (*v*/*v*), successively.	VC derived from each of the substrates enhanced germination at lower concentrations, while 25% VC inhibited the seedling emergence.	[116]

Table 1. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
Studies showing the stimulation at lower concentration and inhibition at higher				
Cow manure and vegetable waste	Kidney bean (*P. vulgaris*)	Seeds were sown in trays containing barren soil, substituted with VC to the extent of 0%, 25%, 50%, 80%, and 100% (*v*/*v*).	VC incorporation up to 50% improved the germination success, thereafter with increased VC concentration the germination inhibited significantly.	[144]
Sheep manure	Radish (*R. sativus*)	Seeds were sown in bags containing peat moss, substituted with VC to the extent of 0%, 10%, 20%, 30%, or 40% (*v*/*v*).	Maximum seed germination was recorded in treatment containing minimum (10%) VC. Further increase in VC concentration reduced the germination rate linearly.	[51]
Cow manure	Alfalfa (*Medicago sativa*) and white clover (*Trifolium repens*)	VC was added to the iron tailing at concentrations 0% (control), 5%, 10%, 20% (*v*/*v*).	The germination success of white clover was highest in the treatment containing maximum (20%) VC. In case of alfalfa maximum germination was recorded in 10% VC treatment, while it reduced significantly in 20% VC.	[145]
Empty fruit bunch of oil palm and chicken manure	Okra (*A. esculentus*)	VC was amended with peat in ratios of 0:100 (control), 25:75, 50:50, 75:25, and 100:0 (VC: peat).	An increase in seed germination was reported on substitution of VC in the 25–75% range; 100% VC treatment inhibited the seedling emergence significantly.	[146]
Organic food and cotton waste	Tomato (*L. esculentum*)	Commercial peat was amended with VC at concentrations 0%, 20%, 40%, 60%, 80%, and 100% (*v*/*v*).	VC substitution at the concentration range 20–40% enhanced the germination success. Further increase in VC treatments (60–100%) reduced the germination success.	[18]
Pig manure	Tomatoe (*L. esculentum*)	Seeds were germinated in a standard commercial greenhouse container medium (Metro-Mix 360), substituted with 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% (by volume) pig manure VC. Unfertilized media was set as control.	Substitution of VC in the container medium at concentration 20–90% enhanced the germination rate; 100% VC treatment inhibited the seedling emergence.	[17]
Animal manure and plant wastes	Radish (*R. sativus*).	In pots, VC was mixed with sand at concentration ranging from 0, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% (*v*/*v*).	Maximum seed germination was recorded in treatments containing minimum (10%) VC. Further increase in VC concentration reduced the germination success.	[147]
Duck waste	Tomato (*S. lycopersicum*), lettuce (*L. sativa*) and pepper (*Capsicum* sp.)	Seeds were sown in peat-based media, substituted with worm-worked duck waste at concentrations 2%, 4%, 6%, 8%, 10%, 15%, and 20% (*v*/*v*).	An increase in seed germination was reported on substitution of VC in the 2–8% range. Further increase in VC proportions reduced the germination success.	[34]

Table 2. Effect of vermicompost (VC) on growth and yield.

