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Review Article

Microorganisms in the Conversion of Agricultural Wastes to Compost

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Microorganisms play an important role in the recycling of agricultural wastes. The compost generated by bioconversion of agroresidues offers several benefits such as enhanced soil fertility and soil health which can lead to increased agricultural productivity, improved soil biodiversity, reduced ecological risks and a healthier environment. These virtues make composting an ideal option for processing of the enormous quantities of agrowastes that are generated in the world. Recent reports also indicate multifarious uses of bioaugmented compost as carrier for bioinoculants, biocontrol agents for diseases suppressivness and bioremediation. There is definite need to intensify research on novel effective microorganisms to prepare high quality compost in a relatively shorter duration and new technologies for large-scale production.

Key Words: Compost; Agroresidues; Effective Microorganisms; Soil Health

Introduction

Crop residues are generated in large quantities and constitute an abundant but underutilized source of renewable biomass in agriculture. The amount of crop residues available in India (Fig. 1) is estimated to be approximately 620 million tons [1]. Half the quantity of agro-residues thus produced finds use as roofing material, animal feed, fuel and packing material, while the other half is disposed of by burning in the field. Burning agro-residues in the field is considered a cheap and easy means of disposal of excess residues. This practice appends to air pollution, increases soil erosion and decreases the efficacy of soil-applied herbicides like isoproturon [2]. Moreover, it also causes respiratory problems and increases the fog incidences even in distant cities [3]. Direct incorporation of agro-residues like rice straw in field solves the problem of air pollution but it is not feasible due to the short time gap between harvesting of rice and sowing of wheat. Besides, it involves additional cost of labour, irrigation and extra tillage [4]. Moreover, observations of long term experiments indicate that though incorporation of agro-residues in soil improves soil health significantly [5-7], it decreases the subsequent crop yields due to production of microbial phytotoxins and allelochemicals [8] and immobilization of the available nitrogen [9]. Incorporation of agro-residues like paddy straw increases the CH_4 emission from field [10, 11] especially in irrigated soils, which in turn adds to the malice of global warming.

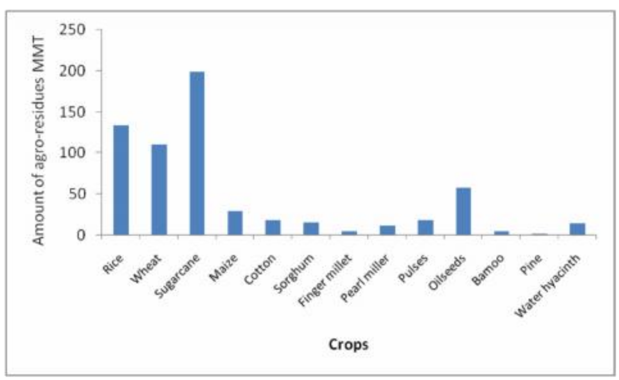

Fig. 1: Annual agro-residues generated from different crops (MMT), Source: [1]

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About 50 % of the total residues generated are produced by three crops *viz*. rice, wheat and oilseed. On an average these residues contain about 0.5% N, 0.2% P_2O_5 and 1.5% K_2O. Assuming that 50% of crop residues are utilized as cattle feed and fuel, the nutrient potential of the remaining residue is 6.5 million tonnes of NPK per annum, which accounts for 30 % of total NPK consumption in India. Hence the recycling of these wastes is not only an ecological necessity but, in a country like ours, is an economic compulsion.

Composting of agricultural residues through the action of lignocellulolytic microorganisms is easier to manage and it recycles the lignocellulosic waste with high economic efficiency. The recycled material when applied to soil, improves soil fertility and health. Composting is the biological degradation and stabilization of organic substrate under conditions that allow development of thermophilic temperature as a result of biologically produced heat [12]. During composting, mesophilic population builds up initially by the utilization of simple nutrients, which raises the temperature of the piles. Thermophilic microbes proliferate in the second phase. The final product is stable, free of pathogens and plant seeds and can be beneficially applied to land.

