Int J Recycl Org Waste Agricult (2017) 6:335–343
https://doi.org/10.1007/s40093-017-0181-7

ORIGINAL RESEARCH

Enhancement in the productivity of ladies finger (*Abelmoschus esculentus*) with concomitant pest control by the vermicompost of the weed salvinia (*Salvinia molesta*, Mitchell)

Naseer Hussain[1] · Tasneem Abbasi[1] · S. A. Abbasi[1]

Received: 19 April 2017 / Accepted: 19 October 2017 / Published online: 11 November 2017

Abstract

Purpose In a novel attempt, vermicompost derived from an intransigent and noxious weed salvinia was assessed for its fertilizer value and pest repellent properties.

Methods In outdoor experiments which simulated the way vegetables are cultivated by farmers, ladies finger (*Abelmoschus esculentus*) seeds were germinated and grown in soil supplemented with salvinia vermicompost at four levels: 0 (V_0), 2.5 (V_1), 3.75 (V_2) and 5 (V_3) t/ha. Besides assessing germination success and subsequent growth, yield, and biochemical content of the plants, the impact of pest attacks on them was also studied.

Results Salvinia vermicompost significantly enhanced germination success, growth, and yield of the plants. Maximum growth in terms of shoot length (96.2 cm), root length (48.2 cm), shoot and root dry weight (23.31, 7.96 g), stem diameter (14.04 mm), and number of leaves and branches (26.8, 4.8) was recorded in V_4 (5t/ha). Likewise, the mineral and biochemical content in vermicompost-treated plants was significantly higher than in the controls. The vermicompost also induced resistance in plants against pests and disease. Compared to the controls, vermicompost had reduced the fruit borer infection by 65, 78 and 82% in V_1, V_2 and V_3, respectively.

Conclusion The toxicity of salvinia is largely eliminated when it is vermicomposted, and the product acquires the qualities of a good organic fertilizer. The present work can potentially lead to the development of an inexpensive, sustainable and eco-friendly method of utilizing billions of tons of phytomass that is generated annually by salvinia, and which presently goes to waste.

Keywords Weed control · Organic fertilizer · Vermitechnology · Pest repellent · *Abelmoschus esculentus*

Introduction

Salvinia molesta Mitchell, a free-floating fern, is among the most widespread and environmentally harmful of the invasive plant species (Schooler et al. 2011). It is distinguished by its explosive rate of multiplication and growth, which is perhaps the highest of all plants (Crites et al. 2006). Salvinia has invaded lakes, rivers, channels and other wetlands in tropical and subtropical habitats around the world (Room 1990), covering several of them from bank-to-bank, and elbowing out most other vegetation (Luque et al. 2014; Bhat 2016). After spreading horizontally, salvinia forms dense mats of up to 1 m thickness that cuts the sunlight off from the underlying water and makes the waterways unnavigable (Coetzee et al. 2011). This also hampers the photosynthesis in the water body and the aerial replenishment of oxygen in the water lying beneath the salvinia carpet is blocked (Hussain et al. 2016b). As a result, the dissolved oxygen levels fall and the neustans and benthos are severely stressed. The stagnation of water caused by the salvinia facilitates mosquito breeding, and there is a rapid and precipitous loss of biodiversity in the invaded water body (Abbasi and Nipaney 1993). Salvinia's unabated spread is because of its ability and to regenerate vegetatively even from tiny pieces of its leaves and its

✉ S. A. Abbasi
prof.s.a.abbasi@gmail.com

1 Centre for Pollution Control and Environmental Engineering, Pondicherry University, Pondicherry 605014, India

propensity to double its number every 3–4 days (Schooler et al. 2011).

With huge tracts of wetlands colonized by salvinia in South America, Africa, South Asia, and Australia (Abbasi and Nipaney 1993; Bhat 2016), billions of tonnes of salvinia biomass is generated every year across the world. As no method exists to utilize any sizeable fraction of this biomass (Ganeshkumar et al. 2014; Bhat 2016), it remains unharvested, causing serious harm to the wetlands (Abbasi and Nipaney 1986; Abbasi 1997). On senescence, it decays aerobically and anaerobically—mostly latter—generating global warming gases carbon dioxide and methane (Abbasi et al. 2011). As anaerobic decomposition in the anoxic epilimnion is the predominant salvinia decay pathway, it becomes a major contributor of methane emissions. With methane having molecule to molecule, 34 times greater global warming potential than carbon dioxide (Shindell et al. 2009), the harm caused by salvinia decay is immense.

The extensive and rapid spread of salvinia has been halted and repelled by the use of a few biological agents (Room et al. 1981; Sullivan et al. 2011) but such successes have been few and far between. Worse, none has led to any enduring solution to the salvinia problem. Mechanical removal of salvinia and use of weedicide have recorded even lesser success in controlling its spread. Attempts to utilize salvinia for the generation of compost, green manure or mulch (Raju and Gangwar 2004; Arthur et al. 2007; Dorahy et al. 2009), as fodder (King et al. 2004; Leterme et al. 2010), as a source of biogas (Abbasi et al. 1990; Abbasi and Nipaney 1991; Abbasi et al. 1992a, b; Abbasi and Abbasi 2010; Ganesh et al. 2005), or for making drugs (Chantiratikul et al. 2009; Choudhary et al. 2008; Li et al. 2013; Tauseef et al. 2013), have all proved uneconomical. Thus, finding a sustainable, ecologically sound, and inexpensive way with which salvinia biomass can be utilized on the scales it is generated appears to be the only recourse which can make it profitable to regularly harvest the weed, thereby keeping a check on its alarming growth.

