Phytopathol. Mediterr. (2010) 49, 381–392

Effect of composts on microbial dynamics and activity, dry root rot severity and seed yield of cowpea in the Indian arid region

Meenu BAREJA, Praveen KUMAR and Satish LODHA

Plant Pathology Laboratory, Central Arid Zone Research Institute,
Jodhpur- 342 003, India

Summary. Nutrient-deficient sandy soil, having poor moisture retention, favors *Macrophomina phaseolina*, a soil-borne plant pathogen, occurring in severe form on many important crops grown in the Indian arid region. In a 2-year field experiment, five composts (4 ton ha^{-1}) prepared from residues of *Calotropis procera*, *Prosopis juliflora*, *Azadirachta indica*, *Acacia nilotica*, and on-farm weeds were tested on cowpea (*Vigna unguiculata*) to determine their effectiveness in limiting the severity of charcoal rot caused by *M. phaseolina* in relation to the microbial population dynamics, microbial activity and the seed yield of cowpea. In general, compost-amended plots retained 8.9% higher moisture than unamended plots. The microbial population increased in amended plots during the crop season. Populations of total fungi and actinomycetes were heighest in *Calotropis* compost-amended soil, while total bacteria were maximum in weed- compost amended soil. Microbial activity in amended plots was 26.3% higher than in unamended plots. Among trace elements, uptake of Zn, Mn, Fe and Cu was highest in plants grown in weed-compost amended soil followed by *A. nilotica* compost-amended soil. Soil amendment with the composts significantly reduced plant mortality due to charcoal rot. The lowest mortality was recorded in plants amended with *A. nilotica* compost (5.5%) followed by *P. juliflora* compost (5.8), while the highest plant mortality (11.5%) from charcoal rot occurred in the unamended control on the basis of the pooled average of two years. There was a significant inverse correlation between microbial activity and charcoal rot incidence in cowpea at 20 days after planting. Composts also had a beneficial effect on yield, with a 28.3% increase in seed yield in *P. juliflora* compost-amended plots. These results suggest that in resource-deficient farming , certain on-farm wastes can be effectively utilized for managing soil-borne pathogens, as well as for enhancing crop productivity.

Key words: *Prosopis juliflora, Acacia nilotica, Azadirachta indica, Calotropis procera, Macrophomina phaseolina.*

Introduction

Cowpea, *Vigna unguiculata* (L.) Walp., grown in the arid regions of India, often faces heat and water stress conditions. When this happens, *Macrophomina phaseolina* (Tassi) Goid., a soil-borne plant pathogen, causes charcoal rot (dry root rot), a disease that limits the profitable cultivation of this legume. A disease incidence of up to 64%, leading to complete failure of the cowpea crop, has been reported (Lodha *et al*., 1986). The population density of the pathogen in the soil increases with number of years susceptible crops are cultivated on it and the density in the soil is directly proportional to the disease intensity in the crop.

Due to the wide host range of *M. phaseolina*, which affects most of the crops grown in the region, crop rotation is of very little significance in reducing *M. phaseolina*-induced diseases. Using the natural resources of the region, non-chemical approaches such as soil solarization, alone or with amendments (Lodha, 1995) and *Brassica* amendments combined with summer irrigation (Mawar and Lodha, 2002) have reduced *M. phaseolina* by 56–63% and disease incidence by 65–75% on guar, *Cyamopsis tetragonoloba* (L.) Taub., another important legume grown in this region. However, the

Corresponding author: S. Lodha
E-mail: satish_lodha@rediffmail.com

requirement that one summer irrigation must be given restricts the adoption of this management strategy in most of this region, where legume cultivation is dependent only on the limited amount of rainfall. Moisture conservation practices such as mulching with plant stover, lower plant density, or amending soil with farmyard manure or with composts, have been advocated for managing *Macrophomina* in these arid regions (Lodha, 1996; Lodha *et al*., 2002).

Composts have been used with varying levels of success to suppress many soil-borne plant pathogens and the diseases they cause (La Mondia *et al*., 1999; Litterick *et al*., 2004). The disease suppressive properties of composts rely on a number of factors, including microbial activity, microbial population dynamics, nutrient concentrations and other associated chemical and physical factors (Bulluck and Ristaino, 2002; Noble and Coventry, 2005). It is suggested that compost enhances the activity of the micro-organisms introduced with the composts and stimulates those micro-organisms already resident in the soil (Lumsden *et al*., 1983). High levels of microbial activity in composts were postulated as the primary factor in disease control (Craft and Nelson, 1996). In a case of "specific suppression", a narrow group of micro-organisms eradicated sclerotia of *Rhizoctonia solani* (Hoitink *et al*., 2001). At least 20% of the bacterial strains isolated from the rhizosphere of cucumber sown in potting mix amended with composted pine bark controlled Pythium damping off when applied to cucumber as seed treatment (Boehm *et al*., 1993). Nothing is known about the relationship between microbial population dynamics, microbial activity and *Macrophomina* induced diseases.

Since livestock husbandry is an integral part of arid farming systems, providing sustenance to the resource-deficient desert inhabitants, much of the crop residues has to be utilized for livestock feeding. The compost to be used for the study therefore had to include only those on-farm wastes that did not need to be used as fodder. In this paper, five composts were studied to determine their capacity to suppress *M. phaseolina*-induced charcoal rot of cowpea as well as their relation to the microbial population and activity, CO_2 evolution and the available micronutrients. The effectiveness of these composts in improving the seed yield of rain-fed cultivated cowpea was also assessed.

Materials and methods

Experimental site

The experiments were conducted at the Central Arid Zone Research Institute, Jodhpur (Rajasthan, India). The loamy sand soil used for the experiments had 85.0% sand, 8.9% clay, 5.5% silt, 0.031% total nitrogen, 0.25% organic carbon, 9 ppm available phosphorus, pH 8.1, electrical conductivity 0.88 dSm^{-1}, a bulk density 1.56 g cm^{-3} and a moisture holding capacity (MHC) of 10.4%.