Composting has been used as a means of disposal of organic wastes like paddy straw, sugarcane trash and other agricultural wastes. Natural succession of microflora takes place during composting. Several fungi like *Trichoderma harzianum*, *Pleurotus ostreatus*, *Polyporus ostriformis* and *Phanerochaete chrysosporium* are known to play important role in composting of lignocellulosic materials [13]. The composting of agricultural residues rich in lignocellulose like paddy straw generally takes 180 days to obtain good and mature compost. High lignin content restricts the enzymatic and microbial access to the cellulose in paddy straw. Cellulose degrading microorganisms hasten the biodegradation of crop residues such as straw, leaves, trash etc. and such cultures have been used for composting of plant residues [12] but still time taken for composting is too long. This time constraint can be overcome by using some lignin degrading microorganisms in combinations with the cellulose-degrading microorganisms.

1. Lignocellulose Degrading Microorganisms Involved in Composting

The organic substrate, bulking agents and the amendments used in composting are mostly derived from plant material. Lignocellulose, the composite of the predominant polymers of vascular plant biomass, is composed of polysaccharides like cellulose and hemicellulose and the phenolic polymer lignin. Hence, the capacity of microorganisms to assimilate organic matter depends on their ability to produce the enzymes needed for degradation of the substrate components i.e., cellulose, hemicellulose and lignin. The more complex the substrate, the more extensive and comprehensive is the enzyme system required. Through the synergistic action of microorganisms, complex organic compounds are degraded to smaller molecules, which can then be utilized by microbial cells [14]. Many organisms viz. fungi, bacteria, invertebrates like earthworms play an important role during composting.

Hundreds of species of fungi are able to degrade lignocellulose. There are mainly three types of fungi living on dead wood that preferentially degrade one or more wood components *viz*. soft rot fungi, brown rot fungi and white rot fungi [15]. Soft rot fungi (Ascomycetes and fungi imperfecti) can efficiently decompose cellulose but are reported to degrade lignin slowly and incompletely. The brown rot fungi (Basidiomycetes) generally exhibit preference for the carbohydrate components of wood with activity towards lignin largely confined to demethylation [16, 17]. White rot fungi are capable of degrading both lignin and cellulose. In majority of soils, 80 per cent of the fungal population belongs to the genera *Aspergillus* and *Penicillium*. However, the most extensively studied lignocellulolytic fungi are *Trichoderma* and *Phanerochaete.*

Cellulolytic bacteria are ubiquitous in nature. Under appropriate conditions bacteria degrade cellulose and hence many bacterial strains are known to solubilize and modify the lignocellulosic structures extensively. But their ability to mineralize lignin is limited [18]. *Cytophaga*. *Sporocytophaga* are dominant cellulolytic microorganisms in all types of composting processes. *Cellulomonas* and *Cytophaga* are the aerobic mesophilic bacteria able to degrade cellulose. More than one-half of the *Bacillus* spp. examined to date produces extracellular cellulases [19]. Mesophilic aerobic and anaerobic forms of *Bacillus, B. subtilis B. polymyxa, B. licheniformis, B. pumilus, B. brevis, B. firmus, B. circulans, B. megaterium* and *B. cereus* are known to be cellulose and hemicellulose degraders [20].

Actinomycetes isolated from soil and related substances show primary biodegradative activity, secreting a range of extracellular enzymes and exhibiting the capacity to metabolize recalcitrant molecules. Composting heavily relies on such prolific actinomycete activity. Thermophilic cellulose degrading *Thermoactinomyces, Streptomyces* and *Thermomonospora* were found to be present in dry, warm land and also where salt concentrations are too high and soil pH is alkaline [21]. From Indian desert soil of Jodhpur, Rao and Venkateswarlu [22] isolated *Streptomyces, Micromonospora* and *Thermoactinomyces*. These organisms were found to depolymerize crystalline celluloses by two cellulase enzyme systems and ß-glucosidase. Though actinomycetes can solubilise cellulose and modify the lignin structure extensively, their ability to mineralize lignin is limited [23, 24]. Recent reports suggest the role of *Streptomyces sp.* in delignification of paddy straw [25] which makes it more susceptible to cellulose degrading enzymes. Actinomycetes follow a characteristic pattern of lignocellulose decomposition with the release of lignin rich, water soluble fragments that are slowly metabolized thereafter or can be recovered as value added products [26].