Vermicomposting is one such option, by which the weed can be regularly harvested and converted it into beneficial biofertilizer. Studies conducted across the world on manure-based vermicompost have shown that such vermicompost is a well stabilized, aesthetically pleasing, and finely divided peat-like material with excellent physicochemical and biological characteristics (Edwards et al. 2011) that one seeks in a good organic fertilizer. In a recent study, Ganeshkumar et al. (2014) have found that salvinia can be directly and quickly converted into vermicompost, following the concept of high-rate vermicomposting earlier developed by Abbasi and co-workers (Abbasi et al. 2009, 2015). But before the process is put to large-scale use, it must be ascertained whether salvinia vermicompost is as much, or at least nearly as much, soil friendly and plant friendly as manure-based vermicompost is known to be. This question is highly significant because salvinia plants contain unusually large concentrations of polyphenols and lignin. This feature makes salvinia strongly allelopathic and hardy (Leterme et al. 2010; Hussain et al. 2016a) and it becomes essential to rule out any adverse effect that the polyphenols and lignin content of salvinia might exert on the utility value of salvinia's vermicompost. To alley this apprehension, the present field-scale study has been carried out to see how a common vegetable ladies finger (*Abelmoschus esculentus*) responds to the application of salvinia vermicompost during its germination growth, and fruit production phases.

Materials and methods

General

All analytical work was performed with analytical reagent grade chemicals, and alkali-resistant borosilicate glassware. The dilution water was deionized and double distilled before use. Dry weight determinations of all samples of soil, plants, and vermicompost were done by heating known quantities of samples at 105 °C to constant weights.

Vermicompost was generated from the whole plants of salvinia, collected from the ponds in the vicinity of Pondicherry University campus, employing earthworm species *Eisenia foetida.* Pulse-fed, high-rate, vermireactors were utilized for the purpose. The setting and operation of the vermireactors were as detailed earlier by Nayeem-shah et al. (2014) and Ganeshkumar et al. (2014). No pre-composting, manure supplementation or any other form of pre-treatment was done. The vermicompost was periodically assessed in the form of easily identifiable, separable, and quantifiable vermicast that was generated in each 20-days pulse (Abbasi et al. 2009, 2015). The total nitrogen, phosphorus and potassium (NPK) contents of the vermicompost were 17.9, 2.92 and 11.45 g/kg, respectively. The soil used in the present experiment was collected from an uncultivated area of Pondicherry University campus. This was done to prevent interference from any previous fertilizer application. The soil, which was characterized as sandy loam, had pH 6.35, and contained organic carbon, total nitrogen, phosphorus and potassium to the extent of 8.8, 2.71, 0.24, and 0.75 g/kg, respectively.

Planting of ladies finger

Germination and plant growth studies were carried out in 50-l plastic containers. In each treatment, 35 such bags were filled with soil and amended with four levels of salvinia vermicompost: V0 (control), V1-25 g, V2-37.5 g, and V3-50 g on dry weight basis. This corresponds to 0, 2.5, 3.75 and 5 t/ha VC, respectively. Five seeds of ladies finger (*Abelmoschus esculentus*) were sown in each container. The study was carried out during February–May which is the period considered ideal for growing ladies finger in the region where authors work (ICAR 2011).

Analysis

The fraction of seeds that germinated within 8 days of sowing was enumerated to determine the germination success. Thereafter, one of the healthy seedlings was retained in each bag while discarding the other four. The growth experiments were then carried out for 15 weeks, irrigating all the containers with tap water every day. 100 days after sowing, five plants from each treatment were randomly harvested. Their shoot length (cm), root length (cm), plant biomass (g), number of leaves, stem diameter (mm) and number of branches were determined. The speed and the extent of flowering were computed in terms of number of days taken by the plants to produce their first flower, and the total number of flowers produced per plant. The number of pods and the average length (cm), diameter (mm), and weight (g) of the pods per plant were recorded.

Fresh leaves of the ladies finger plants were collected for estimation of chlorophyll and carotenoids. These pigments were extracted from the leaves using *N*, *N*-dimethyl formamide (DMF) following a procedure of Moran and Porath (1980). The concentrations of the pigments were determined spectrophotometrically at 470, 647 and 664 nm as detailed by Wellburn (1994). The protein, carbohydrates, and mineral content of the ladies finger pods were estimated by Kjeldahl, Anthrone and dry washing methods, respectively (Nielsen 2010).

Disease incidence and pest infestation

Soon after the start of the experiments, the leaves of the ladies finger plants began getting infected by leaf miners and leaf spot diseases. It could be seen that the prevalence of infection was highly pronounced in the control plants but much lesser in the vermicompost-fertilized plants. The symptoms of the leaf miners infection, which is caused by *Liriomyza* spp, were feeding punctures and white speckles on the leaf surface (Ahmed 2000). The leaf spot disease, caused by the fungus *Alternaria alternate,* was manifested by light brown spots appearing on the leaves, which later turned into concentric dark brown spots (Tohyama et al. 2005; Hussain et al., 2017b). When the infection became particularly severe, it caused the infected leaves to turn brown and fall off (Antonijevic et al. 2007). Another form of infection, which affected only the fruits, was due to *Earias vittella* (Sharma et al. 2010; Halder et al. 2015; Hussain et al. 2017b) called 'borer infection'. It was quantified as the fraction, by weight, of the infected fruits relative to the total fruits.

Tests of significance

These were performed by one-way analysis of variance and least significant difference (Alan and David 2001; Field 2009).

Results and discussion

Seed germination and plant growth

In vermicompost treatments, the germination success was significantly ($P < 0.05$) higher than in the controls. The maximum (97%) germination was observed in V_3 treatment. It was followed by 96% and 87% success in V_4 and V_2 treatments (Fig. 1a). The controls had shown the least germination success. The augmentation of soil with salvinia vermicompost also enhanced the growth of ladies finger in terms of shoot and root length, plant biomass, number of leaves, and number of branches (Fig. 1b–h). The maximum shoot length (96.2 ± 9.4), root length (48.2 ± 4.8), shoot diameter (14.04 ± 0.7), shoot dry weight (23.31 ± 2.3), root dry weight (7.96 ± 0.6), number of leaves (26.8 ± 2.3), and number of branches (4.8 ± 0.5) were recorded in V_4 treatment. The lowest growth was recorded in the controls. With the exception of root length, the improvement in growth even with the lowest (V1) level of vermicompost augmentation in comparison to controls was dramatic and highly significant.