Composts preparation

Five composts were prepared in separate pits (1×1×0.75 m) under partially aerobic conditions, adopting the Indore method (Howard and Ward, 1931). The composted plants are abundant in the region as on-farm wastes and are known to possess biopesticidal properties (Mawar and Lodha, 2006). The composts consisted of twigs of 1, *Calotropis procera* (Aiton) W.T. Aiton; 2, *Prosopis juliflora* (Swartz) DC; 3, neem (*Azadirachta indica* A. Juss.); 4, *Acacia nilotica* (L.) Willd ex. Del.; and 5, complete plants of the weeds *Aerva persica* Merr., *Celosia argentea* L., *Euphorbia hirta* L., and *Heliotropium subulatum* Hochst ex DC collected and cut up into small pieces (1–1.5 cm), since these are more accessible for initial microbial attack (Tarafdar *et al*., 2001). The five composts were placed in individual pits in December. Each pit received four 30 cm layers of compost. Each compost layer in each pit was enriched with 1% gypsum and 2% urea and covered with a 10 cm layer of 2-month-old cow dung. The cow dung compressed the residues of each layer, so that approximately 40% of the volume in each pit was occupied by cow dung. About 60% moisture (w:w) was maintained by adding 6–10 L of water at intervals of 7 to 10 days. Two turnings were given at intervals of 2 months. Mature composts were ready by June after about 6 months. Fresh composts were prepared for each year of the study.

Carbon, nitrogen and phosphorus estimation

A 250 mg finely ground sample of each compost was weighed in a 500 mL conical flask. Twenty-five mL of 1N $K_2Cr_2O_7$ and 25 mL of concentrated H_2SO_4 were added in that order. The mixture was allowed to cool for an hour, after which 200 mL of distilled water was added. The $K_2Cr_2O_7$ reacted with H_2SO_4, producing nascent O_2 which oxidized the soil organic carbon. The volume of $K_2Cr_2O_7$ added was always greater than that required for complete oxidation of the carbon present in the samples. The amount of unused $K_2Cr_2O_7$ was calculated by titrating it with 0.5 N ferrous ammonium sulphate using diphenyl amine as an indicator while the remainder was used to estimate C (Black, 1965). To estimate the nitrogen, 0.5 g of each compost was weighed in a Kjeldahl digestion tube and 35 mL of concentrated H_2SO_4 plus the digestion mixture (K_2SO_4+$CuSO_4$+Se) was added. The contents were digested at 400ºC. After digestion, the contents were allowed to cool and then diluted to 250 mL. Nitrogen was estimated using a flow injection analyzer FIAStar–5010. For phosphorus estimation, 0.5 g of each compost was digested using 10 mL of a triacid mixture H_2SO_4:HNO_3:$HClO_4$ (9:3:1). After digestion, the contents were diluted to 50 mL, filtered through Whatman filter paper No. 42 and the final volume was brought to 100 mL. Then, 10 mL of the filtrate was pipetted into 50 mL volumetric flasks and 10 mL of ammonium molybdate was added. The contents were diluted to approximately 40 mL and colored blue with stannous chloride. The intensity of the color was estimated with of a UV-Vis spectrophotometer at 660 nm. The amount of phosphorus was calculated by plotting the absorbance of the samples against the standard phosphorus solution.

Crop raising

The five composts and farmyard manure (FYM) were separately incorporated into the soil at the rate of 4 ton ha^{-1} to a depth of 30 cm and uniformly mixed with a hand spade in 4×3 m plots at the end of June each year. Plots without any organic amendment or chemical fertilizer served as control. All the treatments were arranged in a fixed layout using a completely randomized block design with three replicates in 2001 and 2003. Cowpea (cv. CAZC 10) seeds were planted on July 13, 2001 and July 12, 2003. Composts were not added to the soil and crops were not raised in 2002 due to a severe drought (total annual rainfall 35 mm).

At the time of planting in 2001, 12 soil samples were randomly collected at a depth of 0–30-cm from each experimental block using a tubular probe (2.5 diam.) to estimate the population of total fungi, bacteria and actinomycetes. Three Petri dishes per sample were used to estimate each group of microbes and their average was taken to be the initial population of the experimental field. During crop growth, two soil sub-samples were collected every 20 days, beginning 20 days after planting (DAP), until harvest, from the same depth at each plot. These two sub-samples were pooled to form one composite sample. Half of the sample was used to determine the soil moisture by the gravimetric method; the other half was used to estimate the total microbial population and microbial activity by methods described elsewhere. CO_2 evolved from soil was estimated by trapping in 4N KOH. A tube containing 10 mL 4N KOH was inserted in the soil at each plot and was covered with a polythene chamber of 1 L headspace (Anderson and Ingram, 1993). The open end of the chamber, having an area of 75.46 cm^2, was inserted 2.5 cm depth into the soil. Tubes were removed every week and replaced with fresh tubes also containing 10 mL KOH. The KOH in the tubes removed from the field was transferred to a 250-mL beaker and 1 g $BaCl_2$ was added. The amount of unused KOH was estimated by titrating with 1N HCl using phenolphthalein as an indicator. CO_2 was calculated from the amount of KOH consumed (Black, 1965).

Four entire plants of cowpea per plot were gently uprooted 45 DAP, washed in running tap water, dried carefully and cut at the junction of root and shoot after which they were weighed. Their length was measured and nodules were counted. Plant mortality due to charcoal rot was also recorded from the initiation of the disease and every week thereafter until harvest.

Biological assays

The soil samples were air-dried soon after collection and ground to pass through a 2 mm sieve for the quantitative estimation of the microbes. Total fungi were enumerated by serial dilutions on Martin's rose-bengal agar, total bacteria on soil extract agar and total actinomycetes on Ken-knight agar. Six Petri dishes of each medium/sample were used to enumerate each microbial category. The number of colony forming units (CFUs) was measured after incubating the plates for 6 days at 30±1°C.