2. Consortium of Microorganisms for Accelerated Composting

Though fungi, bacteria and actinomycetes play unique and important roles during composting, mixed cultures of microorganisms enhance the rate of lignocellulose degradation due to their synergistic activity through utilization of intermediate degradation products [27]. At IARI, New Delhi, a consortium of four fungi has been developed on the basis of their lignocellulolytic enzyme production potential [28]. The consortium of four hypercellulolytic fungal cultures namely *Aspergillus nidulans, Trichoderma viride, Phanerochaete chrysosporium* and *Aspergillus awamori* was used for composting of paddy straw in perforated pits. A prototype was developed for preparation of bioaugmented compost by employing these fungi by using diverse agricultural waste e.g., paddy straw, soybean trash, pearl millet, maize residues and mustard stover effectively [29-31]. Incorporation of poultry droppings and rock phosphate (1%) resulted in generation of N-enriched phosphocompost within two month of composting. Thermophilic fungal consortium of *A. nidulans, Scytalidium thermophilum* and *Humicola* sp. was found highly effective in degradadion of soybean trash and paddy straw mixture during summer months [32]. Similarly, a consortium of thermophilic microorganisms (*Scytalidium thermophilum, Humicola insolens* and *Sporotrichum thermophilum*) is also being used at Directorate of Mushroom Research, Solan for production of compost at high temperature in tunnels to generate pathogen free compost within 10 days for mushroom cultivation. However no efforts have been made for selection of psychotrophic microbial accelerators for agrowaste management in temperate and hilly regions. This becomes imperative as most of the high altitude areas of India, where biomass generation is tremendous due to rich vegetation and forests, do not have effective biological tools for composting.

3. Compost as Soil Conditioner and Organic Fertilizer

The application of compost in soil improves soil physical, biological and chemical properties [33], and also restore soil organic matter and carbon pools [34-36]. Tremendous information is available on use of compost in organic farming. Several experiments were conducted throughout the world to monitor the effect of compost application on vegetable [34, 37] fruits [38-40], ornamental crops [41, 42], legumes and cereal crops [43-45]. Most of the researchers reported significant benefit in terms of increased crop yield and better mineral nutrition under integrated nutrient management practices [13, 46]. Tartoura and Youssef [47] reported stimulation of reactive oxygen species (ROS) scavenging system in squash by compost supplementation under low temperature induced oxidative stress. Composts can be further enriched with minerals (rock phosphate and mica) and microbial inoculants (N fixers, PSB and K solubilizing microbes) to enhance the overall quality of these organomineral fertilizers. The application of such bioaugmented nutrient enriched compost in soil leads to a significant increase in the soil fertility status (in terms of microbial biomass, N and available P) enhancing the overall chemical and biological activity of soil. The phosphorus and nitrogen enriched organic residues thus appear as a better alternative than the commercial fertilizer since their low price is not only economical but will also protect the soil from further deterioration and enrich it with nutrients and microbial flora. The application of mineral enriched compost indirectly satisfied the N and P needs of plants in nutrient deficient soils. Apart from being a source of macro and micro nutrients for plants, compost is also believed to suppress soil-borne diseases in plants [48]. The exact mechanisms of disease suppression is not clear but it may involve antibiotic production by beneficial microorganisms present in compost, activation of disease-resistant genes in plants by microorganisms (induced systemic resistance), improved plant nutrition and vigour leading to enhanced disease resistance, presence of toxic or stimulatory volatile compounds in compost [49].

Investigations have illustrated the potential of microbe amended composts as biocontrol agents, which have superior fungicidal potential, indicative of the utility of compost not only as a nutritive source but also carrier for bioagents [50, 51]. Although successful biological control by compost has been less frequent in field but suppressive effect of compost on diseases such as damping off, root rots and wilts caused by *Fusarium*, *Pythium*, *Phytophthora*, *Verticillium and Rhizoctonia* have been shown by various workers [52, 53]. Besides suppressing soil-borne pathogens, compost has been reported to reduce the severity of some above ground diseases of plants [54].