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Chicken manure	Cucumber (*C. sativus*)	Cucumber was grown on sandy loam soil under four soil amendment conditions: inorganic compound fertilizer (750 kg/ha), replacement of 150 kg/ha of inorganic compound fertilizer with 3000 kg/ha of organic fertilizer or VC, and untreated control.	VC amendment maintained higher fruit yield and quality under continuous cropping conditions.	[65]
Not stated	Broccoli (*B. oleracea*)	VC, farmyard manure and poultry manure were applied to soil at the rate 5, 8 and 5 tonnes/ha, respectively.	VC led to the earliest first and 50% harvesting, maximum number of leaves, most weight of main head, girth of head, largest number of sprouts/plant, yield of sprouts/plant, greatest yield of sprouts (main head + sprouts)/plant, highest total yield, and plant biomass compared with the FYM and poultry manure treatments.	[148]
Rice waste	Tomato (*Lycopersicon* sp.)	VC, rice husk ash (RHS), and coconut fiber (CF) at the following proportions (by volume) were used. 0% VC + 50% RHS + 50% CF (control treatment-T1); 20% VC + 40% RHS + 40% CF (T2); 40% VC + 30% RHS + 30% CF (T3); 60% VC + 20% RHS + 20% CF (T4); 80% VC + 10% RHS + 10% CF (T5); and 100% VC (T6).	In treatments containing 60% and 80% of VC, the yield was higher than in the controls and other treatments.	[149]
Distillation waste of aromatic crops	Basil (*Ocimum basilicum*)	VC and tannery sludge were added to a sodic soil to the extent of 5 t/ha. In addition, two bacterial strains isolated from the same sodic soil were also mixed in the soil. Unamended soil served as control.	VC, tannery sludge and microbial inoculants enhanced the height, number of branches, biomass, root expansion, yield and oil quality.	[150]
Not stated	Soybean (*Glycine max*)	VC was added to the soil at the rate of 0 and 5% of soil weight along with the inoculation and non-inoculation of arbuscular mycorrhizal. In addition, cadmium chloride was added at five levels: 0, 20, 40, 80 and 160 mg per kg of soil.	VC and mycorrhiza decreased the toxic effects of cadmium chloride with concomitant increase in the grain weight per plant, number of pods per plant and seed oil percentage, and root weight and photosynthetic rate.	[151]
Cattle manure	Sweet corn (*Zea mays*)	Treatments include main plots consisting of five VC application rates (5, 10, 15, 20 and 25 Mg ha^{-1}) and subplots consisted of five liquid organic fertilizer application rates (0, 25, 50, 75, and 100%, initial concentration).	VC noticeably increased the NPK uptake and plant height, plant leaf area, shoot weight, weight of the husked and the unhusked ears, diameters of the ears, and weight of the husked ear per plot. Higher the VC concentration greater was the impact.	[152]
Excreta-based	Tomato (*Solanum lycopersicum*)	The experiment consisted of eight treatments where the mineral fertilizer (0%, 25%, 50%, 75% and 100%) and the VC (0, 3.75, 7.5, 11.25, and 15 t/ha) were combined in different proportions, arranged in a completely randomized block design replicated three times.	Combined treatment of mineral fertilizer (75%) and VC (11.25 t/ha) showed maximum growth, yield and quality, compared with sole application of VC or mineral fertilizers and other treatments.	[153]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Cattle dung	Flax (*Linum usitassimum* var LC-54 and LC-2063)	In commercial potting media (perlite, peat and coconut coir) VC was mixed in proportions 0%, 20%, 40%, 60%, 80%, and 100% (*v*/*v*). In addition, the effect of vermiwash and inorganic fertilizers was also explored.	Substituting soil with 60% VC in LC-54 and with 40% VC in LC-2063 improved the performance of seeds, root morphology, and stem growth. Further increase in the VC concentration had no significant effect on the recorded variables. Combined treatment of vermiwash and VC outperformed the chemical fertilizer treatments and controls.	[125]
Rice straw and cow dung	Pea (*Pisum sativum*)	Normal VC and humic acid rich VC were added to the soil to the extent of 9 g/kg of soil. In separate treatments, chemical fertilizer in the form of urea, diammonium phosphate and muriate of potassium was added to the extent of 37.5, 60, 50 kg/ha, respectively. Unamended soil was studied as control.	Compared with the chemical fertilizer treatments and controls, an increase in the height, fresh weight, and dry weight of plants were recorded in VC amended soil. In addition, VC increased the root nodulation and arbuscular mycorrhizal fungi colonization; the increment being higher in the humic acid rich VC.	[154]
Pig manure and wheat straw	Radish (*R. sativus*), onion (*Allium cepa*), marigolds (*Tagetes* spp.) and grass (*Trifolium* spp.).	Plants were grown in soil mixed with VC in concentrations of 0%, 2%, 4%, 6%, 10%, and 12.5%. In another set of greenhouse outdoor experiment VC was added to the soil to the extent of 0, 1, 3, 5, and 7 kg/m^2.	In both, the pot as well as the plot experiments VC improved the growth of all the plants studied.	[155]
Cow dung and *Leucaena leucocephala* leaves	Sunflower (*Helianthus annuus*)	In a randomized complete block design plants were grown in three sets, which comprise of set 1: recommended dose of NPK; set 2: 1 kg/plant VC and set 3: 1 L/plant biogas slurry. In addition, five pots from each set were irrigated with 0.5, 4.8 8.6 dS/m EC levels of saline water.	VC and biogas slurry improved the growth, yield, nitrate and protein content and decreased sodium induced inhibitory effects on sunflower. An increase in the nitrogen assimilating enzymes was also recorded.	[156]
Not stated	Tomato (*Lycopersicon* sp.)	The fertilization treatments included T1, VC (12 t/ha); T2, compost (10 t/ha); T3, integrated plant nutrient system (IPNS) or mixed fertilizers (organic 2/3 part and inorganic 1/3 part); T4, inorganic fertilizers; and a control (T5).	Integrated plant nutrient system resulted in higher growth and yield compared to controls and other treatments.	[157]
Salvinia	Ladies finger (*A. esculentus*)	Plants were germinated and grown in soil fortified with VC to the extent of 2.5, 3.75 and 5 t/ha. Unamended soil served as control.	VC stimulated the germination, growth, yield and quality of fruits, compared with the controls. Higher the VC concentration on the soil better was the performance.	[126]
Parthenium	Ladies finger (*A. esculentus*)	Seeds were sown in soil fortified with VC to the extent of 2.5, 3.75 and 5 t/ha. Unamended soil served as control.	An increase in the germination success, growth and yield was observed in plants grown in VC amended soil.	[127]
Not stated	Chickpea (*C. arietinum*)	VC at the rate of 0%, 10%, 20% and 30% was added in soil subjected to a water deficit stress level of 0, 25 and 75%.	VC reduced the negative effects of water stress by increasing the absorption of calcium and potassium and decreasing the absorption sodium.	[158]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Vegetable waste, agriculture crop residue, weeds and cow dung	Tomato (*L. esculentum*) and cabbage (*Brassica oleracea*)	In field experiment, VC, compost, farmyard manure and inorganic fertilizers were supplemented to the soil to make the NPK 75-60-60 for tomato and 120-60-60 t/ha for cabbage soil.	Combined treatment of VC, compost and inorganic fertilizers stimulated the growth, yield, quality, and storage longevity of both tomato and cabbage.	[159]
Not stated	Pigeon pea (*Cajanus cajan*)	In randomized block design, experiment was conducted with six treatments: Control, recommended dose of NPK for the crop, recommended dose + farmyard manure, recommended dose + VC, farmyard manure only and VC only.	VC enhanced the crude protein, soluble carbohydrate, ash content and total flavonoid content in leaves. In addition, significant impact of VC on the antioxidant and antibacterial properties of the leaves was also recorded.	[75]
Not stated	Salvia (*Salvia Leriifolia*)	VC and compost were added to the soil at the rates 3 and 6 t/ha and 10 and 20 t/ha respectively. One set of each was inoculated with phosphate dissolving bacteria *Pseudomonas putidam* while another set was not inoculated. Control plants were not applied with either organic fertilizers or the bacteria.	Combined treatment of VC (3 t/ha) and phosphate dissolving bacteria *P. putida* led to significantly higher leaf area index, plant height, plant dry weight, seed yield and essential oil yield. Lowest growth and yield was observed in the controls.	[16]
Horse and rabbit manure	Amaranthus (*Amaranthus cruentus*)	VC was applied at the rate 100 cm^3 per stroke. Alongside biodigester effluent and *Trichoderma* sp. were applied for comparison. Unamended soil served as controls.	No significant differences were detected between the average growth of effluent-treated plants and those treated with *Trichoderma* sp., and these averages were significantly higher than those obtained with VC and control treatments. VC, however increased the yield to a significant level, compared with the controls.	[160]
Dairy manure	Strawberry (*Fragaria ananassa*)	Media composed of (1) a peat: perlite soil-less mix and (2) a fine sand soil, was amended with VC to the extent of 0%, 10%, and 25% by weight. Additionally, a biweekly synthetic fertilizer treatment of 150 mg N-P-K L^{-1} was also used.	VC treatments enhanced the vegetative biomass of strawberry, compared with the controls and synthetic fertilizers.	[161]
Not stated	Chickpea (*Cicer Arietinum*)	VC at the rate of 0%, 10%, 20% and 30% was added to soil subjected to water deficit stress levels of 0%, 25% and 75%.	VC treatments under all water deficit stress levels increased plant height, number of pods, leaf area, stem and leaf dry weight, and pod dry weight. In addition, the chlorophyll and carotenoid content, CO_2 assimilation rate, internal CO_2 concentration, and water-use efficiency in the no stress level were improved in 20% and 30% VC treatments.	[162]
Tea, twig and food waste	Roses (*Rosa indica* Thory., *Rosa chinensis* Jacq. and *Rosa damascena* Dieck.)	Treatments included: T1, Sand + Tea waste VC (1:1 *v*/*v*); T2, Sand + Tea waste VC (1:2 *v*/*v*); T3, Sand + Tea waste VC (1:3 *v*/*v*); T4, Sand + Twigs VC (1:1 *v*/*v*); T5, Sand + Twigs VC (1:2 *v*/*v*); T6, Sand + Twigs VC (1:3 *v*/*v*); T7, Sand + Food waste VC (1:1 *v*/*v*); T8, Sand + Food waste VC (1:2 *v*/*v*) and T9, Sand + Food waste VC (1:3 *v*/*v*).	All plant growth and rooting characteristics were significantly affected by different VC treatments. The response, however, differed with different sources of VC.	[163]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
Studies showing the stimulation of plant growth and yield				
Cow manure	American aloe (*Agave Americana*)	In separate treatments, VC (0 or 10 g per plant), rock phosphate (0 or 1 g per plant), *G. fasciculatum* (0 or 1 × 10^6 spores per plant), and *Penicillium* sp. (0 or 1 × 10^9 spores per plant) were used.	VC affected stem dry weight, the fructan, glucose, and fructose in stem and mycorrhization content in the roots.	[164]
Not stated	Spinach (*Spinacia oleracea*)	In separate treatments VC to the extent of 5% and 10% (*v*/*v*) and VC extract at the rate 40 mL was added to the soil.	VC increased leaf number, area biomass, shoot and root biomass, and water use efficiency. It also increased the chlorophyll content, and photochemical efficiency, yield, and electron transport rate of mature leaves. Additionally, it increased the leaf succulence, and the carotenoid, protein, and amino acid content.	[165]
De-oiled waste of ocimum and cow dung	Sweet basil (*Ocimum basilicum*)	VC at the rate of 5 t/ha alone or in combination with bioinoculants was added to the soil. In separate treatments, formally recommended dose of NPK (80:60:60 kg ha^{-1}) was used. Unamended soil was considered as control.	Consortium of VC and bioinoculants significantly improved the biomass, essential oil content, and essential oil yield over control.	[64]
Not stated	Lettuce (*Lactuca sativa*)	VC was added to the mixture of peat and perlite at rates 0% (control), 20%, and 40%.	VC amendments resulted in 20% increase in the size of plants.	[74]
Arecanut plantation leaves	Arecanut (*Areca catechu*)	VC alone or in combination with inorganic fertilizers was supplemented to the extent of equivalent or twice of the recommended dose of nitrogen (100 g) for the growth of arecanut.	VC increased the yield, leaf N and K content compared with the controls.	[73]
Not stated	Fenugreek (*Trigonella foenumgraecum*)	VC, farmyard manure, poultry manure, neem cake, and inorganic fertilizer were supplemented to the soil alone or in combinations equivalent to the 40 kg/ha N. Unamended soil was used as control.	All treatments, organic or inorganic, singly or in combination, significantly increased the growth and yield of fenugreek. Among all the treatments, the VC-inorganic combinations gave the best response.	[166]
Cattle manure	Sorghum (*Sorghum bicolor*)	VC (25 g/pot/month) and vermiwash (l L/pot/week) were used separately and in their combinations in saline and nonsaline soils. Unamended pots were considered as controls.	Combined treatments of VC and vermiwash enhanced the growth under both saline and nonsaline conditions.	[167]
Cow dung, plant wastages and lemongrass spent	Lemon grass (*Cymbopogan flexuosus*)	The plants were treated at 0, 2, 4, 6, 8 and 10 g per plant of VC.	VC increased the height, number of tillers per plant, herb production and oil content of the plants. The best response was reported in 10 g treated plants.	[168]
Not stated	German chamomile (*Matricaria chamomilla*)	Soil was amended with VC at the rate 0, 5, and 10 t/ha in different drought stress conditions (no stress, moderate stress and severe stress).	Application of VC enhanced the nutrient percentages and leaf chlorophyll content in all the drought conditions.	[169]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
Studies showing the stimulation of plant growth and yield				
Crop residues and cattle dung	Maize (*Z. mays*) and wheat (*Triticum aestivum*)	VC, compost and farmyard manure were added to the soil at the rate of 5 t ha^{-1}, alone and in combination with half of the recommended dose of inorganic fertilizer (6:30:30 kg ha^{-1} NPK). In addition, a treatment was set with 100% inorganic fertilizer (12:60:60 kg ha^{-1}). Unamended soil was used as control.	Organic fertilizers when used alone or in combination with mineral fertilizers increased the yields and nutrient uptake compared with the control.	[170]
Mixture of cow and buffalo dung plus bedding material (oak leaves, pine needles and Fingermillet straw	Potato (*Solanum tuberosum*)	VC, farmyard manure (FYM), and chicken manure were supplemented alone or in combination with inorganic fertilizers equivalent to the recommended dose of inorganic fertilizers (IF) (N150P75K75). In addition, microbial consortia were added in each treatment. Unamended soil served as control.	All the treatments performed better in terms of growth, tuber productivity, profitability, tuber quality, and nutrient uptake than controls; however combined application of FYM and IF outperformed all other treatments.	[171]
Not stated	Basil (*Ocimum basilicum*)	VC, farmyard manure, and poultry manure were added to the soil to the extent of 10, 20, and 5 t ha^{-1}, respectively. In addition, a treatment with recommended dose of NPK (100:60:60 kg ha^{-1}) was also set. Unamended soil served as control.	Application of organic manure alone or in combination with chemical fertilizer had a positive effect on the crop, essential oil yield, antioxidant activity, nutritional quality, and nutraceutical attributes of basil.	[172]
Mushroom culture waste, vegetable residue, leaf litter, and cow manure	Cabbage (*Brassica oleracea*)	VC was added to the media (mixture of soil and cow dung) to the extent of 200 g per 10 kg of media. In addition, earthworm species *P. corethrurus* was added in each pot to the extent of 0, 25, 50, 75 and 100 worms per m^2. Pots treated with inorganic fertilizers were considered as control.	VC significantly increased the yield compared to the controls. Co-application of earthworms and VC improved the yield and quality significantly.	[173]
Not stated	Marjoram (*Majorana hortensis*)	Marjoram was grown in soil supplemented with VC to the extent of 0, 6, 8 and 10 m^3/fed and calcium silicate at the rate 0, 10, 15 and 20 kg/fed.	VC increased the plant height, number of branches, biomass, essential oil percentage, fruit yield and total carbohydrates.	[72]
Not stated	Lemon balm (*Elissa officinalis*)	In separate treatments, VC at the rate 0%, 15% and 30% (V/pot), two levels of biophosphate (treated and untreated) and three levels of chemical fertilizers (0, 250 and 500 mg/pot) were used.	VC and biophosphate have stimulatory effects on the quantity and quality of the essential oil in lemon balm.	[174]
Not stated	Coriander (*Coriandrum sativum*)	Three growth media combinations were tested: M1 [VC (5 t/ha), foliar spray of garlic extract (5% @ 2.0 kg/ha) + neem oil (2% @ 5 L/ha], M2 [FYM (10 tonnes/ha), foliar spray of garlic extract (5% @ 2.0 kg/ha) alone] and M3 [sheep manure (10 tonnes/ha), foliar spray of karanj oil (2% @ 5 L/ha)]. In addition, all the modules were supplemented with neem cake (150 kg/ha) and Trichoderma (2.5 kg/ha).	M1 treatment exhibited maximum number of primary and secondary branches, number of umbels and seeds, and highest seed yield.	[175]
Municipal sewage sludge	Winter rye (*Secale cereale*)	Pure sand or mineral-enriched sand was substituted with VC to the extent of 0% (control), 10%, 20%, 30%, 40%, and 50% (*v*/*v*).	VC inhibited the growth at early stages, however at later stages enhancement in leaf chlorophyll content and mineral uptake was observed.	[136]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Not stated	Kale (*Brassica oleracea*)	In separate treatments, VC, humate and volcanic minerals were added to the growth media (Pro-mix BX) to the extent of 50 g, 47.5 g and 100 g per pot, respectively. Pro-mix BX alone served as the control.	Application of single-dose C had shown the highest productivity compared to the other treatments.	[176]
Not stated	Chickpea (*Cicer arietinum*)	VC was mixed with soil in the proportions of 0:100, 10:90, 20:80, and 30:70. In addition the soil was maintained at three levels of drought stress (no stress, moderate drought, and severe drought).	VC treatment under no stress conditions significantly increased the chlorophyll content, intercellular CO_2 concentration, net photosynthetic rate, transpiration rate, and maximal quantum yield of PSII photochemistry (Fv/Fm). However, these impacts were not seen under moderate and severe stress conditions.	[177]
Not stated	Sahendi savory (*Satureja sahendica*)	In separate treatments, VC (4 t/ha), inorganic fertilizers (NPK 100-50-25 kg per ha) plus foliar application of micronutrients, and vermitea (40 liters/ha), were used individually and in combination with each other.	No significant effect on the essential oil percentage was reported. However, the relative superiority of essence belonged to the combined treatment of VC and vermitea. Individual supplementation of VC increased the thymol content.	[178]
Oil palm empty fruit bunch	Oil palm (*Elaeis guineensis*)	In separate treatments mixture of OPEFB (VC cultivated in a media comprising oil palm empty fruit bunch) and POME (anaerobically digested palm oil mill effluent) alone, and in combination with chemical fertilizer at a ratio of 70:30, were applied to the soil at the rate 3 Kg per plant. In addition, a treatment (control) was set with 100% chemical fertilizer.	Mixture of OPEFB and POME alone or in combination with chemical fertilizer gave the best results in terms of stem growth and frond production compared with the controls.	[179]