Dehydrogenase activity, a measure of soil microbial activity, was determined following Tabatabai (1982). One g of soil from each replicate of each treatment was placed in a clean, dry screw-capped borosilicate tube and 0.2 mL of a 3% (w:v) 2, 3, 5-triphenyl tetrazolium chloride (TTC) solution+0.5 mL of a 1% (w:v) glucose solution was added. The contents were mixed thoroughly, the tubes tightly capped and incubated at 30±1°C for 24 h. After incubation, 10 mL methanol was added to each tube and mixed thoroughly for 1 min. The tubes were kept at 4°C for 3 h. The intensity of the color was measured at 485 nm using a Systronics spectrophotometer (UV-Visible, model 118). The amount of triphenyl formazan (TPF) was computed from the standard curve drawn by taking 1–10 ppm TPF in methanol. Dehydrogenase activity was expressed in picokats as the amount of enzyme required to hydrolyze 1 p mole of TTC s^{-1} g^{-1} soil. The soil or compost samples were analyzed in triplicate for each replicate of all the treatments.

Micronutrient estimation

A 5 g sample of each compost was shaken with a 10 mL solution of DTPA (0.005 M) containing TEA (0.1 M) and calcium chloride (0.01 N) for 2 h and filtered through Whatman filter paper No. 42. Micronutrients (Cu, Fe, Zn and Mn) were estimated using an atomic absorption spectrophotometer (GBC-932 AAS). A day before harvesting, three cowpea plants from each replicate of all the treatments were uprooted, dried at 70°C to a constant weight, ground and subjected to tri-acid digestion for the estimation of Cu, Fe, Zn and Mn following Lindsay and Norvell (1978). Ground plant material weighing 0.5 g was placed in dry digester tubes and concentrated HNO_3 (9 mL), H_2SO_4 (2 mL) and $HClO_4$ (1 mL) was added. The contents were digested at 100°C until the solution was clear; then it was cooled, diluted with distilled water, filtered through Whatmann No.1 filter paper and the final volume made up to 50 mL with distilled water. Micronutrients were estimated from the digested samples using an atomic absorption spectrophotometer calibrated with standard solutions (Fluka A.G., Hannover, Germany) made from pure metals. The results were expressed on an oven dry basis.

After the cowpea harvest in 2003, three soil sub-samples were randomly collected at a depth of 0–30 cm from each plot and bulked. Forty mL DTPA extracting solution each was added to 150 mL conical flasks each containing 20 g of soil. The suspension was kept on a shaker for 2 h, then filtered, and the amount of the above micronutrients estimated.

Statistical analysis

The growth parameters, percent plant mortality due to dry root rot, seed yield and micronutrients were subjected to analysis of variance (ANOVA) and the treatment means were compared by LSD ($P \leq 0.05$) separately for each year. Percent mortality was converted to angular transformed values before analysis for each year while the populations of total bacteria, actinomycetes and fungi for 2001 were transformed to a log scale [log (x+1)]. These populations and the data on microbial activity were subjected to analysis in a two-factor factorial design. Composts were considered one factor and the interval as the second factor. Standard deviations or errors were calculated for soil moisture content and micronutrients in cow pea plants. The correlation coefficients were calculated between variables such as microbial population, microbial activity and disease incidence in order to study the relation between these factors (Snedecor and Cochran, 1967).

Table 1. Compost characteristics.

Compost	Carbon (%)	Nitrogen (%)	Phosphorus (%)	pH	Fungi (10^4 g^{-1})	Bacteria (10^7 g^{-1})	Actinomycetes (10^7 g^{-1})
Calotropis procera	16.74	0.63	0.008	9.0	5.7	6.12	10.51
Prosopis juliflora	19.05	0.56	0.013	8.5	11.5	13.75	5.75
Weeds	21.07	0.49	0.011	8.8	4.9	2.14	7.01
Azadirachta indica	16.45	0.57	0.012	8.4	5.5	6.66	4.33
Acacia nilotica	16.74	0.70	0.014	8.3	3.8	10.20	15.67

Table 2. Soil moisture content (mm)[a] in compost amended and unamended plots in a cowpea field during the 2001 crop season.

Amendment	Days after planting			
	0	20	40	60
Calotropis procera	33.7±0.9	18.2±0.3	17.9±0.2	8.3±0.6
Prosopis juliflora	35.3±0.4	17.1±0.1	20.6±0.3	9.3±0.4
Weeds	32.2±0.4	17.9±0.3	18.9±0.3	10.3±0.2
Azadirachta indica	29.7±0.2	11.9±0.2	17.9±0.6	8.6±0.2
Acacia nilotica	30.7±0.2	19.2±0.4	18.8±0.4	7.8±0.6
Farm yard manure	30.4±0.2	19.6±0.4	22.5±0.3	6.7±0.3
Non-amended soil	29.4±0.3	20.2±0.4	20.1±0.5	5.2±0.2

[a] Determined gravimetrically; crop was harvested 65 days after planting.

Results

Chemical composition of composts

The highest carbon content in the composts was found in the weed compost, while nitrogen and phosphorus were highest in the *A. nilotica* compost (Table 1).

Soil moisture

At the time of planting, amended plots generally held more soil moisture (30.4–35.3 mm) than the corresponding unamended plots (29.4 mm), the maximum soil moisture being in *P. juliflora* compost-amended soil. There was a great variation in the treatment plots at 20 DAP, when soil moisture ranged from 11.9 to 9.6 mm in amended plots, with the maximum being with FYM amended soil and the minimum in neem compost-amended soil, compared with 20.2 mm in the unamended control (Table 2). At 40 DAP, the soil moisture did not differ between treatments, but FYM amended plots again held the maximum soil moisture. At the fourth sampling date, which coincided with the maturity of cowpea, all the amended plots held more soil moisture than the unamended control.

Microbial population

At the time of planting, the total fungal population was significantly (P=0.05) greater in the compost-amended plots than in the FYM-amended and unamended plots (Figure 1). A general decline in the fungal population was detected at 20 and 40 DAP, except in *Calotropis* compost-amended soil where the fungal population increased at 40 DAP. At 60 DAP, the amended plots had greater fungal counts than the control. At this date,the actinomycetes population generally was significantly higher in amended plots than in the unamended control, but at subsequent sampling dates it flucated, with no consistent trend (Figure 1). At 60 DAP, only *A. nilotica* compost-amended soil had significantly higher counts of actinomycetes than the control. Total bacterial counts were greatest in the control at the first sampling date (Figure 1). At 20 DAP, though bacterial counts declined with all amendments, except *A. nilotica*, all the amended plots still had significantly higher bacterial counts than the control. There was a sharp increase in the soil bacterial population at 40 DAP with all the composts except *Calotropis*. However, at 60 DAP the maximum bacterial counts were in the weed-amended and *P. juliflora* compost-amended plots.