4. Biougmented Compost for Bioremediation of Contaminated Soil

Besides agriculture, bioaugmented compost is slowly emerging as novel resource for bioremediation of soil contaminated with heavy metals and organic pollutants. Various clean-up technologies like air stripping, incineration and burial of sludge from contaminated sites in landfills are available but expensive [55]. Compost when applied to heavy metal contaminated sites; limit the bioavailability of metals due to presence of humic substance and iron oxide as well as organics in composts. In addition, stabilized organic matter forms complexes with metals and restricted the mobility of the metals and their availability for plant absorption [56]. Moreover, microorganisms involved in composting like bacteria and fungi are capable of accumulating metal ions in their cells by intracellular uptake and can also chelate metal ions by the carboxyl, hydroxyl or other active functional groups on cell (including the dead cell) wall surface. Table 1 summarizes the work carried out by different workers to investigate the effect of compost in reducing heavy metal availability in soil under different cropping systems.

Bioremediation by co-composting is an economically attractive method for cleaning organic pollutants like xenobiotic, petroleum products, polycyclic aromatic hydrocarbons (PAHs) etc. Microorganisms consume contaminants in soils, ground and surface waters and air. The contaminants may be degraded using different mechanisms like mineralization by microbial activity, transformation to non-toxic products, volatilization, and formation of humus and inert byproducts, such as carbon dioxide, water and salts. The critical parameters like aeration, C:N ratio and duration for composting depend on the type of contaminants and waste materials to be used for composting. The efficiency of compost in bioremediation is essentially determined by process parameters like pH, temperature, C:N ratio, moisture content and recalcitrance of the material to be composted. Bulking agents like peat moss, pine wood shavings, bran flakes accelerate composting by favouring the growth of aerobic microorganisms [66-68]. Bioremediation by

Table 1: The effect of different composts on availability of heavy metals in soil

Soil amendments	Metal (loid)	Available Heavy metal	Reference
Solid olive husk compost	Cr, Ni, Cu	Decreased	[57]
Rapeseed residues (*in-situ* composting)	Zn, Cu, Cr	Reduction of Cd by 5–14% and Pb by 30–39%	[58]
Spent Mushroom Compost	Cd, Pb, Ni, Zn	>75% reduction	[59]
Yard waste compost	Cd, Pb	Up to 50 % reduction	[60]
MSW garden waste compost	Cd and Cu	>90% Decreased	[61]
Humic deposit	Cu, Ni, Pb and Zn	15-50% reduction	[62]
MWC or biosolid compost, forest litter	Cu, Ni, Pb and Zn	25-35% reduction Cd, Cu and >90 % reduction in Zn concentration	[63]
MWC or biosolid compost, forest litter	Cd and Zn	25 % reduction Cu and >90 % reduction in Cd & Zn concentration	[63]
Cow manure	Zn, Cu, Ni, Cd, Cr and Pb	Zn, Cu, Cr decreased	[64]
Sewage sludge and bark compost	Cu, Pb and Zn	No effect	[65]

application of compost or co-composting is an economically attractive method for cleaning petroleum-contaminated soil. PAHs are often not fully degradable by a single organism, but are degraded by consortium of organisms, each carrying out different degradative steps [69]. Finstein *et al.* [70] found that the degradation of oil refinery sludge achieved after 35 days of moderately thermophilic composting were comparable with 1280 days of simulated land farm treatment. Beaudin *et al.* [71] studied the composting of hydrocarbon-contaminated soil with alfalfa and maple leaves and found that after 287 days of composting, 73% of all mineral oils and grease had degraded. Heating and forced aeration of soils was found effective in biodegradation of fuel oil hydrocarbons in soil [72]. Mature composts enriched with propane or methane have been used as biofilters to cleanse air of pollutants like trichloroethylene with approximate 99% removal after 96 h of exposure [73]. Mixed populations or consortium of microorganisms are required to enhance the degradation of these complex substances [74]. Marin [75] tested the efficacy of composting as a bioremediation technique for reducing the hydrocarbon content of oil refinery sludge with a total hydrocarbon content (250-300 g kg^{-1}) and achieved 60 % degradation in 3 months when composting was done with bulking agent. Sayara [76] studied the degradation of several PAHs in soil through composting and concluded that 89% of the total PAHs were degraded by the end of the composting period (30 days) compared to the only 29.5% that was achieved by the soil indigenous microorganisms without any co-substrate.