Past studies on the effect of vermicompost derived from animal manure on plants have shown that such vermicomposts have major, medium, and micronutrients in more bioavailable form compared to their parent substrate (Hussain et al. 2016a). The vermicompost is also endowed with much richer and diverse microflora than the parent substrate (Hussain et al. 2015, 2016b). It appears that salvinia-based vermicompost also acquires similar plant-friendly and soil friendly attributes. Additionally, manure-based vermicomposts are known to contain fulvic acids, humic acids, and phytohormones (Atiyeh et al. 2002; Ievinsh 2011; Doan et al. 2015) which rejuvenate the soil and makes it plant-friendly. Recently, Hussain et al. (2016b) have reported that salvinia loses its reproductive ability after it is ingested by earthworms. The microbial and enzymatic degradation of salvinia during its passage through the earthworm gut leads to generation of several fatty acids, alcohols, alkanes, alkenes, and nitrogenous compounds. These compounds together with the presence of growth hormones and humic acids may have contributed

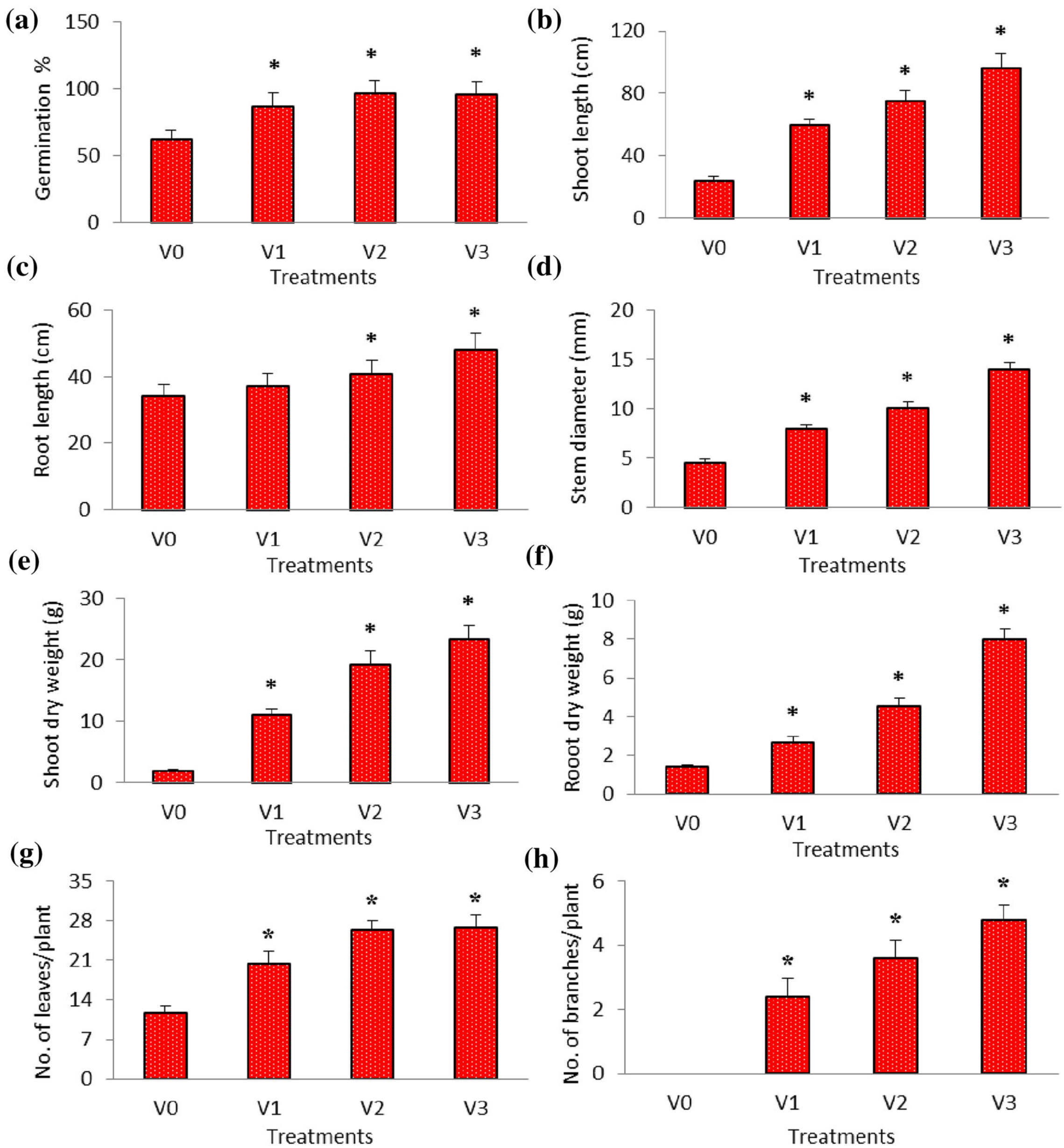

Fig. 1 Effect of salvinia vermicompost on **a** germination percentage; **b** shoot length; **c** root length; **d** stem diameter; **e** shoot dry weight; **f** root dry weight; **g** number of leaves; and **h** number of branches, of ladies finger plants. The standard deviation is indicated on the chart. The results shown in columns accompanied with an asterisk are significantly different from the controls at $P \leq 0.05$

to the better growth in VC-treated plants than in controls, as has been observed earlier in case of manure-based vermicomposts (Atiyeh et al. 2002; Doan et al. 2015; Kumar et al. 2015).

Humic acids are known to stimulate plant growth through increased cell division, enhancement of uptake of nutrients and water, and enhancement of the soil microbial population (Atiyeh et al. 2002; Chen et al. 2004; Delgado et al. 2002; García-Gil et al. 2004; Xu et al. 2014; Hussain et al. 2017a, b). It has been reported that humic acids derived from manure-based vermicompost facilitate elongation of roots and emergence of lateral roots—besides enhancing the root's H^+-ATPase activity in maize (Canellas et al. 2002). Both humic acids and plant growth hormones are probably produced by the diverse microbial population present in vermicompost (Frankenberger and Muhammad 1995). Improvement in the physical properties of the soil, especially enhancing its air and water holding capacity, have also been reported which increase the plant productivity in soil treated with manure-based vermicompost (Edwards 2004). Evidently, salvinia vermicompost possesses similar virtues to be able to generate similar effects.