Microbial activity

Dehydrogenase activity increased soon after the addition of the various composts to the soil, as compared with unamended soil, the maximum activity being in *Calotropis* compost-amended soil (Figure 2). Microbial activity increased with all treatments at the first sampling date, but significantly (P<0.05) greater activity was estimated in the *Calotropis* and weed compost-amended soil than in the other amended soils. Microbial activity declined at DAP 20 in the *Calotropis, P. juliflora* and weed-compost amended soil, but increased significantly with the other amendments, including

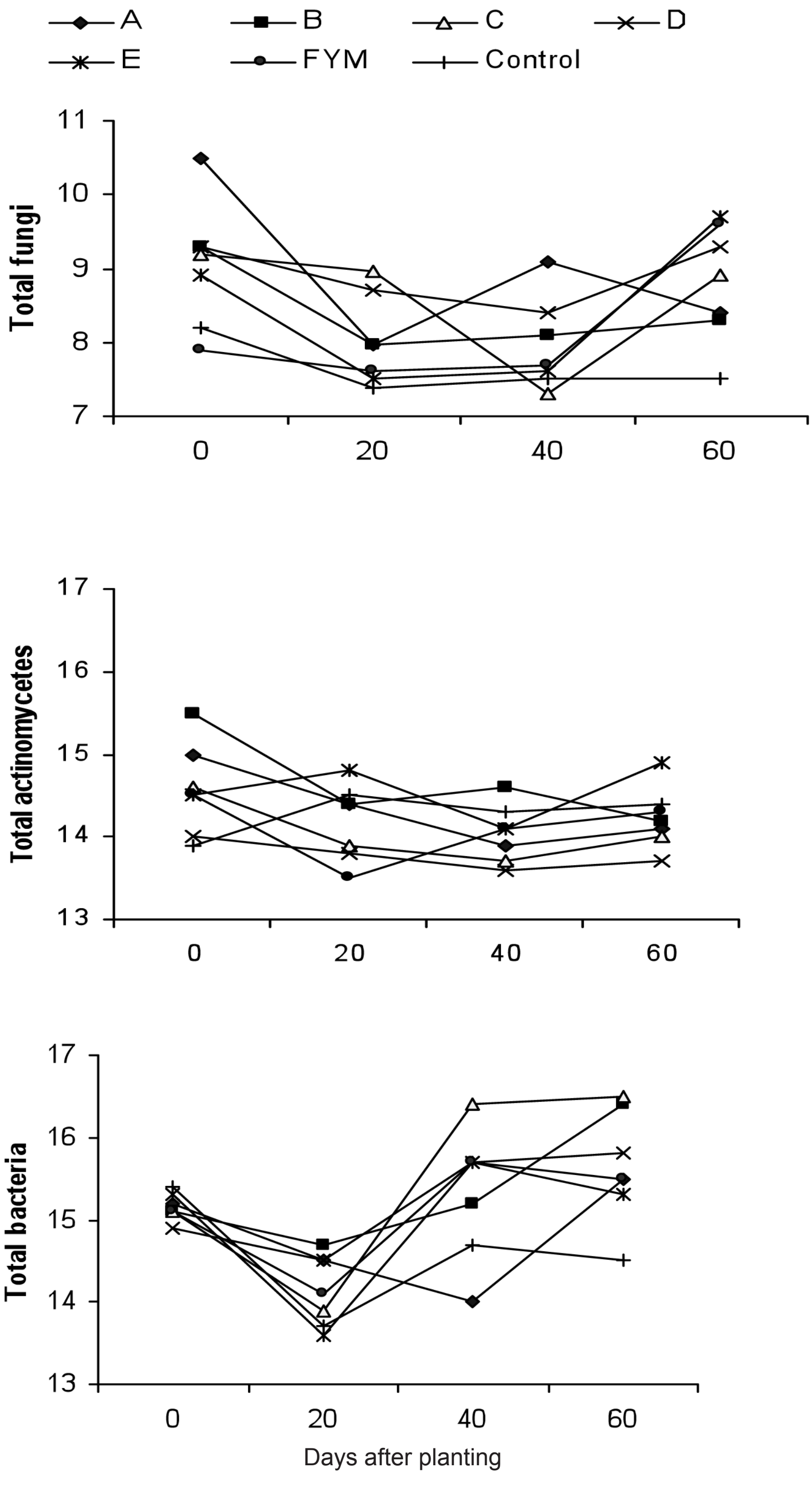

Figure 1. Influence of compost amendments on total fungi, actinomycetes and bacterial population ($\log_n$ cfu g^{-1} soil) at 30 cm soil depth in cowpea planted plots in 2001. [A, *Calotropis procera*; B, *Prosopis juliflora*; C, weeds; D, *Azadirachta indica* and E, *Acacia nilotica*]. LSD (P=0.05) of treatment (fungi, 0.31; actinomycetes, 0.12; bacteria, 0.09) and interval (fungi. 0.23; actinomycetes, 0.09; bacteria, 0.07).

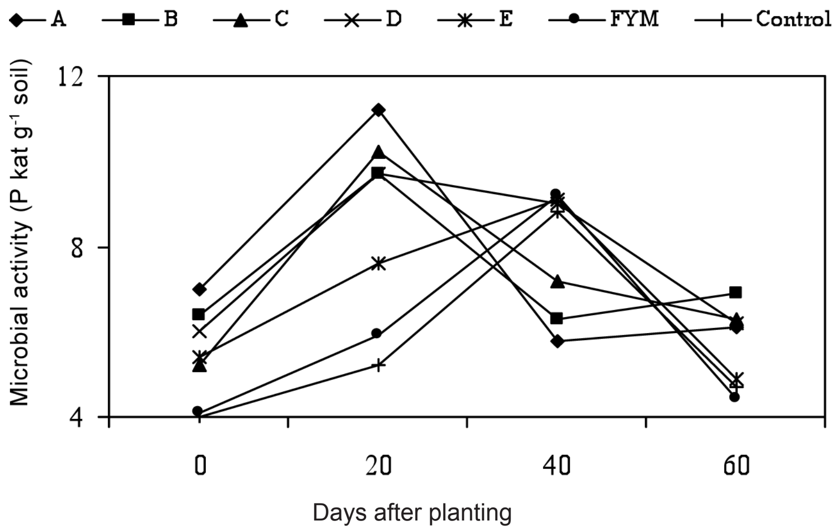

Figure 2. Microbial activity (dehydrogenase assay) at various sampling dates in field soil amended with composts and planted with cowpea in 2001. [A, *Calotropis procera*; B, *Prosopis juliflora*; C, weeds; D, *Azadirachta indica* and E, *Acacia nilotica*]. LSD (P=0.05) of treatment (0.37) and interval (0.28).