Modern xenobiotics used in crop production are mostly organic compounds that are subjected to biological decomposition besides physical and chemical decomposition. Sometimes, lack of readily decomposable organic matter in soil gives inadequate substrate to stimulate microorganisms to decompose pesticides [77]. The vigorous biological activity during composting can be used to accelerate the decomposition of xenobiotics in soil [78]. Strom [79] noted that pesticide levels in composts were low, partly because of low initial contamination of feedstock and because of degradation of pesticides during composting. In the composting of food wastes, diazinon [O-O-diethyl-O-(2-isopropyl-6-methyl-5-pyrimidinyl) phosphorothionate] and parathion (O-O-diethyl-O-4-nitrophenyl phosophorothionate) were quickly destroyed completely; dieldrin (a polychlorinated dimethanonaphthalene) was reduced substantially, but DDT (di-chloro, di-phenyl, tri-chloro-ethane) was recalcitrant [80]. Büyüksönmez *et al*. [78] noted that the majority of the pesticides

Table 2: Standards of compost and vermicompost as described in fertilizer control order (1985)

Parameter	Compost	Vermicompost
Moisture per cent by weight	15.0-25.0	15.0-25.0
Colour	Dark brown to black	Dark brown to black
Odour	Absence of foul odour	Absence of foul odour
Particle size	Minimum 90% material should pass through 4.0mm IS sieve	Minimum 90% material should pass through 4.0mm IS sieve
Bulk density (g/cm^3)	<1.0	0.7-0.9
Total organic carbon, per cent by weight, minimum	12.0	18.0
Total nitrogen (as N), per cent by weight, minimum	0.8	1.0
Total phosphates (as P_2O_5), per cent by weight, minimum	0.4	0.8
Total potash (as K_2O), per cent by weight, minimum	0.4	0.8
C:N ratio	20:1 or less	-
pH	6.5-7.5	-
Conductivity (as dsm^{-1}), not more than	4.0	-
Pathogens	Nil	-
Heavy metal content, (as mg/kg), per cent by weight, maximum		
Arsenic (as As_2O_3)	10.0	10.0
Cadmium (as Cd)	5.0	50.0
Chromium (as Cr)	50.0	50.0
Copper (as Cu)	300.0	-
Mercury (as Hg)	0.15	0.15
Nickel (as Ni)	50.0	50.0
Lead (as Pb)	100.0	100.0
Zinc (as Zn)	1000.0	-

detected in feedstocks or composts were organochlorine insecticides, which were resistant to biodegradation.

Compost addition has also been reported to improve degradation of two herbicides [benthiocarb (S-4-chlorobenzyl diethylthiocarbamate) and MCPA (4-chloro-2-methylphenoxyacetic acid)] in soil [81]. Mineralization of atrazine was enhanced by co-composting with newsprint [82]. Composts lowered pesticide concentrations to nonhazardous levels for crops in soils. However, the intermediates produced during composting of pesticides are not always non-toxic and hence caution has to be maintained while using composts after bioremediation.

5. Fertilizer Control Order and Compost Quality

With the increased commercial production of compost at large scale, it is not unusual to encounter poor quality commercial compost in market. Many countries are now beginning to routinely publish compost guidelines with implied standards to control the sale and export-import of the compost. The standards for compost are fairly well developed in Europe, while the rest of the world, including the United States, lags significantly behind [83]. Till recently there was no regulatory body or legislation that existed in India to control the quality of biological inputs like compost, vermicompost, biofertilizers etc. But now biofertilizers and organic manures are