Not stated	Tomato (*L. esculentum*)	VC was used to the extent of 25%, 50% and 75% in peat and perlite mixture. In addition, a treatment was set using 25% VC and 25% compost and perlite mixture.	Among several ratios of VC, compost, peat, and perlite, VC with 25% compost increased the number of red fruits in the harvest period significantly more than the control. The use of VC, peat and perlite increased root fresh and dry weight, root volume, mean photosynthesis, and the number of fruits at all physiological stages compared to the control.	[180]
Cow dung and agriculture residue	Asparagus (*Asparagus Officinalis*)	In separate treatments, VC and cow manure were supplemented alone or in combination with nitroxin in the sand and soil mixture to the extent of 0%, 15% and 30%.	VC enhanced the length and weight of the roots and shoots compared to the controls.	[128]
Horse manure	Lettuce (*Lactuca sativa*)	VC and compost was added to the peat-based growing medium to the extent of 0%, 10%, 20%, 50%, and 75% (v/v).	VC significantly increased the mean shoot fresh and dry weights compared with the compost and controls. VC also resulted in larger plants with reduced conductivity stress and root/shoot ratio, especially at higher amendment concentrations.	[12]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Not stated	Beetroot (*Beta vulgaris*)	VC, farmyard manure (FYM), and a consortium of biofertilizers were supplemented in the soil to the extent of 5 t ha^{-1}, 25 t ha^{-1}, and 2 kg ha^{-1}, respectively. In addition, biostimulants were supplemented as foliar spray once in 10 days.	VC and consortium of biofertilizers led to higher root length, root girth root weight, and shoot: root ratio per plant, yield per plot and yield per hectare compared with the FYM.	[181]
Vegetable waste, crop residue, cow dung and weeds	Chili (*Capsicum chinense*)	VC was supplemented to the soil in equivalence to the nitrogen, potassium, and phosphorus content of 120:80:80; either fully or half of it along with inorganic fertilizers.	VC when supplemented alone or in combination with the inorganic fertilizers increased the fruit yield, and the content of soluble sugar, protein, fiber, and lycopene.	[182]
Not stated	Bean (*Phaseolus vulgaris*)	VC was added to the soil at proportions of 0:100; 10:90; 25:75; 50:50 and 75:25. In addition four levels of salinity stress (20, 40, 60 and 80 mmol L^{-1} sodium chloride) were maintained in the soil. Untreated soil was used as control.	VC significantly increased the photosynthetic rate and concentrations of potassium (K^{+}) and calcium (Ca^{2+}) in leaf and root tissues.	[183]
Not stated	Japanese mint (*Mentha arvensis*)	Farmyard manure (FYM), VC, and poultry manure (PM) were added to the soil to the extent of 30, 15, and 7.5 Mg ha^{-1}, respectively. Unamended soil was considered as control.	Combined application of FYM, VC and PM resulted in highest yield attributes compared with individual treatments and controls.	[184]
Not stated	Buckwheat (*Fagopyrum* sp.)	Two cultivars of buckwheat (Meethey and Teethey) were grown in soil supplemented with VC to the extent of 0 (control), 1, 1.5 and 2.5 t/ha.	Application of VC at the rate 2.5 t/ha recorded higher values of grains/plant, test weight, grain yield and haulm yield resulting in highest gross returns, in comparison to the controls and other VC treatments.	[185]
Cow manure	Alfalfa (*Medicago sativa*) and vinca rosa (*Catharanthus roseus*)	VC was added to the sandy soil to the extent of 0%, 25%, 50%, 75% and 100%.	Plant height and fresh biomass increased significantly with increasing proportion of the VC.	[186]
Cow dung	Chickpea (*Cicer arietinum*)	Soil fortified with 10% and 20% VC was used as potting media. Unfertilized soil was set as control.	Plant height, shoot biomass, number of pods and photosynthetic pigments were significantly higher in plants grown in media fortified with VC.	[103]
Rice waste	Tomato (*Solanum* spp.)	VC, rice hush ash (RHS) and coconut fiber (CF) were mixed in the following proportions (*v*/*v*): 3/3 VC (control treatment) (T1), 2/3 VC:1/3 RHS (T2), 2/3 VC:1/3 CF (T3), 1/3 VC:2/3 RHS (T4), 1/3 VC:2/3 CF (T5), and 1/3 VC:1/3 RHS:1/3 CF (T6).	Mixture containing equal proportions of VC, rice hush ash and coir fiber significantly influenced the emergence, elongation and biomass allocation of tomato.	[129]
Cow manure	Tomato (*Solanum* spp.) and spinach (*Spinacia oleracea*)	VC enriched with or without PGPR, was added to the soil to the extent of 0 (control), 15 and 30 Mg/ha.	PGPR enriched VC enhanced the yield of tomato and spinach.	[187]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Distillation waste of geranium and ocimum	Patchouli (*Pogostemon cablin*)	VC was added to the soil @ 0%, 25%, 50%, 75%, and 100% in combination with 100%, 75%, 50%, 25% and 0% of recommended dose of NPK, respectively. Unfertilized soil was considered as control.	VC treatments when used alone or in combination with inorganic fertilizers enhanced the plant height and spread, number of branches, fresh herb yield, oil content and oil yield, compared with the control.	[104]
Cow ung	Mung bean (*Vigna radiata*)	VC pretreated with *Trichoderma viride* (0.1% and 0.2%), was incorporated in soil infested with plant pathogen *Macrophomina phaseolina* to the extent of 25 g kg^{-1}. Soil containing only *M. phaseolina* served as a control.	Growth of mung bean in terms of root length, weight of root and shoots was higher in soil containing *T. viride* augumented VC, than in controls.	[188]
Coir waste, paddy husk and cow dung	Black gram (*Vigna mungo*)	VC was added to the soil alone and in combination with earthworms's coelomic fluid. Unfertilized soil was used as control.	VC treatments when used alone or in combination with earthworms's coelomic fluid enhanced the growth of black gram.	[189]
Cassava industrial waste	Maize (*Z. mays*)	Efficacy of VC and compost as soil conditioners in alleviating salt affected soils was assessed. Treatments included: (1) control (unfertilized soil); (2) earthworms only; (3) compost at the rate 10 Mg ha^{-1}); (4) compost + earthworms; (5) VC at the rate 5 Mg ha^{-1}); (6) VC + earthworms; and (7) recommended dose of chemical fertilizers.	VC exhibited better plant height and total dry matter of maize, compared with the control.	[190]
Macrophytes and cow dung	Eggplant (*S. melongena*)	VC was added to the soil at the rates 0 (control), 2, 4 and 6 t/ha.	VC enhanced the number of fruits per plant, fruit weight, yield per plant, and marketable fruits of eggplant. Maximum growth and yield was reported in treatment containing 6 t/ha, followed by 4 and 2 t/ha.	[32]
Chicken manure	Blue lupin (*Lupinus angustifolius*)	VC was added to the soil at the rates 5 and 7.5 Mg ha^{-1} along with varying concentrations of farmyard manure.	Combined treatment of VC and farmyard manure significantly enhanced the growth in terms of number of leaves per plant, leaf area per plant, and fresh and dry leaf biomass per plant.	[105]
Buffalo manure	Maize (*Z. mays*)	VC at the rate 20 t ha^{-1} was added to soil pretreated with chemical fertilizers. Soil amended with only fertilizers was taken as control.	VC improved the growth (plant biomass) and yield of maize.	[21]
Cow manure	Bur-clover (*Medicago polymorpha*)	Pots containing soil were fortified with VC to the extent of 0% (control), 15%, 30%, 45%, 60%, and 75% (*w*/*w*), in combination with and without arbuscular mycorrhizal fungi (AM fungi).	With increasing concentration of VC in the soil, the growth of bur-clover in terms of shoots and root dry weight and leaf area, increased. The total nitrogen content, potassium, and relative water content was also higher in leaves, in all the VC treated plants compared to the controls.	[191]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Cow manure	Ivy morning glory (*Pharbitis nil*) and red chilli (*Capsicum frutescens*)	VC was added to the soil at the rate 0% (control), 10%, 20%, and 30% (by volume).	VC enhanced the plant height, stem width, and dry weight of both the plant species observed. Maximum growth was recorded in 20% VC treatment.	[192]
Geranium distillation waste	Geranium (*Pelargonium graveolens*)	VC alone and in combination with inorganic fertilizers (NPK) were supplemented in plots to the extent of 5 t ha^{-1}. Unfertilized soil was taken as control.	Combined treatment of VC and inorganic fertilizers exhibited better plant growth, in terms of plant height, plant canopy and biomass, and oil yield, then controls.	[71]
Mixture of horse, goat and rabbit manure	Huizache (*Acacia farnesiana*)	Five VC-sand mixtures with proportions of 10:90, 20:80, 30:70, 40:60 and 50:50 (*v*/*v*), were assessed. Unfertilized soil was used as control.	No uniform growth trend was recorded among different VC amendments; however, 10:90 VC-sand mixture had the best variable response in terms of plant height, number of branches and fresh and dry weight.	[85]
Tomato crop waste	Rosemary (*Rosmarinus officinalis*)	VC added to the peat in the proportions 100:0, 75:25, 50:50, 25:75 and 0:100 (control).	VC increased the rooting and shoot dry weight of cuttings, compared with the control.	[111]
Not stated	Banana (*Musa* sp.)	In separate treatments farmyard manure (25 and 12.5 kg $plant^{-1}$), VC (3 and 6 kg $plant^{-1}$), neem cake (1.5, 1.0 and 3 kg $plant^{-1}$) and their mixture were used. In addition, 100 g vesicular aurbuscular mycorhizal (VAM) and 50 g phosphate solubilizing bacteria and Azospirillum $plant^{-1}$ were also supplemented.	Combined treatment of organic fertilizers and inorganic fertilizers enhanced the fruit yield and quality of banana in comparison with the exclusive application of inorganic fertilizers; 100% organic manures gave moderate fruit yield and higher quality.	[115]
Lantana leaves	Cluster bean (*Cyamopsis tetragonoloba*)	Soil was amended with VC at concentrations 0 (control), 5, 7.5, and 10 t ha^{-1}.	VC supported better plant growth in terms of stem diameter, shoot length and mass, number of leaves, and leaf pigments, nodulation and fruit yield, compared with controls.	[106]
Tendu leaf	French bean (*P. vulgaris*)	Soil was amended with VC at the concentrations equivalent of 0%, 50%, 75% and 100% of recommended dose of nitrogen.	VC enhanced the shoot and root length, shoot and root weights, thousand grain weight and grain weight per plant, in comparison to controls.	[130]
Cow dung	Marigold (*Tagetes erecta*)	VC was mixed with soil to the extent of 0% (control), 5%, 10%, 20%.	Addition of VC has significantly positive impact on the plant biomass, plant height, number of buds and flowers.	[193]
Not stated	Sweet orange (*Citrus sinensis*)	VC was supplemented to the extent of 10 and 10 kg/plant. Plants given N:P:K (400:300:400 g/plant/year) were considered as controls.	VC enhanced the plant growth in terms of height and its spread. Total soluble solids and vitamin C content was also higher in VC amended plants.	[194]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Not stated	Coriander (*Coriandrum sativum*)	VC alone and in combination with urea was used in the proportions: 100% VC, 66.6% VC + 33.3% urea, 66.6% urea + 33.3% VC and 100% urea. Untreated soil was considered as control.	VC when used alone or in combination with urea increased seed yield and total dry weight.	[195]
Cattle manure	Lettuce (*Lactuca sativa*)	VC was used alone, and in combination with rice husk, basalt powder, and sand in the proportion of 50:25:15:10, 60:15:15:10, and 60:15:10:15 (*w*/*w*).). Commercial substrate (Plantmax HA) was considered as controls.	VC when used alone or in combination with rice husk, basalt powder and sand, enhanced the growth of the lettuce in comparison to controls.	[196]
Cow manure	Peppermint (*Mentha piperita*)	In separate treatments, VC at the rate 7 Mt ha^{-1}, chemical fertilizers (50, 0, 300 kg NPK) and vermiwash prepared from 100 kg of VC, leachate VC + vermiwash and municipal solid waste compost (50 Mt ha^{-1}) was amended in soil. Soil with no fertilization regime was considered as control.	Organic fertilizers significantly enhanced the chlorophyll, carotenoids, essential oil yield, lateral branches, fresh and dry weight, fresh and dry yield, leaf area index of plants, in comparison to those of controls.	[197]
Not stated	Cucumber (*C. sativus*)	Seeds were germinated in peat containing VC to the extent of 0% (control), 20%, 40%, 60%, 80%, and 100%.	Addition of VC increased the yield of cucumber. Maximum yield was reported in 40% VC treatment.	[198]
Garden waste	Bluemink (*Ageratum hustonianum*) and petunia (*Petunia hybrid*)	Mixture of forest soil, pine sawdust and coconut fiber, was amended with VC at the concentrations 25%, 50% and 75%. Unfertilized soil mixture and 100% VC was considered as control.	VC at the rate 100% enhanced the growth of each of the species studied significantly, compared with unfertilized soil. Other VC treatments, too, exhibit positive impact on plant growth, but was not statistically significant from controls.	[199]
Domestic waste, goat and cow manure	Bhendi (*A. esculentus*)	VC and compost were added to the soil in 1:1 ratio.	Plant height and number of leaves were higher in VC treatments then in composts.	[11]
Mixture of goat, horse, and rabbit manure	Tomato (*Lycopersicon* sp.)	VC was mixed in the river sand in the proportions 0:1 (control), 1:1, 1:2, and 1:3.	Plants grown in 1:1 VC -sand mixtures produced the best yield and quality, in terms of polar diameter, number of fruits, number of locules, soluble solids, pulp thickness, fruit weight, and yield.	[108]
Rice straw	Tomato (*Lycopersicon* sp.)	Mixture of empty fruit bunch (EFB) and coconut coir dust (CD) was fortified with VC to the extent of 10%, 20%, 30%, and 40%; 100% CD served as control.	VC increased the crop growth rate, leaf area index, total fruit number, fresh fruit weight, and fruit dry matter, compared with the controls. Maximum growth however was reported in 20% VC treatment.	[200]
Not stated	Dragonhead (*Dracocephalum moldavica*)	VC was added to the soil to the extent of 0% (control), 15% and 30% of pot volume.	VC enhanced the shoot weight, plant height, seed weight per plant and essential oil content. Maximum growth was observed in 30% VC treatment.	[201]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Cattle dung	Wheat (*Triticum aestivum*)	VC was amended in the soil to the extent of 0 (control), 5, 10, and 20 t/ha.	Growth, yield and quality of wheat in terms of plant height, stem diameter, number of leaves per plant, number of spikes per plant, spike length per plant, number of spikelets per spike per plant, and yield per acre was positively impacted by addition of VC.	[202]
Mixture of bovine manure, melon waste, and wheat straw.	Bean (*Phaseolus vulgaris*)	VC was added to the soil at the rates 0 (control), 28.86, 57.7, and 86.46 g.	VC enhanced the plant height, leaf area, number of pods, grain dry weight, root length, root volume, root dry weight, pod dry weight, grain number, biomass dry weight, and nodule number.	[203]
Tomato crop waste	Evergreen spindle (*Euonymus japonicas*) and lavender (*Lavandula angustifolia*)	In separate treatments, compost and VC were mixed with coir fiber at proportions 100:0, 75:25, 50:50, 25:75, 0:100 (*v*/*v*).	Plants grown in VC amended media performed better in terms of rooting.	[204]
Cattle manure and rock phosphate	Maize (*Z. mays*)	In separate treatments, non-enriched VC and VC enriched with 5% or 20% of rock phosphate were used. Soil enriched with manure was considered as controls.	VC enhanced the height and biomass of the plants when used with rock phosphate powder.	[205]
Cattle manure	Pepper (*Capsicum* Sp.)	VC was supplemented at the rate of 50 and 100 cm^3 per plant. Thirty days after planting, some of the plants fertilized with 50 cm^3 VC were additionally fed with a solution of VC (200 cm^3 per plant). Unfertilized soil was used as control.	Feeding the pepper plants with VC increased their vegetative mass and improved the development of their generative organs. VC treatments also raised the nitrogen content of leaves of pepper plants.	[206]
Solid waste from industry fridge	Lettuce (*Lactuca sativa*)	VC was added to the soil to the extent of 0% (control) and 50% (*v*/*v*).	VC increased the growth of lettuce. A greater height and number of chlorenchyma layers were observed in the leaf blade of plants in VC treatments.	[207]
Crop residue, dry leaves and cow dung	Pigeon pea (*Cajanus cajan*)	VC and farmyard manure were added to the soil to the extent of 50 g.	VC enhanced the length of roots and shoot and increased the dry mass and chlorophyll content.	[208]
Not stated	Radish (*R. sativus*)	VC was mixed with the peat at proportions 1:1, 1:2, 1:4 and 1:8 (by volume). Peat containing inorganic fertilizer (NPK 11:11:22) at 50 g m^{-2} was set as control.	Mixture of VC and peat stimulated the accumulation of assimilates in the radish leaves and enhanced the root dry weight. The best treatment was 1:1.	[209]
Not stated	Cucumber (*C. sativus*)	Four growth media combinations were tested: (M1) 35:40:25 peat moss: perlite: VC; (M2) 25:25:25:25 peat moss: perlite: VC: coco peat; (M3) 100% coco peat; and (M4) 50:50 perlite: peat moss as control.	Addition of VC to the peat moss, perlite, and coco peat enhanced the performance of cucumbers measured in terms of vegetative growth, reproductive growth, and fruit-quality.	[210]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Mixture of cow dung and banana waste	Tomato (*S. Lycopersicum*)	In separate test plots, VC, inorganic fertilizers (IF) and VC+IF was added to the soil. Unfertilized soil was set as control.	VC increased the shoot length, root length and number of leaves, compared with control and chemical fertilizer treatments.	[211]
Cow manure	Tomato (*Lycopersicon* sp.)	In separate treatments, VC was mixed in the soil in the proportions 1:1, 1:2, 1:3, and 1:4.	Significant rise in growth and yield of tomato plants was reported with increasing ratio of VC to soil. Vitamin C and total sugar content in tomatoes, too, increased with increasing VC concentration in the soil.	[107]
Farm waste and cow dung	Onion (*Allium cepa*)	In separate treatments, VC at the rate 10 Mg ha^{-1}, 100% recommended dose of inorganic fertilizer and their combination was added to the soil. Plots that were not amended were considered as controls.	Combined treatment of VC and inorganic fertilizer produced higher plant growth, as measured by the vegetative growth of bulbs, number and length of tillers per bulb, and fresh weight of bulbs, compared with the control. Biochemical characteristics (total chlorophyll, carotenoids, protein, and total sugar contents) of onion leaves/tillers, too, exhibit the same trend as the growth.	[212]
Spent aromatic grasses	Patchouli (*Pogostemon cabli*)	VC alone (control) and in combination with bioinoculants (*Pseudomonas fluorescens*, *Bacillus Subtilis*, *Azotobacter chroococcum*, *Bacillus megaterium*, *Glomus aggregatum*, *G. fasciculatum*, *G. intraradices*, *G. mosseae*, *Trichoderma harzianum*) was used.	Except *Trichoderma harzianum*, VC when used along with bioinoculants, substantially improved the root and shoot biomass of nursery raised rooted cuttings.	[213]
Grape marc	Barley (*Hordeum vulgare*)	VC and compost were added to the peat and commercial sphagnum peat to the extent of 25% and 50% (v/v).	VC enhanced the growth and the productivity of barley.	[214]