Flowering and yield

Salvinia vermicompost not only induced early flowering in the ladies finger plants compared to the controls, but also resulted in the appearance of a significantly ($p < 0.05$) larger number of flowers. In all the vermicompost treatments, the yield was significantly higher than the controls. The fruit yield, reflected in the number and weight of pods per plant (10.90 ± 1.10, 105.23 ± 5.77), and the size (length and diameter) of the pods (12.35 ± 0.98; 16.17 ± 1.54), was significantly higher in VC treatments than in the controls (Fig. 2).

The findings are similar to the ones achieved with manure-based vermicompost by other authors earlier (Jouquet et al. 2011; Abduli et al. 2013; Joshi et al. 2015; Doan et al. 2015; Song et al. 2015), and indicate that the salvinia vermicompost also possesses similar virtues.

Biochemical aspects

Vermicompost application increased the concentration of photosynthetic pigments exemplified by the chlorophyll and carotenoid content in the leaves to a highly significant extent as compared to the controls (Fig. 3a–c). There was also an increase in the protein and carbohydrates content of the pods, but the increase was not statistically significant (Fig. 3f, g). On the other the total solids and ash (mineral) content of the pods grown in vermicompost-augmented soil was significantly higher than that of control soil (Fig. 3d, e). These findings indicate that salvinia-based vermicompost also has as much beneficial effect in terms of plant biochemistry as manure-based vermicomposts are known to cause (Abduli et al. 2013; Yadav et al. 2015).

Disease incidence

Vermicompost caused a reduction in the incidence of diseases in the leaves as well as the pods; the extent of this

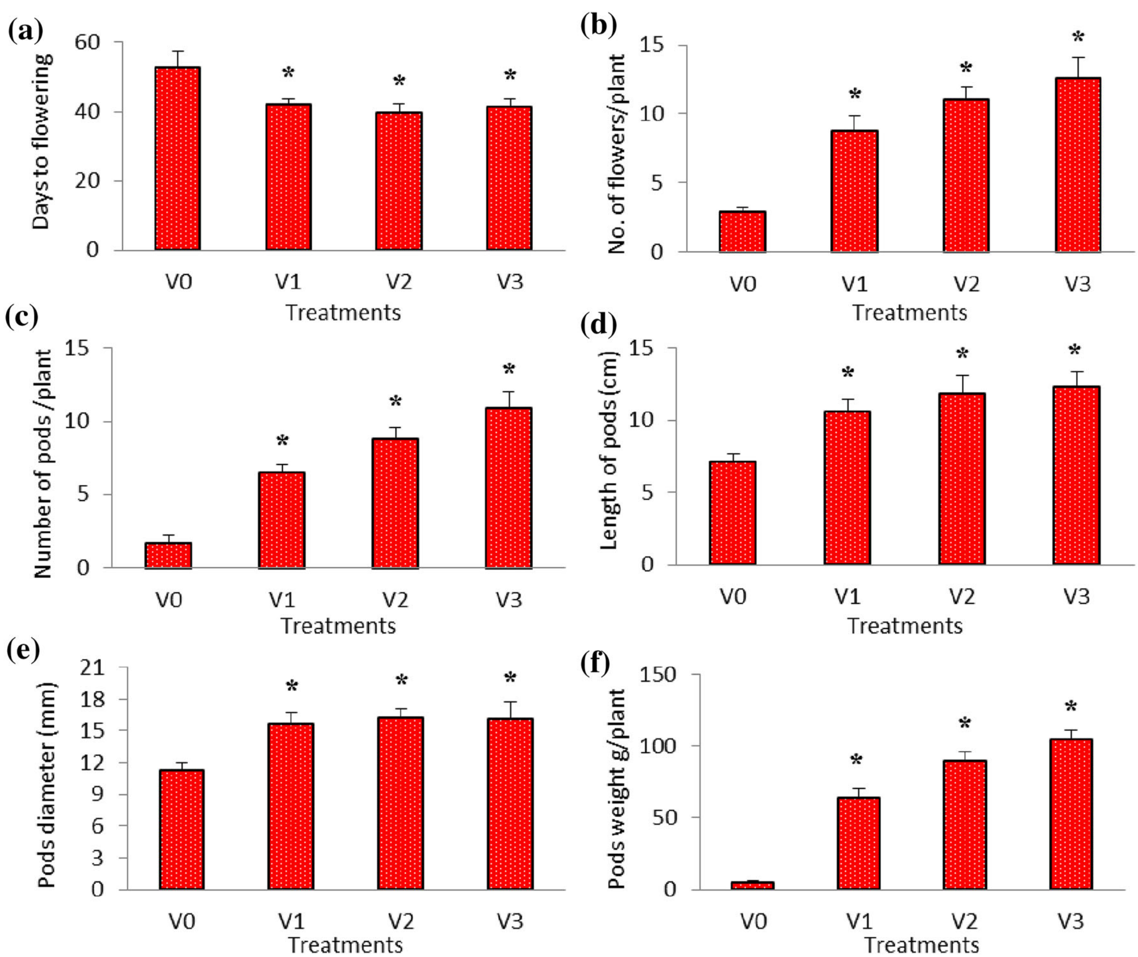

Fig. 2 Effect of salvinia vermicompost on **a** early flowering; **b** number of flowers per plant; **c** number of pods per plant; **d** length of pods; **e** diameter of pods; and **f** weight of pods per plant, of ladies finger. The standard deviation is indicated on the chart. The results shown in columns accompanied with an asterisk are significantly different from the controls at $P \leq 0.05$