the unamended control (Figure 2). At the third and the last sampling dates, microbial activity decline sharply in both amended and unamended soil, except *Calotropis* and *P. juliflora* compost-amended soil, where it increased. On the basis of the pooled average, microbial activity, at different growth stages of the crop was greatest in neem and *Calotropis*-amended soil followed by *P. juliflora*-amended soil, while the lowest activity was in unamended soil. CO_2 evolution was lowest (168 mg C cm^{-2}) in the control plots and highest (281.6 mg C cm^{-2}) in the FYM -amended plots (Figure 3). Among the composts, CO_2 evolution was greatest with neem compost and lowest with *Calotropis*. The value of CO_2 evolution peaked in the 3rd week in all the amended and in the unamended plots but than declined gradually up to the 6th week. At this point, it was greatest in the control plots (137.7 mg C cm^2) and less in the *A. nilotica* –amended plots (69.6 mg C cm^{-2}). In the 7th week CO_2

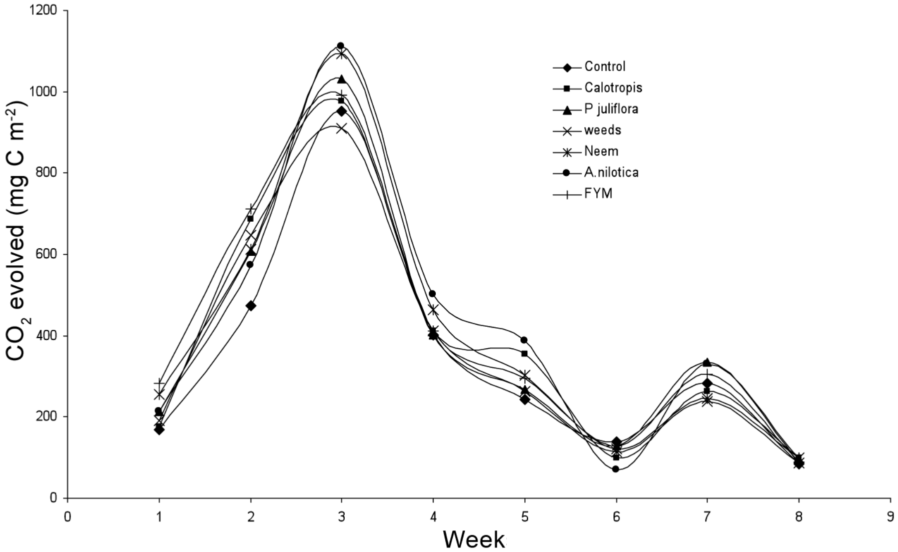

Figure 3. Carbon dioxide evolution from compost amended (*Calotropis procera*, *Prosopis juliflora*, weeds, *Azadirachta indica* and *Acacia nilotica*) and unamended plots at various sampling dates.

Table 3. Effect of compost-amendments on some growth parameters of cowpea (2001).

Amendment[a]	Nodules (No.)	Root			Shoot		
		Length wt. (cm)	Fresh wt. (g)	Dry wt. (g)	Length wt. (cm)	Fresh wt. (g)	Dry wt. (g)
Calotropis procera	15	32	2.01	0.81	69	49	11.6
Prosopis juliflora	12	33	3.44	1.13	93	91	14.9
Weeds	20	24	2.09	0.75	63	55	11.0
Azadirachta indica	19	33	4.16	1.32	85	91	15.5
Acacia nilotica	13	32	3.38	1.01	105	89	16.6
Farm yard manure	22	30	2.63	0.95	92	63	12.2
Unamended control	10	32	3.46	1.05	76	85	14.9
LSD (*P*=0.05)	10	5	0.74	0.36	15	7.0	2.3

[a]Composts or FYM amended at 4 t ha^{-1}; plants uprooted 45 days after planting.

evolution then significantly increased again, and declined thereafter. Differences in CO_2 evolution between the compost amendments gradually tapered off until the 8th week. In general, CO_2 evolution followed a biphasic pattern with a peak on the 3rd week and a second peek in the 7th week (Figure 3). CO_2 production in the 8th week was highest in *A. nilotica*-compost amended soil. Oxidizable C content was greatest in FYM-amended soil (35.2%), followed by soil amended with weeds (21.1%), *P. juliflora* (19%), *A. nilotica* (16.7%) and *Calotropis* compost (16.7%) and it was lowest in neem- amended soil. As regards, the decomposability of the residues, in terms of total $CO_{2,}$ C evolved as percent of total C added showing that residues of *A. nilotica* decomposed most rapidly, followed by those of neem and *Calotropis*.

There was a significant inverse correlation between microbial activity and percent plant mortality (r= -0.52, *P*±0.05) at 20 DAP from dry root rot. At all other sampling intervals, the inverse correlation between microbial activity and disease level was not significant. Microbial activity was significantly correlated with the total number of fungi (r=0.56) and with the total bacterial counts (r=0.62). However, at 40 DAP, microbial activity was negatively correlated (r=-0.50) with the fungal population. At the fourth sampling date, the total bacterial population and microbial activity (r=0.76) were positively correlated in both the amended and unamended plots.

Plant growth

Cowpea plants grown in amended soil had more nodules than plants in unamended soil. Most nodules occurred in FYM amended soil, but in *P. juliflora* and *A. nilotica* compost-amended soil the number of nodules did not differ significantly from the control (Table 3). Root length did not differ significantly between amended and unamended soil, but was significantly less in weed compost-amended plots. There was no consistent trend in the fresh and dry weight of roots between amended and unamended soil (Table 3). Shoot length was greater in all amended plots except those amended with *Calotropis* and with weed compost, but only *P. juliflora, A. nilotica* and FYM- amended plots shoot length differed significantly from unamended plots. Fresh and dry shoot weights, did not exhibit a consistent trend in either amended or unamended plots.