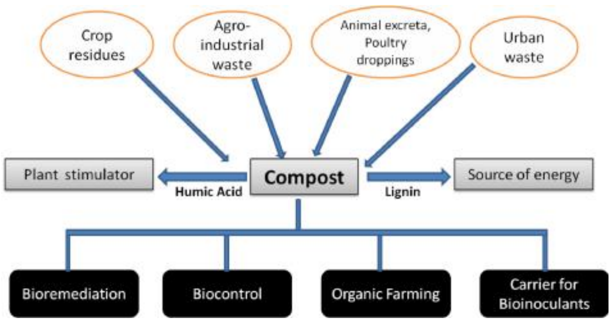

Fig. 2: Recycling of waste and multifarious uses of compost

covered under FCO 1985 [84]. Table 2 gives a brief account about the present standards in India. It should be noted that the certain metals may present in high concentration in composts prepared from agro-industrial residues and municipal solid waste. Generally C:N ratio is considered as a criteria to judge the maturity of compost; several other microbiological and chemical parameters *ex.* degree of humification, ratio of humic acid and fulvic acid, E4/E6 ratio and E2/3 ratio [85-88] are being reported as sensitive parameters to adjudge the quality of compost. Since sophisticated instruments are not available everywhere, FCO has defined the general guidelines so that small scale industries may take-up composting as a suitable option for bioconversion of indigenous waste.

6. Future Prospects

Novel approaches to improve the process of composting, including reducing generation time, inclusion of faecal residues/animal litter, organic/ inorganic compounds and consortia of effective microorganisms has revolutionized the use of compost in diverse spheres of agriculture and made it an essential component in crop-production, crop-protection and natural resource management. Keeping in view the different agro-climatic zones, tailor made bioinoculants and technologies are needed to suit the demands of the local farmers for quality compost production. Although lot of work has been done on microbiology of composting, there is lack of sufficient knowledge about microbial diversity and their exact role during various stages of composting. There is a strong need to carry out work on the unculturable microorganisms and their activities during the composting processes using advanced techniques like denaturing gradient gel electrophoresis (DGGE) and other cultivation independent techniques.

Extension workers and KVKs needs to play a major role in popularizing different compost technologies among farmers. Besides composting, agrowastes may be utilized as a useful resource for production of animal feed, biofuel and enzymes to generate additional income from bioconversion process.

References

1. Pandey A, Biswas S, Sukumaran RK and Kaushik N (2009) *Study on Availability of Indian Biomass Resources for Exploitation: A Report Based on a Nationwide Survey* TIFAC, New Delhi
2. Walia U, Kumar N, Brar H *et al*. *Indian Journal of Weed Science* **31** (1999) 225-228
3. Lalchandani N *Times of India* dt. 05/11/2012 Delhi Edition (2012)
4. Sidhu B, Rupela O, Beri V *et al. Economic and Political Weekly* (1998) 163-168
5. Sidhu BS and Beri V *Biological Wastes* **27** (1989) 15-27
6. Beri V, Sidhu B, Bahl G *et al*. *Soil Use and Management* **11** (1995) 51-54
7. Beri V, Sidhu B, Bhat A *et al*. *Nutrient Management for Sustained Productivity* (1992) 133-135
8. Rao DN and Mikkelsen DS *Plant soil* **47** (1977) 303-311
9. Kimber RWL *Plant soil* **38** (1973) 543-555
10. Conrad R *Nutrient Cycling in Agroecosystems* **64** (2002) 59-69
11. Chidthaisong A, Inubushi K, Muramatsu Y *et al. Microbes and Environments* **11** (1996) 73-78
12. Gaur AC (1999) *Microbial Technology for Composting of Agricultural Residues by Improved Methods*, Indian Council of Agricultural Research, New Delhi
13. Singh S, Singh B, Mishra B *et al.* (2012) *Microorganisms in Sustainable Agriculture and Biotechnology* Springer Netherlands, pp 127-151