Cattle manure	Lettuce (*Lactuca sativa*)	In separate treatments, inorganic fertilizer and VC at the rates 0% (control), 10%, and 20% (w/w) were added to the soil.	VC increased the leaf number, leaf dry weight, root biomass, photosynthetic rate and lettuce yield, in comparison to controls.	[215]
Vegetable waste	Cassava (*Manihot esculenta*)	Soil was supplemented with VC, empty fruit bunch compost and inorganic fertilizer.	Phenolic and flavonoid content were significantly enhanced in the plants grown in VC amended soil.	[216]
Rice straw and animal wastes	Barley (*Hordeum aestivm*)	VC at the rates 5 and 10 g per kg soil, alone or in combination with water treatment residual (WTR) at mixed ratios of 2:1 and 1:1 wet weight (VC: WTR), was added to the saline sodic soil. Unamended soil was taken as control.	Combined application of VC and WTR (2:1) at concentration of 10 g kg^{-1} soil produced the highest grain weight of barley plants, compared to other treatments.	[217]
Rice straw, water hyacinth, Ipomoea and cow dung	Rice (*O. sativa*)	Soil was amended with 500 g of each of the substrate's VC inoculated with *A. chroococcum*, *A. brasilense*, *P. fluorescens*, and consortium of azotobacter, azospirillum, and pseudomonas. Soil amended with VC without microbial inoculation was set as control.	VC enriched with *A. chroococcum* produced the highest plant growth, grain yield, leaf chlorophyll content and nitrate reductase activity of rice, followed by enrichment with *A. brasilense*.	[70]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Not stated	Chilli (*Capsicum annuum*)	VC was added to the perlite at the rate of 0% (control), 15%, 30%, 45%, and 60% (by volume). Controls were treated with Steiner nutritive solution.	With increase in VC concentration the plant height, number of leaves, flowers and fruits, weight, diameter and length of fruits, leaf dry weight, root dry weight, limb dry weight increased significantly.	[218]
Tomato waste mixed with sheep manure	White clover (*Trifolium repens*)	VC was added to soil and sand mixture (contaminated with heavy metals) to the extent of 5% (*w*/*w*).	Shoot and root dry matter of *T. repens* was enhanced by the addition of VC. There is also an increase in the uptake of P, K, Fe, Mn, Cu and Zn.	[219]
Cow and horse manure	Tomato (*Lycopersicon* sp.)	Tomato transplants were grown in 1:1 (*v*/*v*) peat moss and perlite mixture, in which the VC constituted from 10% to 50% of the mixture's volume. Unfertilized peat moss and perlite mixture served as control.	The positive effect of the VC in terms of shoot fresh weight, shoot length, leaf area, and number of leaves increased with the increase of its concentration in the peat moss and perlite mixture.	[220]
Cattle manure and filter cake	Maize (*Z. mays*)	VC was added to the pots containing commercial media (Plantmax Hortaliças HA) at the rate of 5 g/plant.	VC enhanced the growth and the N and P content in leaves of the maize.	[221]
Kitchen scraps, garden waste, coffee grounds, and straw	Swiss chard (*Beta vulgaris*)	VC was added to coir mix in proportion of 2:1, 1:1, and 1:2 (*w*/*w*).	VC increased the number of leaves, leaf expansion and harvest weight. A ratio of 2:1 VC–coir mix showed maximum productivity.	[222]
Green forage, cow manure	Maize (*Z. mays*)	VC was fortified in soil at the concentrations 1780 and 3560 kg fresh organic matter ha^{-1}.	VC enhanced the leaf N, P and K, pigments, soluble carbohydrates and yield of maize.	[223]
Crop residue and cow dung	French bean (*P. vulgaris*)	VC was added to the soil @ 0, 1.25, 2.5, 3.75, and 5 $t\cdot ha^{-1}$ in combination with 100%, 75%, 50%, 25% and 0% of recommended dose of NPK.	Combined treatment of VC at the rate 3.75 t ha^{-1} + 25% of recommended dose of NPK, exhibited better growth in terms of shoot length, number of primary branches, shoot fresh and dry weight than other treatments.	[224]
Cow manure and vegetable waste	Kidney bean (*Phaseolus vulgaris*)	Soil was substituted with VC to the extent of 0%, 25%, 50%, 80%, and 100% (*v*/*v*).	Plants grown in soil fortified with VC were taller and appeared to be healthier looking.	[225]
Woodchips	Grass seed mixture (*Festuca ovina*, *Festuca rubra*, and *Lolium perenne*).	Coal-spoil-contaminated tertiary sand was fortified with VC at rates 0% (control), 3%, 12.5%, and 25% (*w*/*w*).	VC significantly increased the fresh- and dry-matter yield, compared with controls.	[226]
Pig manure	Rose mallow (*Hibiscus moscheutos*)	VC, NPK and pine bark mixture (pine bark, 11% sand, 1.8 $kg\cdot m^{-3}$ dolomitic limestone, and 0.9 $kg\cdot m^{-3}$ Micromax) were used in following proportions: 20VC + NPK (20% VC and 17-6-12), 20VC + NK (20% VC and 17-0-10), 20VC + N (20% VC and 17-0-0). Controls included PBS + NPK (PBS and 17-6-12).	VC increased the dry weight and flower production in comparison with the controls.	[227]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Yard leaf	Corn (*Z. mays*)	VC treatments at the rates 1%, 3%, 6%, and 9%, were substituted alone or in combination with synthetic Fe fertilizers. A positive control received Hoagland's solution.	Combined treatment of VC and Fe sulfate was found as suitable potting mixtures with the recommended mixing rate of 3%.	[228]
Cow manure	Lemongrass (*Cymbopogon citrates*)	VC was added to sand and soil mixture to the extent of 0 (control), 5, and 10 g per plant.	VC increased the essential oil content of lemongrass leaves; however, no significant effect on shoot dry weight was reported.	[229]
Rabbit manure	Sweet corn (*Z. mays*)	Three treatments were compared: (i) inorganic (N, P and K) fertilizers 100%; (ii) 75% N, P and K mineral fertilizers and 25% rabbit manure; and (iii) 75% N, P and K and 25% VC.	VC significantly increased the plant growth and yield.	[230]
Buffalo Dung	Water spinach (*Ipomoea aquatic*)	In separate treatments, VC and compost were added to the soil at the concentration 90.5 g (20 t ha^{-1}) in the soil. In another treatment, inorganic fertilizer was applied.	Highest plant productivity was obtained with VC and synthetic fertilizers, with no significant difference between two treatments.	[231]
Turkey litter and cow dung	Paddy (*Oryza sativa*)	Soil was amended with VC at the concentrations 0 (control), 10, 20, 30, and 40 kg.	VC enhanced the growth and yield of paddy in terms of plant height, root length, shoot length, productive tillers, weight of panicle, weight of spikelet, number of grains per panicle, number of grains per spikelet, number of filled grains per panicle, number of unfilled grains per panicle, grain weight per hill, straw weight per hill, and straw weight per plot.	[61]
Cow dung	Chamomile (*Matricaria chamomilla*)	VC was added to the soil at the rates of 0 (control), 5, 10, 15, and 20 t ha^{-1}. In each of the treatment amino acids were sprayed at budding stage, flowering stage and budding + flowering stage.	VC enhanced the plant height, flower head diameter, fresh and dry flower yield and essential oil content in comparison to the controls.	[232]
Municipal solid waste	Cineraria (*Jacobaea maritime*)	Soil, sand and VC were mixed in the proportions of 1:1:1, 1:0:1, 2:1:1, 2:0:1 and 0:0:1, respectively.	VC enhanced the shoot fresh and dry weights, number of leaves and flower numbers.	[233]
Municipal Sewage sludge and water hyacinth	Tomato (*L. esculentum*)	Soil was fortified with VC to the extent of 10, 20 and 30 t/ha.	VC treatment at the rate 20 tons/ha caused maximum plant height, number of branches, fruits/plant, days to first harvest, and average fruit weight.	[234]
Cow manure	Bristle grass (*Setaria viridis*)	Pots containing iron mine tailings were amended with 0% (control), 10%, 20%, and 30% VC (*v*/*v*).	VC stimulated the survival rate, plant height, root length and fresh and dry matter accumulation in shoots.	[137]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Cow manure	Chinese cabbage (*Brassica rapa*)	VC–soil mixtures with ratios of 0:7 (control), 1:7, 2:7, 4:7 and 7:0 (*w*/*w*) were used.	VC significantly increased the marketable yield, nutrient metabolites (soluble sugar, soluble protein, vitamin C, total phenols, and total flavonoids), and antioxidant capacity of Chinese cabbage, in comparison with the controls.	[235]
Leaves of cassia and leucaena mixed with cow dung	Cowpea (*Vigna unguiculata*)	VC generated by using earthworm species *Eudrilus eugenia* and *Eisenia foetida* was used.	VC derived from *E. foetida* showed high shoot and root length, and greater number of leaves and biomass, in comparison to the VC derived by using *E. eugenia*.	[132]
Crop residue and cow dung	Tomato (*Solanum lycopersicum*)	Soil was fortified with VC to the extent of 3.75, 7.50, 11.25, and 15 t ha^{-1}, in combination with different concentrations of NPK.	Combined treatment of VC and inorganic fertilizers increased the plant height, leaf area, leaf weight, fruit weight, fruit yield, fruit density, post-harvest life and TSS of tomato, compared with exclusively VC or chemical fertilizers (NPK) treatments.	[236]
Filter cake spiked with horse dung	Marigold (*T. erecta*)	Soil was fortified with VC to the extent of 0% (control), 10%, 20%, 30% and 40%.	VC enhanced the plant height, total number of buds, fresh root and shoot weight, number and diameter of flowers, and total chlorophyll content, compared with the controls.	[237]
Rice straw and chick weed and cow dung	Maize (*Z. mays*), beans (*P. vulgaris*) and okra (*A. esculentus*)	Plants were grown in soil, amended with VC to the extent of 1 t/ha.	VC treated plants exhibited better plant height, basal area, productivity and biomass allocation, compared with control.	[133]
Sewage sludge	Habanero pepper (*Capsicum chinense*)	VC was added to the commercial substrate to the extent of 0%, 25%, 50%, 75%, and 100%.	VC enhanced the height of plants significantly; 100% VC treatment led to maximum plant height.	[225]
Agricultural waste mixed with cow dung	Tomato (*S. lycopersicum*), eggplant (*S. melongena*), and chili pepper (*Capsicum frutenscens*)	VC was added to the mixture of sand and soil @ 20%, 25%, 33.33%, and 50%. In separate treatment soil and VC at the proportion 1:1 was used.	VC fortification positively impacted the growth of each of the plant species studied.	[238]
Cow dung, water hyacinth and straw	Mung bean (*Vigna radiate*)	Black or red soils were amended with VC to the extent of 5 t ha^{-1}.	VC enhanced the growth and yield of mung bean in terms of number and weight of nodules, number of primary branches per plant, plant height, number of pods per plant, number of grains per plant, grain yield per plant and straw yield per plant in both the soil types, however the performance was better in black soil compared to the red soil.	[239]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Not stated	Saffron (*Crocus sativus*)	VC was used alone at the rate 2.5 t/ha and in combination with azotobacter, azospirilum, pseudomonas, and VAM. Untreated soil was considered as controls.	VC when supplemented along with azotobacter enhanced the yield.	[240]
Horse, goat, rabbit and cow manure	Muskmelon (*Cucumis melo*)	VC was incorporated in the sand to the extent of 25%, 30%, 35%, and 40% (*v*/*v*).	VC exhibited favorable impact on the yield, fruit weight, equatorial and polar diameters, pulp thickness, placenta cavity, fruits per plant, and days to harvest.	[241]
Not stated	Strawberry (*Fragaria ananassa*)	VC (5 t/ha), farmyard manure (20 t/ha), poultry manure (5 t/ha), rhizosphere bacteria culture (4 kg/ha) and chemical fertilizers (N:P:K—100:80:60 kg/ha) were used alone or in combination with each other.	Combined treatment of VC chemical fertilizer and rhizosphere bacteria had shown maximum plant spread, fruits per plant, fruit yield per hectare, and shelf life of fruits.	[242]
Grass and cattle dung	Okra (*A. esculentus*)	In separate treatments, VC @ 100 g per plant, vermiwash @ 100 mL per plant and their combined treatments were used.	Combined treatments of VC and vermiwash increased the plant growth and yield, compared with their individual supplementation.	[243]
Cow manure	Alfalfa (*Medicago sativa*) and white clover (*Trifolium repens*)	Iron mine tailing was supplemented with VC at the rates 0% (control), 5%, 10%, and 20% (*v*/*v*).	In white clover, VC increased the plant height, shoot and root weights, whereas in case of alfalfa lower VC (5%) had led to maximum height while 10% and 20% VC treatments caused shorter height than that of control. However, the shoot fresh weight was higher in 20% VC treatment.	[145]
Farmyard manure	Garlic (*Allium stivum*)	In separate treatments, soil was fortified with VC alone and in combination with inorganic fertilizers. The treatments were: (1) recommended dose of NPK; (2) 15 t/ha VC; (3) 20 t/ha VC; and (4) 15 t/ha VC + 50% NPK.	Combined treatment of VC and inorganic fertilizer had shown higher growth in terms of root and shoot length, leaf length and number, number of cloves in garlic fruit, and fruit weight.	[244]
Sugar mill wastes	Beans (*Phaseolus vulgaris*)	Efficacy of VC, in comparison to inorganic fertilizers-NPK, when added in clay loam soil and sandy loam soil was assessed. Treatments consisted of: (1) control (unfertilized soil); (2) 100% recommended dose of NPK; (3) 100% recommended dose of VC (5t ha^{-1}); and (4) 50% VC supplemented with 50% NPK	Combined treatment of VC and inorganic fertilizers exhibited better plant growth (shoot and root length, leaf area index and number of root nodules) biochemical properties (sugar, protein and chlorophyll content) and yield (pod length, number of seeds per pod, number of pods per plant, pods weight and sugar and protein contents in the beans), in comparison to their individual treatments and control.	[245]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
Studies showing the stimulation of plant growth and yield				
Cow manure	Tomato (*Solanum lycopersicum*)	Commercial peat substrate was fortified with VC at the concentrations 0% (control), 10%, 20%, 50%, 75%, and 100% (*w*/*w*).	VC significantly improved the growth of tomato in terms of number of leaves and leaf area, and increased root volume and branching, compared with the pure peat-based substrate (control).	[246]
Cow manure	Tomato (*Lycopersicon* sp.)	Iron-enriched VC (prepared by mixing iron refuse in cow manure at the concentrations 0%, 5%, 10%, 15%, and 20% by volume) was incorporated in mixture of soil and sand (7:3) to the extent of 37 g pot^{-1}. Unfertilized soil and sand mixture was considered as control.	Shoot dry matter of plants grown in soil treated with iron-enriched VC (15–20%), was significantly higher than that of plants produced in the other treatments. Iron uptake by tomatoes grown in iron-enriched VC was also higher compared with normal VC and controls.	[247]
Sheep manure	Cucumber (*Cucumis sativus*)	VC was mixed with soil to the extent of 0 (control), 10, 20 and 30 t ha^{-1}.	VC enhanced the leaf area and number, plant height, dry weight of stem and leaf, chlorophyll content, total fruit yield, and number of fruits per plant. VC also led to higher total soluble solids, lower juice acidity and more dry matter of fruits than controls.	[248]
Subabul leaves and cow dung	Ginger (*Zingiber officinale*)	Pots containing saline soil were mixed with VC to the extent of 500 g.	VC improved the net yield, biomass of shoot and rhizome yield. Chlorophyll, carbohydrate and protein contents were also increased.	[109]
Not stated	Strawberry (*Fragaria ananassa*)	Treatments comprised of 100% recommended dose of inorganic fertilizer (80, 40, 40 kg/ha), and combined treatment of inorganic fertilizer and VC or farmyard manure (50% nitrogen requirement substitution through VC or farmyard manure and remaining 50% by inorganic fertilizer). All the treatments were supplemented with azotobacter.	Combined treatment of VC and inorganic fertilizer enhanced the number of crowns and runners, length of runners, number of plantlets, number of flowers and berries, fruit yield and net monetary return.	[249]
Vegetable wastes mixed with cow dung	Strawberry (*Fragaria* × *ananassa*)	VC was added to the soil at the concentrations 0 (control), 2.5, 5.0, 7.5, and 10 t ha^{-1}. All the plots were supplemented with appropriate amount of inorganic fertilizers, to equalize the recommended rate/dose of nutrients 120/170/150 kg NPK ha^{-1}) among the treatments.	VC increased the plant spread, leaf area, dry matter, and total fruit yield of strawberry, compared with the control.	[20]
Animal manure	Parsley (*Petroselinum crispum*)	VC-soil mixture in the proportions 0:100, 10:100, 20:100, and 30:100 (*v*/*v*; VC: soil) were used.	VC enhanced the plant height, number of leaves and root fresh weight of parsley plants. Maximum growth however was reported in 10:100 (VC: soil) treatment.	[250]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Banana leaves and cow dung	Banana (*Musa* spp.), cassava (*Manihot esculenta*) and cow-pea (*V. unguiculata*)	Soil was fortified with VC generated by *E. eugineae*, *E. foetida*, *Perionyx sansibaricus*, *Pontoscolex corethrurus* and *Megascolex chinensis* along with inorganic fertilizers (NPK).	VC significantly improved the root growth, and the yield, biometric character and quality of banana, cassava and cow-pea.	[251]
Sheep manure	Peppers (*Capsicum annum* L)	VC was mixed with soil in proportions of 0:1, 1:1, 1:2, 1:3, 1:4, and 1:5 (VC: soil).	VC enhanced the plant height, plant thickness, and the number of leaves, flower and fruits. Additionally, VC enhanced the soluble solids and nitrogen content of the fruits.	[252]
Sheep manure	Maize (*Z. mays*)	VC was added to peat moss at the rates 0%, 5% and 10% (v/v), along with diazotrophic bacteria and mycorrhiza.	VC enhanced the weight of maize plants when applied along with *G. fasciculatum* and diazotrophic bacteria	[253]
Pig manure	Tomato (*L. esculentum*), marigold (*T. patula*), pepper (*Capsicum annuum*), and cornflower (*Centaurea cyanus*)	VC was added to the commercial potting substrate (Metro Mix 360), to the extent of 0% (control), 10%, and 20% (v/v).	VC enhanced the shoot and root weight, leaf area, and shoot: root ratios of tomato and French marigold seedlings; however, VC substitution had little influence on pepper and cornflower growth.	[141]
Not stated	Cucumber (*C. sativum*)	Treatments include peat compost (100%), VC (100%) and their mixture (1:1).	VC addition significantly increased the relative growth rate, dry matter per plant, relative stem elongation rate and relative leaf expansion rate.	[254]
Sheep manure	Tomato (*L. esculentum*)	Soil was fortified with VC to the extent of 0 (control), 5, 10, and 15 t ha^{-1}.	Significant rise in growth and yield of tomato was reported in 15 t ha^{-1} VC treatment. Other VC concentrations, too, impacted positively, but not significant to a statistically extent.	[255]
Food and paper waste	Petunia (*Petunia hybrida*)	Commercial bedding plant container medium (Metro-Mix 360) was substituted with VC to the extent of 0% (control), 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% or 100% (v/v).	VC enhanced the shoot and root dry weights in comparison to the controls.	[83]
Food and cotton waste	Tomato (*L. esculentum*)	VC was added to the commercial peat substrate at the rate of 0%, 20%, 40%, 60%, 80%, and 100% (v/v).	VC increased the biomass of tomato.	[18]
Manures	Tomato (*L. esculentum*)	VC was added to peat-based compost at rates 0%, 10%, 20%, 40%, and 100% (v/v).	VC improved the marketability of fruits at 40% and 100% substitution rates; however, the fruit yield and fruit number remain unaffected by the addition of VC.	[134]