Disease incidence and seed yield

All soil amendments significantly reduced plant mortality from charcoal rot as compared with the unamended control in both years of the field experiment (Table 4). The reduction in the incidence of charcoal rot ranged from 26.1 to 65.7%. In 2001,

Table 4. Effect of compost-amendments on severity of dry root rot and seed yield of cowpea. Values are mean of three replicates.

Amendment[a]	Dry root rot mortality (%)		Seed yield (kg ha^{-1})	
	2001	2003	2001	2003
Calotropis procera	7.5 (15.85)[b]	5.0 (12.72)	683	1028
Prosopis juliflora	7.9 (16.28)	3.8 (11.04)	806	1101
Weeds	8.4 (16.82)	6.1 (14.03)	734	1012
Azadirachta indica	4.6 (12.36)	8.2 (16.29)	701	968
Acacia nilotica	5.9 (14.02)	5.2 (12.83)	775	960
Farm yard manure	8.5 (16.98)	6.5 (14.78)	729	961
Unamended soil	11.9 (20.14)	11.1 (18.97)	588	897
LSD (P=0.05)	2.27	3.36	37	70

[a] Composts or FYM amended at 4 t ha^{-1} .
[b] Angular transformed values.

plant mortality from charcoal rot was lowest in plots amended with neem, and was significantly higher (P= 0.05) with all the other composts except *A. nilotica*, which was also low. However, in the second season, all amendments significantly reduced plant mortality compared to the control, except neem. In that season, the lowest plant mortality (3.8%) from charcoal rot occurred in plots amended with *P. juliflora*. In general, however, *A. nilotica* compost most consistently reduced plant mortality in both years of the study.

All the amendments significantly improved seed yield of cowpea in both years, except *A. nilotica* and FYM in 2003 (Table 4). The maximum seed yield was obtained in the *P. juliflora* compost-amended plots in both years, and the increase in yield was significantly greater with this than with any other compost except *A. nilotica* in 2001. In both years, seed yield increase by 22.7–37.1% in *P. juliflora* compost-amended plots as compared with the unamended plot.

Micronutrients in plants and soil

Contents of Cu, Fe, and Mn were heighest in plants grown in weed compost-amended soil, while the Zn content was highest in *P. juliflora* amended

Table 5. Micronutrients (ppm)[a] in compost-amended and unamended soil and cowpea plants after harvest in 2003.

Amendment	Cu	Fe	Zn	Mn
Calotropis procera	2.14 d	5.22 f	0.62 c	10.08 f
	99	238	36	47
Prosopis juliflora	2.30 c	7.62 d	0.52 d	13.10 c
	101	218	44	56
Weeds	2.52 a	8.32 b	0.80 ab	14.42 a
	103	287	35	64
Azadirachta indica	2.32 c	7.58 d	0.64 c	12.13 e
	102	205	38	53
Acacia nilotica	2.40 b	8.72 a	0.80 ab	13.16 b
	98	256	37	62
Farm yard manure	2.44 b	7.84 c	0.86 a	12.72 d
	99	196	36	37
Unamended soil	2.40 b	5.84 e	0.76 b	9.76 g
	92	208	40	56

[a] Values are the mean of three replicates. For each parameter, values in the same column followed by an identical letter are not significantly different according to Fisher's LSD test (P≥0.05). Standard Error Cu=3.6; Fe=32.6; Zn=3.1; Mn=9.1.

soil (Table 5). Interestingly, the Zn content was lower in plants grown in weed compost-amended soil. There was great variation in the Mn content between plants grown in amended soil and plants grown in unamended soil. Overall, the uptake of nutrients was greatest in plants grown in weed-amended soil followed by plants grown in *A. nilotica* compost-amended soil.

After two successive crops of cowpea, the maximum contents of Cu and Mn occurred in weed compost-amended soil, while contents of Fe was heighest in *A. nilotica* -amended soil, and Zn was heighest in FYM amended soil (Table 5). In general, Zn levels remained lower (0.52–0.86 ppm) and Mn levels higher (9.76–14.42 ppm) in both amended and unamended soils after harvest of the cowpea crop.

Discussion

Compost amendments in nutrient deficient sandy soil not only lowered charcoal rot incidence but also increased the seed yield of cowpea. There were however considerable variations depending on the type of compost used.

Soil moisture was greater in compost-amended than in unamended plots, benefiting crop growth. The greater soil moisture, in our study increased the native bacterial population and decreased the total fungi. It may also have reduced the population of *M. phaseolina*. It is well documented that adequate soil moisture favours the antagonistic role of some soil bacteria, thus reducing the sclerotial population of *M. phaseolina* (Dhingra and Sinclair, 1975; Lodha, 1996). The increase in the actinomycetes population in compost-amended soil that was observed in the present study was also reported by Lodha *et al.* (2002). In addition, higher levels of some micronutrients are important not only for plant growth, but also for enhancing resistance against some soil-borne diseases (Engelhard, 1989).

The better nodulation with the soil amendments could be a consequence of the higher levels of soil moisture and nutrients. These factors and the greater population of beneficial microbes may explain the better growth of cowpea in *P. juliflora* compost-amended soil. Differences in the growth parameters of cowpea with the various composts can be ascribed to differences in the biological and chemical properties of the composts (Widmer *et al.*, 1998; Abbasi *et al.*, 2002).

In our experiment, the significant increase in microbial activity in the composted soil, compared with the unamended soil, reflected the greater microbial population and biomass. Microbial activity and charcoal rot incidence were inversely correlated only at 20 DAP, which indicated that *M. phaseolina* infected the seedlings either at this stage or just before, but that it was not expressed until late in the season. In earlier studies, the maximum inoculum build-up of *M. phaseolina* and plant mortality from charcoal rot were recorded when cowpea seedlings became infected at 15 DAP (Singh and Lodha, 1986). A number of studies have reported that microbial activity and microbial biomass are the main predictors of disease suppressiveness, where an inverse correlation exists (Boehm and Hoitink, 1992; You and Sivasithamparam, 1995).