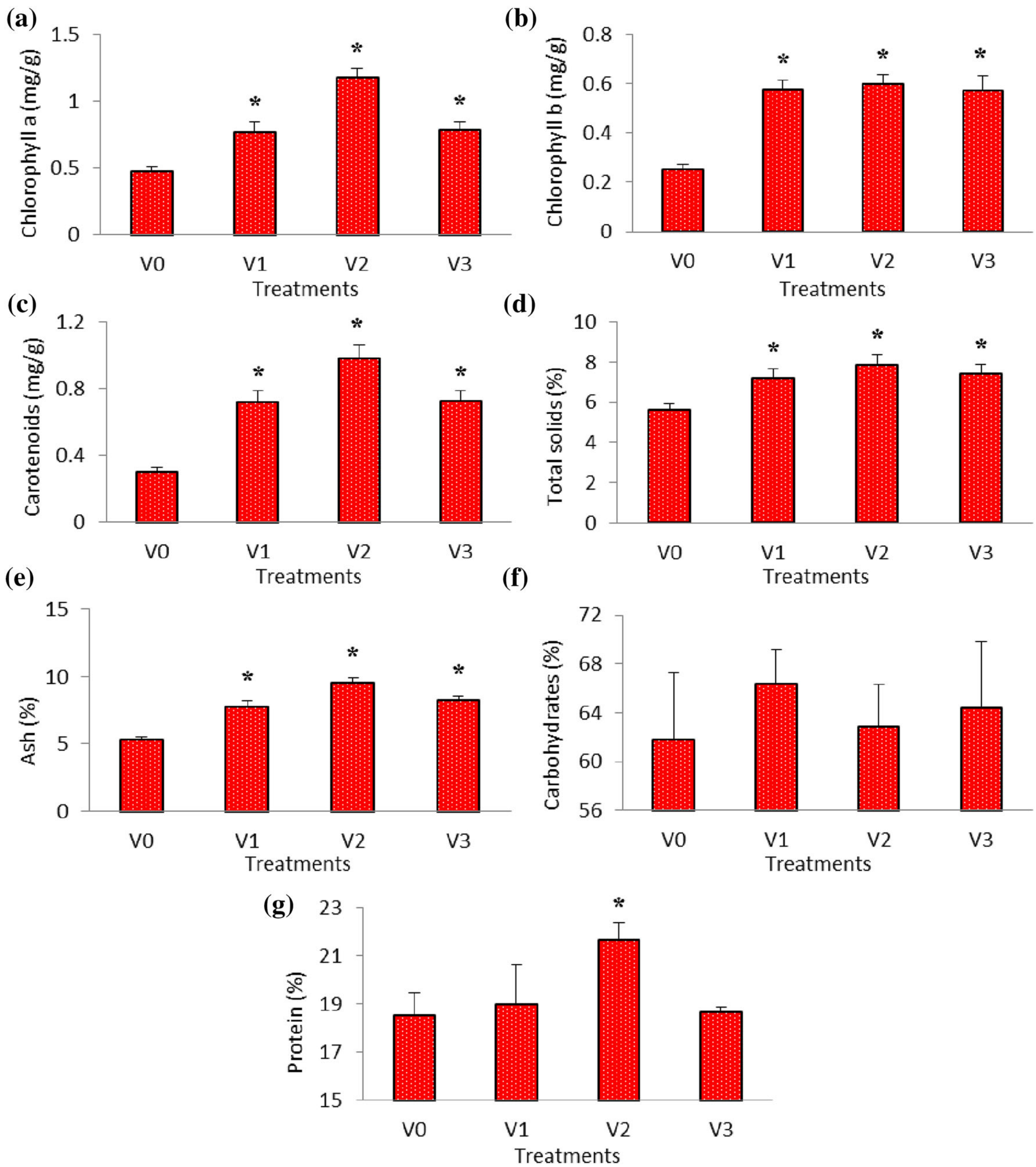

Fig. 3 Effect of salvinia vermicompost on **a** chlorophyll ‘a’; **b** chlorophyll ‘b’; **c** carotenoids content of ladies finger leaves and **d** total solids; **e** ash; **f** carbohydrates and **g** protein content, of ladies finger fruits. The standard deviation is indicated on the chart. The results shown in columns accompanied with an asterisk are significantly different from the controls at $P \leq 0.05$

effect increased in proportion to the VC concentration (Fig. 4). At the early stages of growth, the seedlings were seen severely infested by leaf liner, but the infection subsided as the growth increased. In this respect, also, the salvinia vermicompost seems to possess beneficial effects similar to the ones known to be possessed by manure-based vermicomposts.

There is no definite knowledge on the mechanism governing the pesticidal properties of the vermicompost (Hussain 2016). A possible cause can be that vermicompost supplies highly bioavailable nutrients which enhance the vitality of the plants, empowering them to ward off infection. Another likely reason is the presence of pathogen-destroying microorganisms in the vermicompost (Yardim et al. 2006; Aghamohammadi et al. 2016; Datta et al. 2016; Xiao et al. 2016).

Past studies have reported that vermicompost derived from animal manure possesses both these virtues (Edwards 2004; Edwards et al. 2011) and, hence, induced the resistance in plants against several plant pathogens (Szczech

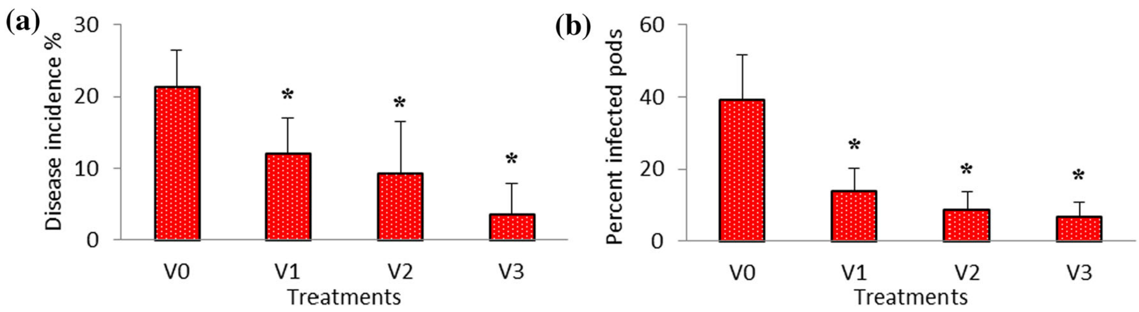

Fig. 4 Disease incidence and percentage of infected fruits in ladies finger as affected by the salvinia vermicompost. The standard deviation is indicated on the chart. The results shown in columns accompanied with an asterisk are significantly different from the controls at $P \leq 0.05$

1999; Szczech and Smolinska 2001; Choudhary et al. 2010; Nath and Singh 2011). The present study indicates that salvinia vermicompost may also be acquiring similar virtues which enable it to induce resistance against pathogens in ladies finger plants.