14. Golueke C (1991) *The Staff of BioCycle Journal of Waste Recycling. The Art and Science of Composting,* The JG Press Inc., Pennsylvania, USA, pp 14-27
15. Kirk TK (1983) *The Filamentous Fungi*, US Gov Printing Office, 266-295
16. Ander P and Eriksson KE *Physiologia Plantarum* **41** (2006) 239-248
17. Janshekar H *Fiechter and Pentoses and Lignin, Adv Biochem Eng Biotechnol* **27** (1983) 119-178
18. Ball A, Betts W and McCarthy A *Appl Environmental Microbiol* **55** (1989) 1642-1644
19. Soundar S and Chandra TS *J Indl Microbiol* **2** (1987) 257-265
20. Strom PF *Appl Environmental Microbiol* **50** (1985) 906-913
21. Stutzenberger FJ *Appl Microbiol* **24** (1972) 83-90
22. Rao AV and Venkateswarlu B *Agri Ecosys Environ* **10** (1983) 361-369
23. Eriksson KEL, Blanchette RA and Ander P (1990) *Microbial and Enzymatic Degradation of Wood and Wood Components*, Springer-Verlag USA
24. Godden B, Ball AS, Helvenstein P *et al*. *J Gen Microbiol* **138** (1992) 2441-2448
25. Saritha M, Arora A, Singh S *et al. Bioresource Technology* (2012) http://dx.doi.org/10.1016/j.biortech.2012.1011.1040
26. Vicuña R *Enzyme and Microbial Technology* **10** (1988) 646-655
27. Kanotra S and Mathur RS *Bioresource Technology* **47** (1994) 185-188
28. Lata, Shukla L and Surender S *Composting Agroresidues with Fungal Inoculants* ICAR News Research (2008) 5
29. Gaind S and Nain L *Bioresource Technology* **101** (2010) 2996-3003
30. Gaind S, Nain L and Patel VB *Biodegradation* **20** (2009) 307-317
31. Pandey A, Gaind S, Ali A *et al*. *Biodegradation* **20** (2009) 293-306
32. Kumar A, Gaind S and Nain L *Biodegradation* **19** (2008) 395-402
33. Paul EA (2007) *Soil Microbiology, Ecology and Biochemistry* Academic Press, USA
34. Smith DC, Beharee V and Hughes JC *Scientia Horticulturae* **91** (2001) 393-406
35. Wu T, Schoenau JJ, Li F *et al*. *J Plant Nutr Soil Sci* **168** (2005) 100-107
36. Wu T, Schoenau JJ, Li F *et al*. *Soil Tillage Res* **77** (2004) 59-68
37. Paredes C, Cegarra J, Bernal MP *et al*. *Environment International* **31** (2005) 305-312
38. Prince W SPM, Sivakumar S, Ravi V *et al. Biores Technol* **72** (2000) 95-97
39. Akanbi WB and Togun AO *Scientia Horticulturae* **93** (2002) 1-8
40. Tiquia S and Tam N (2000) *Proc Inter Compos Symp* (ICS 1999) pp 648-669
41. Perner H, Schwarz D, Bruns C *et al*. *Mycorrhiza* **17** (2007) 469-474
42. Carmona E, Moreno M, Avilés M, *et al*. *Spanish J Agricul Res* **10** (2012) 482-491
43. Hue N, Ikawa H and Silva J *Commun Soil Sci Plant Analysis* **25** (1994) 3291-3303
44. Goyal S, Singh D, Suneja S *et al*. *Ind J Agricul Res* **43** (2009) 263-268
45. Lawson IYD, Muramatsu K and Nioh I *Soil Sci Plant Nutrition* **41** (1995) 721-728
46. Gajalakshmi S and Abbasi S *Critical Reviews in Environmental Science and Technology* **38** (2008) 311-400
47. Tartoura KAH and Youssef SA *Scientia Horticulturae* **130** (2011) 862-868
48. Termorshuizen AJ, van Rijn E, van der Gaag DJ *et al*. *Soil Biol Biochem* **38** (2006) 2461-2477
49. Smolinska U *J Phytopathol* **148** (2000) 343-349
50. Chaudhary V, Prasanna R, Nain L *et al*. *World J Microbiol Biotechnol* **28** (2012) 3301-3310
51. Dukare AS, Prasanna R, Chandra Dubey S *et al*. *Crop Protection* **30** (2011) 436-442
52. Trillas MI, Casanova E, Cotxarrera L, *et al*. *Biological Control* **39** (2006) 32-38
53. Castaño R, Borrero C, Trillas MI, *et al*. *BioControl* (2012) 1-12
54. Trankner A (1992) *NATO ASI Series: Series A: Life Sciences* Plenum Press, New York, pp 35-92
55. Vasudevan N and Rajaram P *Environ Int* **26** (2001) 409-411
56. Paré T, Dinel H and Schnitzer M *Biol Fertil Soils* **29** (1999) 31-37
57. de la Fuente C, Clemente R, Martínez-Alcalá I *et al*. *J Hazardous Materials* **186** (2011) 1283-1289
58. Ok YS, Usman ARA, Lee SS, *et al*. *Chemosphere* **85** (2011) 677-682