Composts in the soil may warsen, alleviate or leave unaffected diseases caused by soil-borne pathogens (Hoitink and Fahy, 1986; Rotenberg *et al.*, 2007; Chen and Nelson, 2008). In the present study, the suppression of charcoal rot in cowpea by adding compost to the soil could have been due to the following factors: 1. better physical structures in the soil improving aeration of the roots; 2. higher levels of the total microbial population including antagonists that prevented *M. phaseolina* from infecting the roots; 3. improved moisture-holding capacity of the soil that reduced the amount of pathogenic propagules of *M. phaseolina* and hence the disease; and 4. biological factors in compost-amended soil that increased nitrogenase activity, resulting in vigorous plants more resistant to the pathogen. The lower mortality from dry root rot in *A. nilotica* compost-amended plots can also be partly attributed to the greater decomposability of this compost, as shown by its CO_2 evolution

Antagonistic micro-organisms such as *Trichoderma harzianum, Aspergillus versicolor* and *Bacillus* spp. may also have contributed to lowering the disease incidence. However, the actual mechanism of disease suppression was not addressed in our study. One possible biological mechanism in which disease can be suppressed is by stimulating tha germination of sclerotia with the subsequent lysis of the germ-tubes in the soil (Papavizas and Lumsden, 1980). The germination of *M. phaseolina* is stimulated by amendments (Smith, 1969), and the germ-tube and hyphae are sensitive to bacteria and actinomycetes, leading to the lysis of the fungal cell walls (Kovoor, 1954). Since the compost-amended soil of our field experiments held more soil moisture, the high population of antagonists estimated in the final compost samples may have accelerated the antagonism against *M. phaseolina* in a wet soil.

The higher seed yield with all the compost-amendments may be the combined effect of increased soil moisture, a greater availability of nutrients, qualitative and quantitative improvements in microbiological properties, a greater microbial activity and a lower disease incidence. The beneficial effect of compost amendment in reducing disease incidence and increasing seed yield has been well documented for sunflower, tomato and clusterbean (Allievi *et al.*, 1993; Lodha *et al.*, 2002). The improved seed yield of cowpea in 2003 compared to 2001 is mainly attributed to the amount and the distribution of rainfall. In 2001, four well-distributed rain events (254 mm) occurred during the vegetative and the flowering stage, but no significant rain events occurred after that leading to severe moisture stress at the pod formation stage and onwards till maturity. In 2003, on the other hand, there were six good and uniformly distributed rain events (282 mm) up till the pod formation stage, so that the crop did not experience any moisture stress untill after seed formation.

The superiority of *P. juliflora* compost in charcoal rot suppression can have a number of causes: 1. because it increased the microbial population; 2. because it increased microbial activity; and/or 3. because it produced high level of sugars and growth hormones such as triacontanol (Santos and Pereira, 1988; Khan *et al.*, 1992). Since in an earlier study (Lodha *et al.*, 1999), *Prosopis* pods were found to promote growth of *T. harzianum* more than did other synthetic or non-synthetic media. it can not be ruled out that *P. juliflora* compost in the soil also increased the population of *T. harzianum* in the present study.

Prosopis juliflora (Mesquite) is an abundant shrub in the arid regions of India and in agricultural lands that is posing a threat to the cultivation of a number of crops. Its utilization as a compost, even when prepared by the growers themselves, can help in the sanitation of agricultural fields. Similarly, *Calotropis,* neem and *A. tortilis* are abundant in the Indian arid region and also possess anti-fungal properties. The use of on- and off-season weeds for composts has an additional advantage for nutrient deficient sandy soil. Most of the weeds, used for compost reduce *M. phaseolina* propagules and charcoal root rot incidence as well as enhancing the population of antagonistic actinomycetes (Mawar and Lodha, 2006).

In summary, soil amendment with composts prepared from on-farm wastes can be a practical strategy to manage charcoal rot of cowpea and other legumes grown under rainfed conditions. In the resource-deficient farming of the arid regions, compost can be beneficial as an integral part of low external input sustainable agriculture (LEISA) and can also be a cost effective and natural way of improving the fertility of sandy soils.

Literature cited

Abbasi P.A., J. Al-Dahmani F. Sahin, H.A.J. Hoitink and S.A. Miller, 2002. Effect of compost amendments on disease severity and yield of tomato in organic and conventional production systems. *Plant Disease* 86, 156–161.

Allievi L., A. Marchesini, C. Salardi, V. Piano and A. Ferrari, 1993. Plant quality and soil residual fertility six years after a compost treatment. *Bioresource Technology* 43, 85–89.

Anderson J.M. and J.S.I. Ingram, 1993. *Tropical Soil Biology and Fertility; a Handbook of Methods*, CAB International, Wallingford, UK, 221 pp.

Black, C.A., 1965. *Methods of Soil Analysis – Part 2 Chemical and Microbiological Properties*. American Society of Agronomy, Madison, WI., USA, 1572 pp.

Boehm M.J. and H.A.J. Hoitink, 1992. Sustenance of microbial activity in potting mixes and its impact on severity of Pythium root rot of poinsettia. *Phytopathology* 82, 259–264.

Boehm M.J., L.V. Madden and H.A.J. Hoitink, 1993. Effect of organic matter decomposition level on bacterial species diversity and composition in relationship to Pythium damping-off severity. *Applied Environmental Microbiology* 59, 4171–4179.

Bulluck L.R. III and J.B. Ristaino, 2002. Effect of synthetic and organic soil fertility amendments on southern blight, soil microbial communities, and yield of processing tomatoes. *Phytopathology* 92, 181–189.

Chen M-H. and E.B. Nelson.2008. Seed-colonizing microbes from municipal biosolids compost suppress *Pythium ultimum* damping-off on different plant species. *Phytopathology* 98, 1012–1018.

Craft C.M. and E.B. Nelson, 1996. Microbial properties of composts that suppress damping-off and root rot of creeping bentgrass caused by *Pythium graminicola*. *Applied Environmental Biology* 62, 1550–1557.