Conclusion

The paper reports studies which have assessed the effect of the vermicompost of the aquatic weed salvinia on the germination, growth, yield, and quality of the fruits of a common food plant ladies finger (*Abelmoschus esculentus*). The role of the vermicompost in warding off the diseases of the ladies finger leaves and pods was also witnessed. In general, a positive effect was exerted by the vermicompost in increasing germination success, plant growth, yield, and pest resistance. The degree of benefit increased in proportion to the concentration of the applied vermicompost when it was varied in the range 2.5–5 tonnes/ha. In contrast to the toxic and allelopathic nature of salvinia, its vermicompost proved totally benign, and appeared to be highly plant friendly, with virtues of an organic fertilizer similar to the ones known to be possessed by the vermicomposts derived from animal manure.

Acknowledgements SAA thanks the Council of Scientific and Industrial Research (CSIR), New Delhi, for the Emeritus Scientist grant (21(1034)/16/EMR-II). NH thanks the UGC for the Maulana Azad National Fellowship.

References

Abbasi SA (1997) Wetlands of India. Vol III: Kerala. Discovery Publishing House, New Delhi, p 276

Abbasi T, Abbasi SA (2010) Production of clean energy by anaerobic digestion of phytomass—new prospects for a global warming amelioration technology. Renewable Sustainable Ener Rev 14:1653–1659

Abbasi SA, Nipaney PC (1986) Infestation by aquatic weeds of the fern genus salvinia—its status and control. Environ Conserv 13:235–241. doi:10.1017/S0376892900036286

Abbasi SA, Nipaney PC, Schaumberg GD (1990) Bioenergy potential of eight common aquatic weeds. Biol Wastes 34(4):359–366

Abbasi SA, Nipaney PC (1991) Effect of temperature on biogas production from aquatic fern Salvinia. Indian J Technol 29:306–309

Abbasi SA, Nipaney PC (1993) World's worst weed (salvinia): its impact and utilization. International Book Distributors, Dehradun, p 226

Abbasi SA, Nipaney PC, Ramasamy EV (1992a) Studies on multiphase anaerobic digestion of Salvinia. Indian J Technol 30:483–490

Abbasi SA, Nipaney PC, Ramasamy EV (1992b) Use of aquatic weed salvinia (*Salvinia molesta,* Mitchell) as full partial feed in commercial biogas digesters. Indian J Technol 30:451–457

Abbasi T, Gajalakshmi S, Abbasi SA (2009) Towards modeling and design of vermicomposting systems: mechanisms of composting/vermicomposting and their implications. Indian J Biotechnol 8:177–182

Abbasi T, Tauseef SM, Abbasi SA (2011) Global warming and the role of wetlands. Lap Lambart Academic, Germany, p 264 **(ISBN 978-3846556009)**

Abbasi SA, Nayeem-Shah M, Abbasi T (2015) Vermicomposting of phytomass: limitations of the past approaches and the emerging directions. J Cleaner Prod 93:103–114

Abduli MA, Amiri L, Madadian E, Gitipour S, Sedighian S (2013) Efficiency of vermicompost on quantitative and qualitative growth of tomato plants. Int J Environ Res 7:467–472

Aghamohammadi Z, Etesami H, Alikhani HA (2016) Vermiwash allows reduced application rates of acaricide azocyclotin for the control of two spotted spider mite, *Tetranychus urticae* Koch, on bean plant (*Phaseolus vulgaris* L.). Ecol Eng 93:234–241. doi:10.1016/j.ecoleng.2016.05.041

Ahmed MMM (2000) Studies on the control of insect pests in vegetables (okra, tomato, and onion) in Sudan with special reference to neem-preparations. Doctoral dissertation, University of Göttingen

Alan CG, David SH (2001) Practical statistics and Experimental Design for Plant and Crop Sciences. Wiley, England, p 239

Antonijevic D, Fakultet P, Zemun B, Mitrovic P (2007) Leaf spot of oilseed rape Biljni lekar (Serbia). Plant Doctor 35:443–449

Arthur GD, Stirk WA, Novák O, Hekera P, van Staden J (2007) Occurrence of nutrients and plant hormones (cytokinins and IAA) in the water fern Salvinia molesta during growth and composting. Environ Exp Bot 61:137–144. doi:10.1016/j.envexpbot.2007.05.002

Atiyeh RM, Lee S, Edwards CA, Arancon NQ, Metzger JD (2002) The influence of humic acids derived from earthworm-processed organic wastes on plant growth. Bioresour Technol 84:7–14. doi:10.1016/S0960-8524(02)00017-2

Bhat MA (2016) Waste water treatment with a novel clean-green bioreactor SHEFROL. Pondicherry University, Pondicherry, p 116

Canellas LP, Olivares FL, Okorokova-Façanha AL, Façanha AR (2002) Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence, and plasma membrane H^+-ATPase activity in maize roots. Plant Phys 130:1951–1957. doi:10.1104/pp.007088

Chantiratikul P, Meechai P, Nakbanpotec W (2009) Antioxidant activities and phenolic contents of extracts from *Salvinia molesta* and *Eichornia crassipes*. Res J Biol Sci 4:1113–1117

Chen Y, De Nobili M, Aviad T (2004) Stimulatory effect of humic substances on plant growth. In: Magdoff F, Weil RR (eds) Soil organic matter in sustainable agriculture, pp. 103–130. doi:10.1201/9780203496374.ch4

Choudhary MI, Naheed N, Abbaskhan A, Musharraf SG, Siddiqui H (2008) Phenolic and other constituents of fresh water fern *Salvinia molesta*. Phytochem 69:1018–1023. doi:10.1016/j.phytochem.2007.10.028

Choudhary S, Pareek S, Saxena J (2010) Management of dry root rot of greengram (*Vigna radiata*) caused by *Macrophomina phaseolina*. Indian J Agric Sci 80:988–992