Green waste and biosolids	Wheat (*Triticum aestivum*)	VC at the rates 1, 10 and 30 t ha^{-1} was added to the soil alone or in combination with inorganic fertilizers (NPK), where the N addition rate was normalized to 150 kg N ha^{-1}. Unfertilized soil was used as control.	Co-application of inorganic fertilizers and VC exhibited better plant growth, photosynthetic pigments and yield, than individual VC treatments and control.	[256]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Sheep manure	Tomato (*L. esculentum*)	VC and soil were employed in proportions of 0:1, 1:1, 1:2, 1:3, 1:4 and 1:5 (*v*/*v*).	VC increased the plant height significantly but had no significant effect on the numbers of leaves or yield. VC also enhanced the soluble and insoluble solids in tomato fruits compared to those harvested from plants cultivated in unamended soil.	[257]
Sugar mill waste	Black gram (*Vigna mungo*)	In separate treatments, soil was fortified with recommended dose of VC (5 t/ha), inorganic fertilizer (NPK; 50:25:0 kg/ha) and mixture of VC and NPK (50/50). Unamended soil was considered as controls.	VC enhanced the yield and quality (protein and sugar content in seed) of black gram.	[258]
Cow dung	Marigold (*T. erecta*)	Mixture of peat-perlite and pine bark-sand was mixed with VC in the proportions 1:1, 2:1 and 3:1 (*v*/*v*). In separate treatments, mixture of peat-perlite (PP), pine bark-sand (PBS) and sunshine mix (SM) was also used.	VC increased the plant growth index, stem diameter root growth, dry weight and number of flower of marigold compared with PP, SM and PBS.	[259]
Pistachio solid wastes, cotton residues, animal manure	Pistachio (*Pistacia vera*)	VC enriched with or without Fe sulfate, was added to the soil at the rates 0% (control), 10% and 20% (*w*/*w*).	Fe enriched VC enhanced the plant height, shoot dry weight, leaf area index, chlorophyll content of the leaves and photosynthesis rate.	[260]
Municipal waste	Ryegrass (*Lolium perenne*)	VC and compost were added to the degraded volcanic soil to the extent of 20 and 40 g kg^{-1}.	VC significantly increased the yield of ryegrass.	[66]
Cattle manure	Tomato (*L. esculentum*), eggplant (*Solanum melongena*), and pepper (*Capsicum annuum*)	Seedling transplants were grown in a commercial soilless mix fortified with VC to the extent of 0% (control), 10%, and 20% (*v*/*v*).	VC improved the transplant quality of peppers and eggplants, whereas tomato transplant quality was slightly reduced.	[261]
Not stated	Guava (*Psidium guajava*)	Treatments comprised of 30 kg/plant VC, 100% recommended dose of fertilizers (RDF: 100:40:75 g NPK/plant), 75% RDF + 10 kg VC/plant, 50% RDF + 10 kg VC/plant. Untreated plants served as controls.	Combined supplementation of VC and inorganic fertilizer (75% RDF and 10 kg VC) enhanced the polar diameter, fruit weight, fruit volume and pulp thickness and its weight. Total soluble solids, ascorbic acid and total sugars were also increased.	[262]
Food and paper waste, cattle manure	Pepper (*C. annuum*)	Soil was fortified with VC at the rate of 10 t ha^{-1} or 20 t ha^{-1} in first year and at rates of 5 t ha^{-1} or 10 t ha^{-1} in second year.	VC increased the leaf areas, plant shoot biomass, and marketable fruit weights.	[79]
Rice straw	Sorghum (*Sorghum bicolor*)	VC generated by using *Perionyx excavatus*, and *Octochaetona phillotti*, was added to the soil at concentrations 75% and 25%. Unamended soil served as control.	VC increased the growth of sorghum, compared with the controls.	[263]
Dairy manure	Tomato (*Lycopersicon* sp.)	Sand and soil in pots were amended with VC to the extent of 0% (control), 15%, 30%, and 45% of pot volume.	VC fortification produced significantly higher biomass than the control.	[264]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
Studies showing the stimulation of plant growth and yield				
Neem leaves	Brinjal (*Solanum melongena*)	VC was added to the soil at the rate of 1 kg m^{-2}. Unfertilized soil was considered as control. After 2 months, the unfertilized (control) soil was also amended with equal quantity of VC.	VC led to better height, root length, biomass per unit time, quicker onset of flowering, and fruit yield in brinjal.	[265]
Food waste	Pepper (*C. annum*)	VC was added to the commercial bedding plant container medium, Metro-Mix 360 (MM360) to the extent of 0% (control), 10%, 20%, 40%, 60%, 80% and 100%.	Peppers grown in potting mixtures containing 40% food waste VC yielded high fruit weights and mean number of fruits. Mean heights, numbers of buds and numbers of flowers in 10–80% VC treatments although greater did not differ significantly from control.	[266]
Food and paper waste	Strawberry (*Fragaria ananasa*)	VC was added to the soil so as to attain the initial fertilizer rates 85/155/125 kg ha $^{-1}$ NPK.	VC increased the leaf area, plant shoot biomass, numbers of flowers, numbers of plant runners and marketable fruit weights significantly.	[267]
Cattle manure	Papaya (*Carica papava*).	VC was added in proportions of 0% (control), 5%, 10%, 15%, 20% and 25% to the mixture of rice hulls, coconut sawdust and thin sand (1:1:1).	VC enhanced the leaf area, plant height, stem thickness and total dry weight. The largest growth was found with the highest ratios of VC.	[268]
Food and recycled paper waste, cattle manure	Tomato (*L. esculentum*), bell pepper (*C. anuum*), and strawberry (*Fragaria* spp.)	For growing tomato and pepper VC was applied at rates 10 or 20 t ha^{-1}, while for growing strawberry VC was applied to the extent of 5 or 10 t ha^{-1}. One set of plots with recommended rates of inorganic fertilizer: 130–95–95 kg NPK ha^{-1} for peppers; 80–75–75 kg NPK ha^{-1} for tomatoes; and 85–155–125 kg NPK ha^{-1} for strawberries, was also used.	VC enhanced the growth and yield of each of the species studied, compared with inorganic fertilizer.	[49]
Sheep, cattle, and horse manure	Chrysanthemum (*Dendranthema x grandiflora*)	Peat-perlite mixture was fortified with each of the substrate's VC to the extent of 0% (control), 25%, 50%, 75%, 100% (*v*/*v*).	VC derived from each of the substrate enhanced the growth of chrysanthemum in terms of foliar area, dry weight, flower number, and days to flowering.	[269]
Sheep, cattle, and horse manure	Poinsettia (*Euphorbia pulcherrima*)	VCs derived from each of the substrate was mixed in the peat–perlite mixture in the proportions 0:1 (control), 1:3, 1:1, 3:1, and 1:0 (*v*/*v*).	Growth index, foliar area, bract area and dry weight were higher in plants grown in mixture fortified with each of the substrate's VC.	[270]
Pig manure	Tomato (*L. esculentum*), pepper (*Capsicum* sp.), lettuce (*L. sativa*) and marigold (*Calendula officinalis*)	In separate treatments, standard commercial soilless plant growth medium (Metro-Mix 360), and coir/perlite and peat/perlite-based container media were substituted with VC to the extent of 10% or 20% (*v*/*v*).	Substituting coir/perlite and peat/perlite mixtures with 10% or 20% of VC enhanced the growth significantly.	[135]
Animal manure and plant wastes	Radish (*R. sativus*).	VC was mixed with sand at concentrations 0% (control), 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% (*v*/*v*).	Harvest weights were proportionately increased with the increase of VC.	[147]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
Studies showing the stimulation of plant growth and yield				
Cassava peel guava leaves, cow dung and poultry droppings	Cowpea (*Vigna unguiculata*)	VC added to the soil @ 8 kg fresh compost per plot. Unfertilized plots were considered as control.	Significant increased biomass was recorded in VC amended soil.	[271]
Cow farmyard manure	Radish (*R. sativum*) and lettuce (*Lactuga sativa*)	Seedlings were grown in pots containing either mixture of dry alluvial soil, peat, and sand or VC.	Earthworm casts increased the protein synthesis in both lettuce and radish, however no significant difference was observed.	[77]
Studies showing stimulation of plant growth and yield at lower VC concentration and inhibition at higher				
Municipal solid waste (food, paper and yard waste)	Green bean (*Phaseolus vulgaris*)	In plastic pots mineral brown-earth soil was fortified with VC and compost to the extent of 0% (control), 10%, 20%, 30%, 40%, 50%, and 100% (v/v).	Compared to the compost and controls, VC at the rate 40% application led to higher growth and yield. With further increase in the compost and VC concentration the growth and yield declined.	[272]
Fly ash	Marigold (*Tagetes* spp.)	Seeds were sown in media composed of pine bark compost and VC. The proportion of VC was 0%, 25%, 50%, 75%, and 100%. Additionally, in one set of treatments chemical fertilizers were added, while keeping another treatment without fertilizer fortification.	VC treatment up to 50% was recommended for the effective germination and growth of marigold. With further increase in the VC concentration, deleterious effects were recorded.	[142]
Salvinia	Green gram (*Vigna radiata*), ladies finger (*Abelmoschus esculentus*) and cucumber (*Cucumis sativus*)	Seedlings were raised in soil supplemented with VC to the extent of 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (w/w).	VC in the range of 4–20%, VC enhanced the growth of the seedlings and their biochemicals compared with the controls. Further increase in VC concentration showed an adverse effect on the growth.	[38]
Ipomoea	Green gram (*V. radiata*), ladies finger (*A. esculentus*) and cucumber (*C. sativus*)	Seedlings were germinated and grown in soil amended with VC at the rates 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (by weight).	When supplemented to soil in the range of 2–4%, VC enhanced the germination, growth and biochemicals compared with the controls. Further increase in VC concentration inhibited the growth.	[37]
Cow solids	Thyme (*Thymus vulgaris*)	Seeds were germinated and grown in soil amended with VC at the rate 0%, 25%, 50%, and 75%.	VC enhanced the length, fresh and dry weights of the aerial parts and the root; chlorophyll and carotenoid contents, photosynthetic efficiency; and essential oil content. Best response was observed in 50% VC substitution. Further increase in VC proportion retarded the growth.	[143]
Fly ash and cow dung	Marigold (*Tagetes* spp.)	Mixture of VC and pine bark compost was used as media, with VC added to the extent of 0%, 25%, 50%, 75%, and 100%. Seeds were sown in media with or without fertilizer.	VC enhanced the growth of seedlings, with maximum growth, in terms of plant height, leaf area, number of flowers and buds was observed in media containing up to 25 and 50% VC.	[142]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
Studies showing the stimulation of plant growth and yield				
Parthenium leaves	Green gram (*V. radiata*), ladies finger (*A. esculentus*) and cucumber (*C. sativus*)	Seedlings were germinated and grown in soil amended with VC at the rates 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (by weight).	VC when applied up to 4, 8, and 20% enhanced the growth (shoot and root length, plant biomass, chlorophyll content) of green gram, ladies finger and cucumber respectively. Further increase in VC concentration inhibited the growth.	[36]
Rubber leaf litter and cow dung	Pineapple (*Ananas comosus*)	VC was added to the soil to the extent of 0 (control), 5, 10, 20 and 30 tons ha^{-1}.	VC treatments up to 20 t ha^{-1} increased the average length and width of leaves, number of leaves per plant, plant girth, fruit weight, fruit yield and fruiting percentage compared to the control. Further increase in the VC concentration declined growth and yield.	[273]
Lantana leaves	Green gram (*V. radiata*), ladies finger (*A. esculentus*) and cucumber (*C. sativus*)	Soil was amended with VC to the extent of 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (*w*/*w*).	VC when applied in the range 0.75–4% enhanced the growth (shoot and root length, plant biomass, chlorophyll content) of all the species studied, compared with control. Further increase in VC concentration inhibited the growth.	[35]
Temple floral waste, yard waste, cow dung	Chickpea (*Cicer arietinum*)	Soil was substituted with each of the three substrate's VC to the extent of 5%, 10%, and 25% (*v*/*v*).	VC supplementation to the extent of 10% increased the root length, number of secondary roots, and plant biomass, compared with the controls. Further increases in VC concentration (25%) either exhibited the inhibitory effect or have no significant difference than controls.	[116]
Kitchen waste	Sugar peas (*Pisum sativum*)	VC was added to garden soil to the extent of 0% (control), 10%, 25%, and 50%.	VC when used at 10% concentration enhanced the total biomass and height of plants. Further increase in VC concentration had no impact on plant growth.	[274]
Tomato crop waste	Garden marigold (*C. officinalis*) and horned pansy (*Viola cornuta*)	VC was mixed with sphagnum peat in the proportions 100:0, 75:25, 50:50, 25:75, and 0:100 (peat control) by volume.	VCs treatment at lower proportion (25:75) increased total leaf chlorophyll, shoot and root dry weight, and percentage of flowering plants, compared with controls; 100% VC treatment reduced the growth significantly.	[204]
Sheep manure	Radish (*R. sativus*).	VC was added to peat moss at the rates 0%, 10%, 20%, 30%, or 40%.	Growth of radish in terms of shoot and root dry weight was higher in 10% VC treatment. Further increase in VC concentration caused an inhibitory effect.	[51]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Sewage sludge and cattle dung	Marigold (*Tagetes erecta*)	VC was mixed with black soil in the proportions of 10%, 20%, and 30% (dry weight).	VC enhanced plant height, stem diameter, leaf number, branch number, aboveground biomass, underground biomass, and ratio of root to shoot, flower bud number, flower yield, flower diameter, and flower biomass. Maximum growth was observed in 20% VC treatment, while 30% had shown a slight inhibition.	[275]
Rabbit manure	Maritime Pine (*Pinus pinaster*)	Peat and perlite mixture was substituted with VC at the concentrations 0% (control), 2.5%, 5%, 10%, and 25% (*v*/*v*).	VC treatments up to 10% increased the seedling height and aerial biomass, while 25% VC reduced the growth.	[276]
Not stated	Tomato (*L. esculentum*)	Seeds were sown in pots containing sand amended with VC to the extent of 0% (control), 10%, 25%, 50%, and 100%.	Addition of VC enhanced the plant height, internode length, shoot diameter and chlorophyll content in all the VC treatments except 100%, which inhibited the growth.	[277]
Cattle manure	Petunia (*Petunia hybrida*)	Commercial bedding plant container medium (Metro-Mix 360) was substituted with VC to the extent of 0% (control), 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% or 100% (*v*/*v*).	Shoot and root dry weights were increased after substituting container medium with 10–60% VC; thereafter slight decrease was reported with increasing concentration. Number of flowers increased only up to 40% VC treatments.	[83]
Cow manure	Dieffenbachia (*Dieffenbachia* spp.)	Mixture of peat and perlite (2:1) was amended with VC at the rate of 0% (control), 25%, 50%, 75%, and 100% (*v*/*v*).	VC enhanced the growth of the dieffenbachia plant when substituted up to 50%. Further increase in VC concentration reduced the growth.	[278]
Rice straw and cow dung slurry	Sorghum (*Sorghum bicolor*)	VC was added to the soil at the rates 2.5, 5 and 10 tonnes (t) ha^{-1}. In one set of VC treatments, arbascular mycorrhizal (AM) fungi were added where as another set left unamended.	AM fungi enriched VC at the rate 2.5 t ha^{-1} led to better shoot length, leaf area, plant biomass, and root volume in sorghum then other treatments. Further increase in VC (amended with AM fungi) decreased the plant biomass.	[279]
Green waste	Lettuce (*L. sativa*)	Mixture of VC and compost were employed in the proportions 0/100, 50/50 and 20/80, and 100/0 (*v*/*v*).	Plant biomass was maximum in 20/80 (*v*/*v*) compost blend, while pure VC or compost yielded poorer growth.	[280]
Pig manure	French marigold (*Tagetes patula*)	Standard commercial greenhouse container medium (Metro-Mix 360) was substituted with VC to the extent of 0% (control), 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% (*v*/*v*).	The vegetative growth was higher in plants treated with 30% and 40% VC; while the lowest growth was reported in 90% and 100% VC treatments.	[50]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the stimulation of plant growth and yield		
Pig manure	Tomato (*L. esculentum*)	VC was mixed with container media (Metro-Mix 360) to the extent of 0%, 5%, 10%, 25%, 50%, and 100% (v/v).	VC enhanced the growth of tomato seedlings when grown in media substituted up to 50% VC; 100% VC treatment reduced the growth. Maximum growth was reported in 25% and 50% VC.	[114]
Pig manure	Tomato (*L. esculentum* Mill)	Standard commercial greenhouse container medium (Metro-Mix 360) was substituted with VC to the extent of 0% (control), 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% (v/v).	Seedlings grown in 100% VC were significantly shorter, had fewer leaves, and weighed less than those in controls. VC treatments up to 50% enhanced the growth and yield.	[17]
		Studies showing no effect of VC on plant growth and yield		
Cow manure	Pepperleaf (*Piper auritum*)	Treatments included VC @ 10, 20, and 30 g/plant, vermiwash @ 5, 10, and 15 mL/plant, and rock phosphate @ 1, 2, and 3 g/plant.	VC, vermiwash, and rock phosphate rock had no statistically significant effect on plant growth.	[25]
Cow and sheep manure	Chincuya (*Annona purpurea*)	In separate treatments, VC was added to plants at the rate 0, 50, and 100 g plant^{-1}.	VC amendment had no significant impact on the plant height and stem diameter. Total phenols in leaves and antioxidant activity decreased, while the flavanones increased on VC addition.	[86]
Paper waste spiked with cow dung	Cluster bean (*C. tetragonoloba*)	VC was added to soil at the rate of 0, 5, 7.5, and 10 t/ha.	Application of VC had no beneficial impact on plant growth and yield.	[24]
Buffalo manure	Maize (*Z. mays*) and tomato (*Lycopersicon* sp.)	VC was mixed with soil to generate 20 t ha^{-1} organic substrate concentration (90.5 g pot^{-1}). Controls contained soil amended with NPK equivalent to that of VC. Initially maize was grown followed by tomato and maize in the same pots.	VC treatments had no significant impact on the above-ground plant biomass of first maize planting. Plant yields were always highest in controls.	[23]
Vegetable waste	Tomato (*S. lycopersicum*)	In separate treatments, mixture of commercial blonde sphagnum peat, coconut coir dust, perlite and VC were studied. The proportion of VC was 0%, 25%, and 50%.	VC substitution had no impact on the growth of tomato.	[140]
Green waste	Sunflower (*Helianthus annuus*)	Peat based growing media was supplemented with VC to the extent of 0%, 20%, 40%, 60%, 80% and 100% (v/v).	VC produced no significant impact on growth rate, overall height and total biomass,	[22]
		Studies showing the inhibition of plant growth and yield		
Cow manure	Garden bean (*P. vulgaris*), peas (*P. sativum*), beetroot (*Beta vulgaris*), radish (*R. sativus*), cabbage (*B. oleracea*) and Swedish turnip (*B. napobrassica*)	Commercial sphagnum peat was substituted with VC @ 0% (control), 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% (v/v).	VC treatments exhibited inhibitory effects on the early seedling development of all the species studied.	[117]