59. Frutos I, Gárate A and Eymar E (2008) IV *International Symposium on Ecologically Sound Fertilization Strategies for Field Vegetable Production*, pp 261-268
60. Antonious GF *J Environ Sci Health Part A* **44** (2009) 1019-1024
61. Alvarenga P, Gonçalves AP, Fernandes RM, *et al*. *Sci Total Environ* **406** (2008) 43-56
62. Karaca A, Turgay OC and Tamer N *Biol Fertil Soils* **42** (2006) 585-592
63. Pérez-de-Mora A, Burgos P, Madejón E, *et al*. *Soil Biolo Biochem* **38** (2006) 327-341
64. Garcýìa-Gil JC, Plaza C, Soler-Rovira P, *et al*. *Soil Biolo Biochem* **32** (2000) 1907-1913
65. Pinamonti F, Nicolini G, Dalpiaz A, *et al*. *Communications in Soil Science & Plant Analysis* **30** (1999) 1531-1549
66. Paredes C, Bernal MP, Roig A, *et al*. *International Biodeterioration & Biodegradation* **38** (1996) 205-210
67. Meysami P and Baheri H *Advances in Environmental Research* **7** (2003) 881-887
68. Alburquerque JA, Gonzálvez J, García D, *et al*. *Process Biochem* **41** (2006) 127-132
69. Floodgate G (1984) *Petroleum Microbiology*, Macmillion, New York, NY, USA, pp 355-397
70. Finstein M, Miller F, Hogan J, *et al*. *BioCycle: Journal of Waste Recycling* **28** (1987) 20-26
71. Beaudin N, Caron RF, Legros R, *et al*. *Biodegradation* **10** (1999) 127-133
72. Yeung PY, Johnson RL and Xu JG *J Environ Qual* **26** (1997) 1511-1516
73. Sukesan S and Watwood M *J Appl Microbiol* **85** (2004) 635-642
74. Frontera-Suau R, Bost FD, McDonald TJ *et al*. *Environ Sci Technol* **36** (2002) 4585-4592
75. Marín J, Moreno J, Hernández T *et al*. *Biodegradation* **17** (2006) 251-261
76. Sayara T, Borràs E, Caminal G *et al*. *International Biodeterioration & Biodegradation* **65** (2011) 859-865
77. Felsot AS, Dzantor EK (1990) *Enhanced Biodegradation of Pesticides in the Environment*, American Chemical Society, pp 249-268
78. Büyüksönmez F, Rynk R, Hess T *et al*. *Compost Science and Utilization* **8** (2000) 61-81
79. Strom PF *Biocycle* **39** (1998)
80. Farrow R, Elkins E, Rose W *et al*. *Residue Reviews* **29** (1969) 73
81. Duah-Yentumi S and Kuwatsuka S *Soil Science and Plant Nutrition* **26** (1980) 541-549
82. Rao N, Grethlein H and Reddy C *Compost Science and Utilization* **4** (1996)
83. Brinton WF *Biocycle* **42** (2001) 74-76
84. Anonymous (2006) *The Fertilizer (Control) Order 1985*, 10th ed, The Fertilizer Association of India, New Delhi
85. Hue N and Liu *J Compost Science and Utilization* **3** (1995) 8-15
86. Chen Y, Senesi N and Schnitzer M *Soil Science Society of America Journal* **41** (1977) 352-358
87. Thomsen M, Lassen P, Dobel S *et al*. *Chemosphere* **49** (2002) 1327-1337
88. Hautala K, Peuravuori J and Pihlaja K *Water Research* **34** (2000) 246-258.