Coetzee JA, Hill MP, Byrne MJ, Bownes A (2011) A review of the biological control programmes on *Eichhornia crassipes* (C. Mart.) Solms (Pontederiaceae), *salvinia molesta* D.S. Mitch. (Salviniaceae), *Pistia stratiotes* L. (Araceae), *Myriophyllum aquaticum* (Vell.) Verdc. (Haloragaceae) and *Azolla filiculoides* Lam. (Azollaceae) in South Africa. Afr Entomol 19:451–468. doi:10.4001/003.019.0202

Crites RW, Middlebrooks EJ, Bastian RK (2006) Natural wastewater treatment systems. CRC Press, Boca Raton

Datta S, Singh J, Singh S, Singh J (2016) Earthworms, pesticides and sustainable agriculture: a review. Environ Sci Pollut Res 23:8227–8243. doi:10.1007/s11356-016-6375-0

Delgado MA, Farinas JC, Ruano S (2002) Firm productivity and export markets: a non-parametric approach. J Int Econ 57:397–422. doi:10.1016/S0022-1996(01)00154-4

Doan TT, Henry-des-Tureaux T, Rumpel C, Janeau JL, Jouquet P (2015) Impact of compost, vermicompost and biochar on soil fertility, maize yield and soil erosion in Northern Vietnam: a three year mesocosm experiment. Sci Tot Environ 514:147–154. doi:10.1016/j.scitotenv.2015.02.005

Dorahy CG, Pirie AD, McMaster I, Muirhead L, Pengelly P, Chan KY, Jackson M, Barchia IM (2009) Environmental risk assessment of compost prepared from Salvinia, and Alligator weed. J Environ Qual 38:1483–1492. doi:10.2134/jeq2007.0555

Edwards CA (2004) Earthworm ecology, 2nd edn. CRC Press, Washington

Edwards CA, Arancon NQ, Sherman RL (2011) Vermiculture technology: earthworms, organic wastes, and environmental management. CRC Press, Boca Raton, pp 17–19

Field A (2009) Discovering statistics using SPSS statistics. Sage Publications, London

Frankenberger WT Jr, Muhammad A (1995) Phytohormones in soils: microbial production and function. Marcel Dekker Inc., New York, p 503

Ganesh PS, Ramasamy EV, Gajalakshmi S, Abbasi SA (2005) Extraction of volatile fatty acids (VFAs) from water hyacinth using inexpensive contraptions, and the use of the VFAs as feed supplement in conventional biogas digesters with concomitant final disposal of water hyacinth as vermicompost. Biochem Eng J 27(1):17–23

Ganeshkumar T, Premalatha M, Gajalakshmi S, Abbasi SA (2014) A new process for the rapid and direct vermicomposting of the aquatic weed salvinia (*Salvinia molesta*). Bioresour Bioprocess 1(1):26. doi:10.1186/s40643-014-0026-4

García-Gil JC, Plaza C, Senesi N, Brunetti G, Polo A (2004) Effects of sewage sludge amendment on humic acids and microbiological properties of a semiarid Mediterranean soil. Biol Fertil Soils 39:320–328. doi:10.1007/s00374-003-0709-z

Halder J, Sanwal SK, Rai AK, Rai AB, Singh B, Singh BK (2015) Role of physico-morphic and biochemical characters of different okra genotypes in relation to population of okra shoot and fruit borer, *Earias vittella* (Noctuidae: Lepidoptera). Indian J Agric Sci 85:278–282

Hussain N (2016) Gainful utilization of toxic and allelopathic weeds for the generation of biofertilizer through vermicomposting: an assessment of the fertilizer value of the resultant vermicompost. PhD thesis, Pondicherry University

Hussain N, Abbasi T, Abbasi SA (2015) Vermicomposting eliminates the toxicity of lantana (*Lantana camara*) and turns it into a plant friendly organic fertilizer. J Hazard Mat 298:46–57. doi:10.1016/j.jhazmat.2015.04.073

Hussain N, Abbasi T, Abbasi SA (2016a) Vermiremediation of an invasive and pernicious weed salvinia (*Salvinia molesta*). Ecol Eng 91:432–440. doi:10.1016/j.ecoleng.2016.03.010

Hussain N, Abbasi T, Abbasi SA (2016b) Transformation of toxic and allelopathic lantana into a benign organic fertilizer through vermicomposting. Spectrochim Acta A 163:162–169. doi:10.1016/j.saa.2016.03.019

Hussain N, Abbasi T, Abbasi SA (2017a) Toxic and allelopathic ipomoea yields plant-friendly organic fertilizer. J Clean Prod 148:826–835. doi:10.1016/j.jclepro.2017.01.176

Hussain N, Abbasi T, Abbasi SA (2017b) Detoxification of parthenium (Parthenium hysterophorus) and its metamorphosis into an organic fertilizer and biopesticide. Bioresour Bioprocess 4:26. doi:10.1186/s40643-017-0156-6

ICAR (2011) Handbook of agriculture. Indian Council of Agricultural Research, Pusa

Ievinsh G (2011) Vermicompost treatment differentially affects seed germination, seedling growth and physiological status of vegetable crop species. Plant Growth Regul 65:169–181. doi:10.1007/s10725-011-9586-x

Joshi R, Singh J, Vig AP (2015) Vermicompost as an effective organic fertilizer and biocontrol agent: effect on growth, yield and quality of plants. Rev Environ Sci Bio/Technol 14:137–159

Jouquet EP, Bloquel E, Doan TT, Ricoy M, Orange D, Rumpel C, Duc TT (2011) Do compost and vermicompost improve macronutrient retention and plant growth in degraded tropical soils? Compost Sci Util 19:15–24. doi:10.1080/1065657X.2011.10736972

King C, McIntosh D, Fitzsimmons K (2004) Giant Salvinia (*Salvinia molesta*) as a partial feed for Nile Tilapia (*Oreochromis niloticus*). In: Proc. 6th Int. Symp. Tilapia in Agric, pp 12–16