Table 2. *Cont.*

Source of VC	Impacted Plant Species	Type of Experiment	Main Findings	Reference
		Studies showing the inhibition of plant growth and yield		
Agriculture waste and pig manure slurry	Pansy (*Viola× wittrockiana*) and primula (*Primula acaulis*)	Peat-based conventional greenhouse medium was substituted with VC to the extent of 0% (control), 5%, 15%, and 25% (*v*/*v*).	VC supplementation had no beneficial effects on the growth and flowering of all the plant species studied; rather the plants grown in VC amended media showed less growth and flowering than controls.	[19]
Green waste	Sunflower (*Helianthus annuus*), garden cosmos (*Cosmos bipinnatus*) and golden poppy (*Eschscholzia californica*)	Peat based growing media was supplemented with VC to the extent of 0%, 20%, 40%, 60%, 80% and 100% (*v*/*v*).	VC treatments yielded no positive impact on plant growth, flowering and seed production (except flower numbers and seed weight of cosmos), rather VC have a suppressive effect on all the species studied.	[22]

Table 3. Effect of vermicomposts on soil.

Source of VC	Type of Experiment	Main Findings	Reference
	Manure based VCs		
Chicken manure	Cucumber was grown on sandy loam soil under four soil amendment conditions: inorganic compound fertilizer (750 kg/ha,), replacement of 150 kg/ha of inorganic compound fertilizer with 3000 kg/ha of organic fertilizer or VC, and untreated control.	VC significantly improved the total nitrogen, ammonium nitrogen, nitrate nitrogen, microbial nitrogen, organic matter, soluble organic carbon, total phosphorus, available phosphorus, available potassium, water content, and bulk density of the soil. In addition, VC induced a significant change in the rhizosphere soil fungal community compared to the other treatments.	[65]
Chicken manure	VC in the rate 0% (control), 5%, 10%, and 100% (*v*/*v*) was mixed with autoclaved quartz sand supplemented with or without rhizobia.	With increases in VC concentrations, the nematode numbers and diversity increased.	[281]
Animal waste	Mixture of sandy loam, loam and clay textured soils was supplemented with VC at the concentration 0% (control), 0.5%, 1%, 2%, and 4% (*w*/*w*).	VC supplementation in all three soils significantly increased organic matter content, wet aggregate stability and air permeability–with concomitant decrease in bulk density and penetration resistance.	[282]
Cow manure	Pots containing soil were supplemented with VC at the rate 0%, 15%, 30%, 45%, 60%, and 75% (*w*/*w*), with and without arbuscular mycorrhizal fungi.	VC treatments significantly decreased the bulk density of the soil.	[191]