Dhingra O.D. and J.B. Sinclair, 1975. Survival of *Macrophomina phaseolina* sclerotia in soil: effects of soil moisture, carbon: nitrogen ratios, carbon sources and

nitrogen concentrations. *Phytopathology* 65, 236–240.
Engelhard A.W., 1989. Historical highlights and prospects for the future. In: *Management of Diseases with Macro and Microelements* (A.W. Engelhard, ed.), The American Phytopathological Society, St. Paul, MN, USA, 9–17.
Hoitink H.A.J. and P.C. Fahy, 1986. Basis for the control of soilborne plant pathogens with composts. *Annual Review of Plant Pathology* 24, 93–114.
Hoitink H.A.J., M.S. Krause and D.Y.Han, 2001. Spectrum and mechanisms of plant disease control with composts. In: *Compost Utilization in Horticultural Cropping Systems*. (P.J. Stofella, B.A.Kahn, ed.), Lewis Publishers, Boca Raton, FL, USA, 263–273.
Howard A. and Y.D. Ward, 1931. *The Waste Products of Agriculture and their Utilization as Humus*. Oxford University Press, London, UK 167 pp.
Khan H.A., V. Lodha and A. Ghanim, 1992. Triacontanol from leaves of *Prosopis cineraria* and *Prosopis juliflora*. *Transactions of Indian the Society of Desert Technology* 17, 29–32.
Kovoor A.T.A., 1954. Some factors affecting the growth of *Rhizoctonia bataticola* in soil. *Journal of Madras University* 24, 47–52.
LaMondia J.A., M.P.N. Gent, F.J. Ferrandino, W.H. Elmer and K.A. Stoner, 1999. Effect of compost amendment or straw mulch on potato early dying disease. *Plant Disease* 83, 361–366.
Lindsay W.L. and W.A. Norvell, 1978. Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* 42, 421–428.
Litterick A.M., L. Harrier, P. Wallace, C.A. Watson and M. Wood, 2004. The role of uncomposted materials, composts, manures, and compost extracts in reducing pest and disease incidence and severity in sustainable temperate agricultural and horticultural crop production – a review. *Critical Reviews in Plant Sciences* 23, 453–479.
Lodha S., 1995. Soil solarization, summer irrigation and amendments for the control of *Fusarium oxysporum* f. sp. *cumini* and *Macrophomina phaseolina* in arid soils. *Crop Protection* 14, 215–219.
Lodha S., 1996. Influence of moisture conservation techniques on *Macrophomina phaseolina* population, dry root rot and yield of clusterbean. *Indian Phytopathology* 49, 342–349.
Lodha S., M.D. Bohra and L.N. Harsh, 1999. Evaluation of *Prosopis* pods as a source of carbohydrate for enhancing the growth of soil borne fungi. *Indian Phytopathology* 52, 24–27.
Lodha S., G.K. Gupta and S. Singh, 1986. Crop disease situation and some new records from Indian arid zone. *Annals of Arid Zone* 25, 311–320.
Lodha S., S.K. Sharma and R.K. Aggarwal, 2002. Inactivation of *Macrophomina phaseolina* propagules during composting and effect of composts on dry root rot severity and on seed yield of clusterbean. *European Journal of Plant Pathology* 108, 253–261.
Lumsden R.D., J.A. Lewis and P.D. Milner, 1983. Effect of composted sewage sludge on several soilborne pathogens and diseases. *Phytopathology* 73, 1543–1548.
Mawar R. and S. Lodha, 2002. *Brassica* amendments and summer irrigation for the control of *Macrophomina phaseolina* and *Fusarium oxysporum* f. sp. *cumini* in hot arid region. *Phytopathologia Mediterranea* 41, 45–54.
Mawar R. and S. Lodha, 2006. Relative efficacy of on-farm weeds as soil-amendment for managing dry root rot of cluster bean in an arid environment. *Phytopathologia Mediterranea* 45, 215–224.
Noble R. and E. Coventry, 2005. Suppression of soil-borne plant diseases with composts: a review. *Biocontrol Science and Technology* 15, 3–20.
Papavizas G.C. and R.D. Lumsden, 1980. Biological control of soilborne fungal propagules. *Annual Review of Phytopathology* 18, 389–413.
Rotenberg D., A.J. Wells, E.J. Chapman, A.E. Whitfield, R.M. Goodman and L.R. Copperband, 2007. Soil properties associated with organic matter–mediated suppression of bean root rot in field soil amended with fresh and composted paper mill residuals. *Soil Biology and Biochemistry* 39, 2936–2948.
Santos G.L.C. and M.S.V. Pereira, 1988. Utilization of *P. juliflora* as culture medium and as enriching source for phytopathogenic fungi culture. In: *The Current State of Knowledge on* Prosopis juliflora (M.A. Habit, J.C. Saavendra, ed.), FAO, Rome, Italy, 335–337.
Singh S. and S. Lodha, 1986. Varietal resistance of cowpea to *Macrophomina phaseolina* (Tassi.) Goid. causing dry root rot and its control. *Indian Journal of Agricultural Sciences* 56, 552–555.
Smith W.H., 1969. Germination of *Macrophomina phaseolina* sclerotia as affected by *Pinus lambertiana* root exudates. *Canadian Journal of Microbiology* 15, 1387–1391.
Snedecor G.E. and W.J. Cochran, 1967. *Statistical Methods*. Oxford & IBH Publishing Co., Calcutta, India, 258–298 pp.
Tabatabai M.A., 1982. Soil enzymes. In: *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. (A.L. Page, R.H. Miller, D.R. Keeney, ed.), Soil Science Society of America, Madison, WI, USA, 903–948.
Tarafdar, J.C., S.C. Meena and S. Kathju, 2001. Influence of straw size on activity and biomass of soil microorganisms during decomposition. *European Journal of Soil Biology* 37, 157–160.
Widmer T.L., J.H. Graham and J.D. Mitchell, 1998. Composted municipal waste reduces infection of citrus seedling by *Phytophthora nicotianae*. *Plant Disease* 82, 683–688.
You M.P. and K. Sivasithamparam, 1995. Changes in microbial populations of an avocado plantation mulch suppressive of *Phytophthora cinnamomi*. *Applied Soil Ecology* 2, 33–43.

Accepted for publication: November 23, 2010