Kumar R, Singh MK, Kumar V, Verma RK, Kushwah JK, Pal M (2015) Effect of nutrient supplementation through organic sources on growth, yield and quality of coriander (*Coriandrum sativum* L.). Indian J Agric Res 49:278–281. doi:10.5958/0976-058X.2015.00045.1

Leterme P, Londoño AM, Ordoñez DC, Rosales A, Estrada F, Bindelle J, Buldgen A (2010) Nutritional value and intake of aquatic ferns (*Azolla filiculoides* Lam. and *Salvinia molesta* Mitchell.) in sows. Anim Feed Sci Technol 55:55–64. doi:10.1016/j.anifeedsci.2009.10.002

Li S, Wang P, Deng G, Yuan W, Su Z (2013) Cytotoxic compounds from invasive giant salvinia (*Salvinia molesta*) against human tumor cells. Bioorg Med Chem Lett 23:6682–6687. doi:10.1016/j.bmcl.2013.10.040

Luque GM, Bellard C, Bertelsmeier C, Bonnaud E, Genovesi P, Simberloff D, Courchamp F (2014) The 100th of the world's worst invasive alien species. Biol Invasions 16:981–985. doi:10.1007/s10530-013-0561-5

Moran R, Porath D (1980) Chlorophyll determination in intact tissues using *N*,*N*-dimethylformamide. Plant Physiol 65:478–479

Nath G, Singh K (2011) Combination of vermicomposts and biopesticides against nematode (*Pratylenchus* sp.) and their effect on growth and yield of tomato (*Lycopersicon esculentum*). IIOAB J 2:27–35

Nielsen SS (2010) Food analysis, 4th edn. Springer, London and New York. doi:10.1007/978-1-4419-1478-1

Raju RA, Gangwar B (2004) Utilization of potassium-rich green-leaf manures for rice (*Oryza sativa*) nursery and their effect on crop productivity. Indian J Agron 49:244–247

Room PM (1990) Ecology of a simple plant-herbivore system. Biological control of Salvinia. Trends Ecol Evol 5:74–79. doi:10.1016/0169-5347(90)90234-5

Room PM, Harley KL, Forno IW, Sands DP (1981) Successful biological control of the floating weed salvinia. Nature 294:78–80

Schooler SS, Salau B, Julien MH, Ives AR (2011) Alternative stable states explain unpredictable biological control of *Salvinia molesta* in Kakadu. Nature 470:86. doi:10.1038/nature09735

Shah MN, Gajalakshmi S, Abbasi SA (2014) Direct vermicomposting of vegetable waste using the concept of high-rate vermireactor operation. Int J Environ Sci Eng Res 4:59–65

Sharma RP, Swaminathan R, Bhati KK (2010) Seasonal incidence of fruit and shoot borer of okra along with climatic factors in Udaipur region of India. Asian J Agric Res 4:232–236. doi:10.3923/ajar.2010.232.236

Shindell DT, Faluvegi G, Koch DM, Schmidt GA, Unger N, Bauer SE (2009) Improved attribution of climate forcing to emissions. Science 326:716–718. doi:10.1126/science.1174760

Song X, Liu M, Wu D, Griffiths BS, Jiao J, Li H, Hu F (2015) Interaction matters: synergy between vermicompost and PGPR agents improves soil quality, crop quality and crop yield in the field. Aust Soil Ecol 89:25–34. doi:10.1016/j.apsoil.2015.01.005

Sullivan PR, Postle LA, Julien M (2011) Biological control of Salvinia molesta by *Cyrtobagous salviniae* in temperate Australia. Biol Control 57:222–228. doi:10.1016/j.biocontrol.2011.03.009

Szczech MM (1999) Suppressiveness of vermicompost against *Fusarium wilt* of tomato. J Phytopathol 147:155–161. doi:10.1046/j.1439-0434.1999.147003155.x

Szczech M, Smolińska U (2001) Comparison of suppressiveness of vermicomposts produced from animal manures and sewage sludge against *Phytophthora nicotianae* Breda de Haan var. nicotianae. J Phytopathol 149:77–82. doi:10.1046/j.1439-0434.2001.00586.x

Tauseef SM, Premalatha M, Abbasi T, Abbasi SA (2013) Methane capture from livestock manure. J Environ Manag 117:187–207

Tohyama A, Hayashi K, Taniguchi N, Naruse C, Ozawa Y, Shishiyama J, Tsuda M (2005) A new post-harvest disease of okra pods caused by *Alternaria alternate*. Jpn J Phytopathol 61:340–345. doi:10.3186/jjphytopath.61.340

Wellburn AR (1994) The spectral determination of chlorophylls a and b, as well as total carotenoids, using various solvents with spectrophotometers of different resolutions. J Plant Physiol 144:307–313. doi:10.1016/S0176-1617(11),81192-2

Xiao Z, Liu M, Jiang L, Chen X, Griffiths BS, Li H, Hu F (2016) Vermicompost increases defense against root-knot nematode (*Meloidogyne incognita*) in tomato plants. Appl Soil Ecol 105:177–186. doi:10.1016/j.apsoil.2016.04.003

Xu Y, Wang C, Bi Y, Zhang Y, Cheng W, Sun Z, Zhang J, Lv Z, Guo X, Jiuxianzhen YC (2014) Influence of cow manure vermicompost soil mixtures on two flowers seedling cultivation. Acta Hort 1018:583–588. doi:10.17660/ActaHortic.2014.1018.64

Yadav A, Suthar S, Garg VK (2015) Dynamics of microbiological parameters, enzymatic activities and worm biomass production during vermicomposting of effluent treatment plant sludge of bakery industry. Environ Sci Pollut Res 22:14702–14709. doi:10.1007/s11356-015-4672-7

Yardim EN, Arancon NQ, Edwards CA, Oliver TJ, Byrne RJ (2006) Suppression of tomato hornworm (*Manduca quinquemaculata*) and cucumber beetles (*Acalymma vittatum* and *Diabotrica undecimpunctata*) populations and damage by vermicomposts. Pedobiologia 50:23–29. doi:10.1016/j.pedobi.2005.09.001

Publisher's Note