Table 3. *Cont.*

Source of VC	Type of Experiment	Main Findings	Reference
		Manure based VCs	
Cattle dung	Pots containing soil were supplemented with 500 g (wet weight) of either VC or cattle dung. Treatment without organic fertilizer was used as a control.	Soil nutrient content (total nitrogen, available phosphorus and potassium) and microbial biomass, nematode, and mite abundance was increased with VC amendment.	[62]
Rabbit manure	In a field study, impact of three types of fertilization regimes was compared: (1) conventional fertilizer regime with inorganic fertilizer; and combined integrated fertilizer regimes in which 25% of the nutrients were supplied by either: (2) rabbit manure; or (3) VC.	Integrated fertilizer regimes stimulated microbial growth and increased enzyme activity relative to inorganic fertilization.	[230]
Turkey litter and cow dung	VC was supplemented at the rate 10, 20, 30 and 40 kg along with farmyard manure (FYM) at the rate 2 t/ha. Plots without any amendment served as control.	VC amendment increased the available NPK concentrations in soil amended with VC.	[61]
Cow manure	Pots containing iron mine tailings were amended with 0% (control), 10%, 20%, and 30% VC (*v*/*v*).	Microbial population was significantly higher in VC amended iron mine tailing than controls.	[137]
Cow dung	Cow dung VC was applied to the soil at concentrations 3 and 6 Mg C ha^{-1}.	Substitution of VC increased the microbial biomass carbon, dehydrogenase, urease, ß-glucosidase, phosphatase, and arylsulfatase activity in soil.	[283]
Pig manure slurry	VC was substituted in the peat-based conventional greenhouse medium to the extent of 0% (control), 5%, 15%, and 25% (*v*/*v*).	VC supplementation reduced the bulk density and increased the water holding capacity of the container media. It also increased the ammonium and nitrate content, total nitrogen, phosphorus and potassium content of media.	[19]
Cow dung	VC was supplemented in pots containing soil to the extent of 10 t ha^{-1}. Pots without any amendments served as control.	The counts of fungi, bacteria and actinomycetes were higher in VC treated pots in comparison to the controls.	[92]
Cow manure	Iron mine tailing was supplemented with 0% (control), 5%, 10%, and 20% (*v*/*v*) VC.	An increase in the cultural bacteria and actinomyces was reported in the rhizosphere of plants grown in VC amended iron tailings.	[145]
Cattle manure	VC was supplemented in the soil to maintain 0% (control), 50%, 75%, 100%, and 125% of recommended dose of nitrogen.	In comparison with the controls, VC increased the organic carbon, dehydrogenase, protease, and cellulase activity in the amended soil, while the bulk density was reduced.	[284]
Cow manure	VC at the rate 2.25 and 5 Mt ha^{-1} was supplemented in soil, in combination with 50% recommended dose of chemical fertilizers + 5 Mt ha^{-1} cow manure and 50% recommended dose of chemical fertilizers, respectively.	VC substitution increased the soil organic carbon and reduced its bulk density. It also increased the available nitrogen and phosphorus content of the amended soil.	[285]
Sheep manure	Soil was amended with VC to the extent of 0 (control), 5, 10, 15 t ha^{-1}.	A decrease in bulk density and an increase in the porosity and organic carbon content was recorded in VC amended soil. VC also enhanced the nitrogen, phosphorus, potassium, calcium, zinc, and manganese in amended soil.	[255]

Table 3. *Cont.*

Source of VC	Type of Experiment	Main Findings	Reference
		Manure based VCs	
Sheep manure	VC and soil were mixed in the proportions of 0:1, 1:1, 1:2, 1:3, 1:4 and 1:5 (VC: soil; *v*/*v*).	Water holding capacity of the soil amended with VC increased with increasing proportion of VC.	[257]
Sheep, cattle, and horse manures	Peat-perlite mixture was substituted with each of the substrate VC to the extent of 0% (control), 25%, 50%, 75%, 100% VC (*v*/*v*).	The bulk density, percentage of pore space, and water holding capacity increased as VC content increased while the percentage of air space decreased.	[269]
Pig manure	Standard commercial greenhouse container medium (Metro-Mix 360) was substituted with 0% (control), 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% (*v*/*v*) of VC.	Substitution of VC produced significant increase in nitrate N concentration.	[50]
Pig manure	VC was mixed with container media (Metro-Mix 360) to the extent of 0%, 5%, 10%, 25%, 50% and 100% (*v*/*v*).	Total porosity and percentage air space of the container medium decreased significantly, whereas its bulk density and container capacity increased with increasing concentration of VC. An increase in nitrate concentration and microbial activity was also observed.	[114]
		Phytomass and manure-based VCs	
Vegetable waste, agriculture crop residue, weeds and cow dung	In field experiment, VC, compost, farmyard manure and inorganic fertilizers were supplemented to the soil to make the NPK 57/60/60 t/ha for tomato and 120/60/60 t/ha for cabbage soil.	Application of VC and compost improved the soil nutrient availability, physical stability and microbial diversity. In addition, there was an increase in the soil organic carbon.	[159]
Ocimum and cow dung	VC was added to the soil at the rate 5 t/ha along with bioinoculants. In addition a treatment was set in which recommended dose of inorganic fertilizers (N, P, K, at 80, 60, and 60 kg/ha) were applied. Unamended soil was considered as control.	VC increased the soil organic carbon, NH_4+N, NO_3–N, available P, and available K when used along with bioinoculants.	[64]
Farmyard manure	VC and farmyard manure were applied to the extent of 0, 10, 20, 30 and 40 t/ha, alone or their combined treatments (1:1). In addition, a plot was supplemented with inorganic fertilizers N, P, K at 15 t/ha each	VC increased the N, P, and Ca content in comparison to farmyard manure. In addition, VC also elevated the alkaline phosphatase and ß-glycosidase activities in soil.	[63]
Crop residues and cattle dung	VC, compost and farmyard manure were added to the soil at the rate of 5 t ha^{-1}, alone and in combination with half of the recommended dose of inorganic fertilizer (6:30:30 kg ha^{-1} NPK). In addition, a treatment was set with 100% inorganic fertilizer (12:60:60 kg ha^{-1}). Unamended soil was used as control.	Organic manures and fertilizers enhanced the organic carbon, mineral N, Olsen-P and ammonium acetate-extractables in the amended soil.	[170]

Table 3. *Cont.*

Source of VC	Type of Experiment	Main Findings	Reference
		Phytomass and manure-based VCs	
Mixture of cow and buffalo dung plus bedding material (oak leaves, pine needles and Finger millet straw	VC, farmyard manure (FYM), and chicken manure were supplemented alone or in combination with inorganic fertilizers equivalent to the recommended dose of inorganic fertilizers (IF) N, P, K at 150, 75, and 75 t/ha respectively. (In addition, microbial consortia were added in each treatment. Unamended soil served as control.	Combined application of VC, FYM and IF increased the available NPK and soil microbiological properties.	[171]
Cow dung and water hyacinth	VC at the rate 2.5 t/ha was supplemented in field soil in combination with 50% and 75% recommended dose of inorganic fertilizers (NPK) and biofertilizers (Azotobacter and phosphate solubilizing bacteria); 100% recommended dose of NPK supplementation was served as control.	Applications of VCs and biofertilizers increased the organic matter, porosity and water holding capacity and reduced the bulk density and particle density of the soil. Further VC enhanced the available nitrogen, phosphorus, and potassium contents as well as micronutrient availability of iron, manganese, zinc, and copper in the soil.	[286]
Organic waste (coir waste, paddy husk) cow dung	VC was supplemented in soil alone and in combination with earthworms's coelomic fluid. Unfertilized soil was used as control.	VC supplementation increased the soil porosity, water holding capacity, nutrient content (N, P, K, Cu, Zn, Fe, B, Mn, and Mo) and the microbial count in the treated soil.	[189]
Cow dung, municipal solid waste, duckweed, water hyacinth, bermuda grass, fly ash, and kitchen waste	VC was supplemented in soil to maintain 1.7% N, 0.7% P_2O_5, and 0.86% K_2O. Unfertilized soil was considered as control.	Mineral N (NH_4–N and NO_3–N) were significantly higher in all the VC-treated plots than the control.	[287]
Farm waste and cow dung	In separate treatments, VC at the rate 10 Mg ha^{-1}, 100% recommended dose of inorganic fertilizer (IF) and their combination was supplemented in soil. Study plots that were not amended were used as control.	Combine treatment of VC and inorganic fertilizers increased the total organic carbon, total sulfate content, microbial biomass carbon, β-glucosidase, alkaline phosphatase, and the dehydrogenase activities in amended soil.	[212]
Rice straw, water hyacinth, ipomoea and cow dung	Soil was amended with 500 g of each of the substrate's VC inoculated with *A. chroococcum*, *A. brasilense*, *P. fluorescens*, and a consortium of azotobacter, azospirillum, and pseudomonas. Soil amended with VC without microbial inoculation was set as control.	Available N, P, K, and CEC in post-harvest soil were significantly higher in microbial enriched VCs amendments.	[70]
Animal manure, grasses, green leaves of vegetables, herbs and plants)	VC was supplemented in soil at rates of 1780 kg fresh organic matter ha^{-1}. Soil fertilized with 250 kg N ha^{-1}, 80 kg P ha^{-1}, and 120 kg K ha^{-1} served as the control.	Microbial biomass, dehydrogenase, urease, β-glucosidase, phosphatase and arylsulfatase activities increased significantly in soils amended with VC than the control.	[223]

Table 3. *Cont.*

Source of VC	Type of Experiment	Main Findings	Reference
		Phytomass and manure-based VCs	
Residues of soybean and partially decomposed cattle dung	In a field experiment, VC was supplemented in soil in combination with farmyard manure compost (FYM), poultry manure (PM) and biofertilizers. The treatments are: (1) VC 7.5 tonnes/ha + biofertilizers; and (2) FYM 10 tonnes/ha + PM and VC each 1.5 tonnes/ha + biofertilizers. Unfertilized soil was considered as controls.	Combined treatment of VC, FYM and PM increased the organic carbon and available nutrients (NPK) in amended soils, while the bulk density was significantly reduced in comparison to the controls.	[288]
Straw, green material and rabbit manure	VC and compost (mix) prepared from orchard waste (straw, green material and rabbit manure) was applied alone at the rates 1 and 2 kg m^{-2} and in combination with bone meal (2 kg m^{-2} VC + 0.15 kg m^{-2}) in soil. Unfertilized plots were considered as controls.	An increment in particulate organic carbon, extractable P, fulvic, humic and humin fractions, electrical conductivity, cation exchange capacity and microbial respiration was reported in soils amended with VC-compost mixture and the combination of compost and bone meal.	[289]
Green forages: grasses, green vegetable leaves, herbs and plant materials	VC was supplemented in soil at rates 0 (control), 5, and 10 t ha^{-1} organic matter.	VC amendment reduced the bulk density of the amended soil, while the microbial biomass carbon, dehydrogenase, urease, β-glucosidase, phosphatase and arylsulfatase activity were increased significantly.	[290]
Residues of soybean and partially decomposed cattle dung	VC was supplemented in soil in combination with farmyard manure compost (FYMC), poultry manure (PM) and biofertilizers (BF; Azotobacter + phosphorus solubilizing bacteria). The treatments were: (1) VC 7.5 Mg ha^{-1} + BF; and (2) FYMC 10 Mg ha^{-1} + PM and VC each 1.5 Mg ha^{-1} + BF. Unfertilized soil was set as control.	VC in combination with FYMC, poultry manure and biofertilizers greatly lowered the bulk density and enhanced the soil oxidizable organic carbon, and NPK levels compared with the controls.	[291]
Crop residues (soybean) and partially decomposed cattle dung	Composted farmyard manure, VC and lantana compost were supplemented in the soil at the rate 60, 90, 120, and 150 kg N ha^{-1}.	Organic amendments, irrespective of source and rate, greatly lowered the bulk density and increased the oxidizable organic carbon, dehydrogenase, β-glucosidase, urease and phosphatase activities in soil compared with mineral fertilizer treatment and controls.	[292]
Yard leaf, sewage sludge + woodchips, municipal wastes, saw dust, wheat straw + urea, sugar cane filter cake and dairy cattle manure	Potting mixes containing four rates of VC (0%, 15%, 30%, and 45% of pot volume), one rate of soil (33% of pot volume) and sand (remaining pot volume).	VC amendment decreased the bulk density and particle density with an increase in the water holding capacity of the potting media.	[293]

Table 3. *Cont.*

Source of VC	Type of Experiment	Main Findings	Reference
		Phytomass and manure-based VCs	
Filter cake and bovine manure	VC was added to clay soil at the rates 0 (control), 20, 40 and 60 Mg ha^{-1}.	The bulk density of the soil reduced with increasing concentration of VC. Soil treated with higher VC concentrations (40 and 60 Mg ha^{-1}) showed more stable soil macro aggregates.	[294]
Cattle manure, leaves, and food scraps	In separate treatments, earthworm casts, conventional compost and inorganic fertilizer (NPK) was supplemented in pots containing soil. The treatment rates utilized were designed to equalize the quantity of N in the container media.	Microbial respiration and biomass were significantly greater in the soil amended with earthworm compost and cow manure in comparison to the inorganic fertilizer treated soil and controls.	[295]
		Phytomass based VCs	
Distillation waste of aromatic crops	VC and tannery sludge were added to a sodic soil to the extent of 5 t/ha. In addition, two bacterial strains isolated from the same sodic soil were also mixed in the soil. Unamended soil served as control.	With the addition of VC in the soil an increase in the pH, EC, exchangeable sodium, microbial biomass carbon and nitrogen, soil respiration, microbial quotient, and metabolic quotient was recorded.	[150]
Ipomoea	Seedlings were germinated and grown in soil amended with VC at the rates 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (by weight).	The bulk and particle density of soil decreased with increasing concentration of VC. An increase in total porosity, water holding capacity, and an increase in the nitrate, ammonium and microbial biomass carbon concentration was also seen in VC amended soils.	[37]
Salvinia	Soil was supplemented with VC at the rates 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (*w*/*w*).	With the addition of VC in soil the bulk and particle density of the later decreased with concomitant increase in their total porosity, and water holding capacity. In addition, an increase in the nitrate, ammonium and microbial biomass carbon concentration was also seen in VC amended soils.	[38]
Arecanut plantation leaves	VC alone or in combination with inorganic fertilizers was supplemented to the extent of equivalent or twice of the recommended dose of nitrogen (100 g) for the growth of arecanut.	VC significantly increased soil organic carbon and the availability of calcium, magnesium, manganese and copper, but reduced exchangeable K in the soil.	[73]
Parthenium leaves	VC was added to the soil to the extent of 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20% and 40% (by weight).	With an increase in the VC concentration the density of the soil reduced with a concomitant increase in the porosity and water holding capacity. An increase in nitrate, ammonium and microbial biomass carbon was also reported in VC amended soils.	[36]
Distillation waste of geranium and ocimum	In field trials VC was added to the soil at concentrations 0, 1.25, 2.5, 3.75, and 5 t/ha in combination with 100%, 75%, 50%, 25% and 0% of recommended dose of NPK, respectively. Unfertilized soil was set as control.	Total organic carbon, available NPK content and microbial biomass carbon in the soil increased, while the bulk density in the soils reduced in VC amended soils.	[104]

Table 3. *Cont.*

Source of VC	Type of Experiment	Main Findings	Reference
		Phytomass based VCs	
Cassava industrial waste	Efficacy of VC and compost as soil conditioners in alleviating salt affected soils was assessed. Treatments included: (1) control (unfertilized soil); (2) earthworms only; (3) compost at the rate 10 Mg ha^{-1}); (4) compost + earthworms; (5) VC at the rate 5 Mg ha^{-1}); (6) VC + earthworms; and (7) recommended dose of chemical fertilizers.	VC and compost treatments increased the soil microbial activities, cation exchange capacity, total nitrogen and extractable phosphorus in soil. These amendments also increased exchangeable K^+, Ca2$^+$ and Mg^{2+} while decreasing exchangeable Na^+, pH and EC in the saline soil.	[190]
Lantana leaves	In separate treatments, soil was supplemented with VC at the rate 0% (control), 0.75%, 1.5%, 2%, 4%, 8%, 20%, and 40% (by weight).	With increasing VC concentration, the bulk density and particle density of soil decreased significantly. An increase in total porosity and water holding capacity, nitrate, ammonium and microbial biomass carbon was also reported in VC amended soils.	[35]
Distillation waste of geranium	VC alone and in combination with inorganic fertilizers (NPK) was supplemented in plots at the concentration 5 t ha^{-1} and 10 t ha^{-1}.	Mineral nutrients such as total nitrogen and available, phosphorus, and potassium and microbial biomass carbon and nitrogen increased in integrated nutrient management. In addition, soil organic carbon significantly increased in VC amended soil	[71]
Distillation waste of patchouli	In separate treatments nitrogen concentration at the rate 66 kg ha^{-1} $harvest^{-1}$ was supplied through bioinoculants-enriched VC, bioinoculants enriched compost, VC and chemical fertilizers. Unamended soil was considered as control.	VC application resulted in a marked decrease in bulk density of soil with an increase in its water holding capacity, and available NPK content.	[116]
Woodchips	Coal-spoil-contaminated tertiary sand was mixed with VC at ratios of 0.0%, 3.0%, 12.5%, and 25.0% (dry weight, *w*/*w*).	VC supplementation caused an increase in the water holding capacity, total porosity and organic matter and decreased bulk and particle density. An increase in the exchangeable bases (Ca^{++}, Mg^{++}, K^+, Na^+), total exchangeable acidity (c mol kg^{-1}), and effective CEC (c mol kg^{-1}) was also reported.	[226]
Green forage	Green forage VC was applied to the soil at the rate 3 and 6 Mg C ha^{-1}.	VC increased the microbial biomass carbon, dehydrogenase, urease, ß-glucosidase, phosphatase, and arylsulfatase activity in soil.	[283]
Spent grape marc	Efficacy of single or combined VC, urea, and/or diuron on soil enzyme activities and the persistence of this herbicide in soils with low organic carbon content was assessed.	VC supplementation enhanced the microbial and dehydrogenase activity in the amended soil.	[296]
Bagasse, municipal solid wastes, water hyacinth, paddy straw, and fly ash	VCs were supplemented in the soil at 15 t ha^{-1}. Unfertilized soil was considered as controls.	VCs enhanced the organic C, mineralizable N, available P and exchangeable K in the soil. An increase in microbial respiration, microbial biomass C and N and fungal population in lateritic soil was reported. Amylase, protease, urease, acid phosphatase activities and ergosterol and chitin content were also significantly higher in VC treated soils compared with the control.	[69]

Table 3. *Cont.*

Source of VC	Type of Experiment	Main Findings	Reference
		Phytomass based VCs	
Vegetable waste	The treatments evaluated were: a control T1 (75% peat and 25% perlite), T2 (25% peat, 25% coconut coir dust, 25% VC and 25% perlite), T3 (50% peat, 25% VC and 25% perlite), T4 (25% peat, 50% VC and 25% perlite), T5 (50% coconut coir dust, 25% VC and 25% perlite), and T6 (25% coconut coir dust, 50% VC and 25% perlite).	The bulk density and water-soluble elements, contained in the substrate, increased with increasing amounts of VC in the substrate, whereas the total porosity, easily available water and total water holding capacity decreased significantly with increasing amounts of VC.	[140]
Grape marc	Mixtures of slate processing fines at the rate 4%, 8%, and 16% dry weight (60, 120, and 240 Mg ha^{-1}) were mixed in VC and incubated in the laboratory for 90 days at 25 °C.	An increase in nutrient content, dehydrogenase activity, water holding capacity and Atterberg's limits, defining consistency, was reported in slate processing fines with the addition of VC.	[68]
Sugar mill wastes	Efficacy of VC, in comparison to inorganic fertilizers-NPK, when supplemented in clay loam soil and sandy loam soil was compared. Treatments consisted of: (1) control (unfertilized soil); (2) 100% recommended dose of NPK; (3) 100% recommended dose of VC (5 t ha^{-1}); and (4) 50%VC supplemented with 50% NPK.	VC amendment increased the organic carbon, pore space, water holding capacity and reduced the bulk density and particle density of both the soil types.	[115]
Pressmud, sugarcane trash and fine bagasse	VC was supplemented alone and in combination with inorganic fertilizers in clay loam, sandy loam and red loam soils. The treatments were: (1) control (unfertilized soil); (2) NPK; (3) VC 5 t/ha; and (4) VC supplemented with 50% NPK (*w*/*w*).	VC supplementation increased the pore space, water holding capacity, and organic carbon content and reduced the particle and bulk density, of all the soil types. Increase in available NPK and microbial population and activity was also recorded in VC amended soils.	[67]
		Impact of VC generated from substrates other than manure and phytomass	
Fly ash	Seeds were sown in media composed of pine bark compost and VC. The proportion of VC was 0%, 25%, 50%, 75%, and 100%. Additionally, in one set of treatments, chemical fertilizers were added, while keeping another treatment without fertilizer fortification.	VC improved the water-holding capacity, total porosity, and air-filled porosity of the media.	[142]
Sugar mill waste	In separate treatments, soil was fortified with recommended dose of VC (5 t/ha), inorganic fertilizer (NPK; 50:25:0 kg/ha) and mixture of VC and NPK (50/50). Unamended soil was considered as controls.	VC increased the pore space, water holding capacity and cation exchange capacity, with concomitant reduction of particle and bulk density. Further it also enhanced the organic carbon, available NPK content and microbial population in soil.	[258]
Municipal waste	VC and compost were added to the degraded volcanic soil to the extent of 20 and 40 g kg^{-1}.	VC increased the nitrogen mineralization, enzymatic and microbial activity in amended soil.	[66]

Table 3. *Cont.*

Source of VC	Type of Experiment	Main Findings	Reference
	Studies with no mention of substrates used for generating VC		
No stated	In randomised block design, experiment was conducted with six treatments: Control, recommended dose of NPK for the crop, recommended dose + farmyard manure, recommended dose + VC, farmyard manure only and VC only.	VC positively influenced the total Kjeldahl nitrogen, available N, P and K content, total organic carbon, and the soil pH.	[75]
Not stated	VC was added to the commercial mix of peat and perlite at the rate 0% (control), 20% and 40% of VC.	Addition of VC resulted in a linear increase in pH, electrical conductivity, nutrient level, bulk density and total porosity of the substrate, while organic matter decreased linearly and quadratically the percentage of pores occupied by water.	[74]
Not stated	Marjoram was grown in soil supplemented with VC to the extent of 0, 6, 8 and 10 m^3/fed and calcium silicate at the rate 0, 10, 15 and 20 kg/fed.	VC treatments the nitrogenase and dehydrogenase activities and nutrient contents of N, P, K and Ca of rhizosphere soil.	[72]

Table 4. Effect of vermicompost in suppressing plant disease and pests.

Source of VC	Target Plant Species	Plant Pathogen Suppressed by VC	Factors Deemed to Have Been behind the Suppression of Plant Pathogens by VC	Reference
Cattle manure	Tomato (*Lycopersicum* spp.)	Tomato leafminer (*Tuta absoluta*)	Enrichment of nutrient and phenolic content in plant tissues.	[297]
Parthenium	Ladies finger (*A. esculentus*)	*Liriomyza* spp, *Alternaria alternate* and *Earias vittella*	Better nutrient availability and presence of pathogen-destroying microorganisms	[127]
Salvinia	Ladies finger (*A. esculentus*)	*Liriomyza* spp, *Alternaria alternate* and *Earias vittella*	Better nutrient availability and presence of pathogen-destroying microorganisms	[126]
Cattle solids	*Thymus vulgaris*	*Fusarium oxysporum* and *Phytophthora infestans*	Presence of phenolic substances such as gallic acid and chlorogenic acid.	[143]
Cow manure	Tomato (*Solanum lycopersicum* L.)	*Meloidogyne incognita*	Increased secondary defense compounds, related gene expression, plant growth and the changes of soil properties particularly the increase of pH, IAA and microbial activity.	[96]
Not stated	Walnut (*Juglans regia*)	*Agrobacterium tumefaciens*	Biotic nature	[298]
Cow dung	Mung bean (*Vigna radiata*)	*Macrophomina phaseolina*	Microbial activity	[188]
Not stated	Cucumber (*C. sativus*)	*Meloidogyne javanica*	Hydrogen sulfide, ammonium and nitrates and rhizobacteria accumulation around the plant roots	[95]

Table 4. *Cont.*

Source of VC	Target Plant Species	Plant Pathogen Suppressed by VC	Factors Deemed to Have Been behind the Suppression of Plant Pathogens by VC	Reference
Lantana leaves	Cluster bean (*Cyamopsis teteragonoloba*)	*Xanthomonas campestris*, *Aternaria* spp., *Bemisia tabaci*	Better nutrient availability, antimicrobial compounds such as phenols, flavonoids and humic acid	[106]
Distillation waste of patchouli	Patchouli (*Pogostemon cablin*)	*Rhizoctonia* spp.	Microbial activity and balanced plant nutrients	[299]
Not stated	Rice (*Oriza sativa*) cv Pusa Basmati	*Rhizoctonia solani*, *Nilaparvata lugens and Leptocorisa acuta*	Proper nutrient management	[300]
Distillation waste of lemongrass and citronella	Coleus (*Coleus forskohlii*)	*Fusarium chlamydosporum and Ralstonia solanacearum*	Beneficial microflora, production and release of allelochemicals	[301]
Not stated	Cucumber (*C. sativus*)	*Aphis gossypii*	Microbial activity	[302]
Not stated	Curly bamboo (*Dracaena sanderiana*)	*Erwinia* spp.	Soil borne microbes	[303]
Food waste	Corn (*Zea mays*)	*Helicoverpa zea*	Microbial activity	[94]
Medical plant wastes and cattle manure	Potato (*Solanum tuberosum*)	*Globodera rostochiensis and G. pallida*	Ammonium content	[304]
Animal manure and agro wastes	Tomato (*L. esculentum*)	*Pratylenchus* spp.	Plant nutrients (nitrogen, phosphorus, Ca^{++}, K^{+}) vitamins, enzyme, and plant hormones	[305]
Not stated	Arabidopsis (*Arabidopsis thaliana*)	*Helicoverpa zea*	Microbial activity	[93]
Agro waste of medicinal and aromatic plants	Tomato (*Lycopersicon* spp.)	*Meloidogyne incognita*	-	[306]
Cow dung	Green gram (*Vigna radiata*)	*Macrophomina phaseolina*	Soil microflora which includes fungi, bacteria and actinomycetes	[92]
Agro-wastes and cow dung	Cucumber (*C. sativus*)	*Rhizoctonia solani*	Bio-control agents (microbial population)	[91]
Vegetable waste and cow dung	Strawberry (*Fragaria x ananassa* Duch.)	*Botrytis cinerea*	Microbial activity	[20]

Table 4. *Cont.*

Source of VC	Target Plant Species	Plant Pathogen Suppressed by VC	Factors Deemed to Have Been behind the Suppression of Plant Pathogens by VC	Reference
Food waste	Tomato (*Lycopersicon* spp.) and cucumber (*C. sativus*), bush beans (*P. vulgaris*) and eggplant (*Solanum melongena*)	*Tetranychus urticae*, *Pseudococcus* sp., and *Myzus persicae*	Available plant nutrients and phenols	[90]
Food waste	Tomato (*Lycopersicon* spp.) and cucumber (*Cucumis sativus*)	*Manduca quinquemaculata and Acalymma vittatum and Diabotrica undecimpunctata*	Plant nutrition, controlled slower release rates of mineral nutrients in plants, and presence of phenolic compounds	[26]
Not stated	Impatiens (*Impatiens wallerana*)	*Rhizoctonia solani*	Microbial activity	[307]
Food waste	Tomato (*Lycopersicon* spp.), pepper (*Capsicum* spp.) and cabbage (*Brassica oleracea*)	*Myzus persicae*, *Pseudococcus* spp. *and Peiris brassicae*	Essential nutrient elements	[89]
Cattle, sheep and horse manure	Tomato (*Lycopersicon* spp.)	*Phytophthora nicotianae*	Available plant nutrients	[88]
Cattle manure	Tomato (*Lycopersicon* spp.)	*Fusarium oxysporum*	Biotic nature (microbial activity)	[87]

5. Summary and Conclusions

Extensive assessment of past studies on the effect of vermicompost (VC) on plants and soils was carried out. A summary of the 252 reports, located in primary literature, is presented. The reports reveal that, in general, VC is beneficial to germination, growth and yield of plants. It also improves the physical and chemical properties of soil vis-à-vis agriculture productivity. These effects are seen irrespective of whether the VC is derived from animal manure, phytomass, or manure-phytomass blends. The reports also reveal that, in general, VC may become detrimental if applied in concentrations far greater than the ones found beneficial. All possible reasons for this dual behavior of VC were culled from the reports and catalogued in the review. Future work should focus on determining the ranges of beneficial VC concentrations under typical soil–water plant–micrometeorological regimes.

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