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Microbial Decomposition of a Forest Leaf Litter as Influenced by Certain Edaphic Factors

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Microbial population, microbial activity and the rate of decomposition of leaf litter of a tropical dry mixed decidous forest of Varanasi, were studied in relation to temperature, moisture and pH. In general, 25% moisture content at 35 C and 6.5 pH were most suitable for microbial growth, microbial respiration and weight loss of the leaf litter. The highest fungal population but the least number of species was recorded at 50 C. Under water-logged condition a few fungi particularly *Aspergillus fumigatus* became dominant while others were suppressed. The number of fungal species was reduced at lower (10%) and higher (40%) moisture levels. A sizable increase in bacterial population was recorded under water-logged condition and at pH 8.5. The rate of CO2 evolution was high at 50 C during early sampling but declined sharply later on. The minimum weight loss of litter was recorded at 15 C under water-logged condition at pH 8.5.

Key Words Activity Growth Litter Microbe Respiration

Litter decomposition is influenced by a combination of environmental factors including physico-chemical properties of the substrate, the external environment and the organisms active under a particular substrate and environmental conditions (Daubenmire & Prusso, 1963; Williams & Gray, 1974; Meentemeyer, 1978). Witkamp (1966) obtained correlations of temperature with carbon dioxide evolution from forest floor. The influence of environmental factors i.e., temperature and water content on soil respiration has been demonstrated by Wildung *et al.* (1975), Bunnell *et al.* (1977a) and Edwards (1975). Meentemeyer (1978) suggested actual evapotranspiration (AET) as an index of the climatic forcing function (energy and moisture) of the specialized decomposers. DEcomposition of litter in relation to environmental factors has been studied by several workers (Witkamp & van der Drift, 1961; Witkamp, 1963, 1966; Wicklow & Moore, 1974; Pal & Broadbent, 1975). Witkamp (1966) demonstrated that microbial populations is influenced in decreasing order by temperature, moisture and age of litter.

A vast quantity of the leaf litter (70%) in the selected forest of Varanasi is decomposed in rainy season (Rai & Srivastava, 1982a). Change in environmental and substratal conditions due to variation in temperature, moisture and pH during this period is expected to exert some definite effect on litter decomposition on the forest floor. Therefore, a short term in vitro study was conducted to determine the microbial population and activity and the rate of decomposition of forest leaf litter as influenced by certain edaphic factors like temperature, moisture and pH.

MATERIALS & METHODS

Freshly fallen leaf litter of various tree species dominated by *Diospyros melanoxylon, Anogeissus latifolia and Ruchnania lanzen* was collected from 50 different spots in a dry deciduous forest floor of Chandraprabha sanctuary, Varanasi and brought to laboratory. Soil, beneath the litter, was also collected from the spots and brought to the laboratory after mixing the samples. Aluminium pots (30 cm diam, 20 cm height) were filled each with 2 kg of forest soil (ground and passed through 2 mm sieve) over which a quantity of 50 g air dried mixed leaf litter per pot was dispersed to study the following aspects.

Effects of Temperature, moisture and pH on microbial population and their activity in the leaf litter To assess the effect of temperature the pots were incubated at 15, 35 and 50 C. The pots were regularly supplied with adequate moisture (25-30%). To see the effect of moisture the pots were

Table 1 Effect of Temperature, Moisture and pH on Microbial Population of Decomposing Leaf Litter (Average Number g $^{-1}$ Dry Weight)

Treat-ment	Fungi (x 10^4)					Bacteria (x 10^4)					Actinomycetes (x 10^4)				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S 4	S5
Initial sampling			23.09				14.52					0.98			
Temperature (C)															
15	26.89	34.75	56.38	58.50	58.17	9.05	10.74	11.80	13.54	16.09	2.05	11.00	13.42	19.87	19.54
35	50.34	57.62	83.13	72.84	63.97	30.48	36.89	36.57	21.54	12.31	5.07	11.50	17.31	24.05	23.17
50	230.66	256.94	327.09	281.95	258.46	16.75	20.50	22.13	19.20	18.23	1.01	5.72	7.54	4.94	4.34
Moisture content (%)															
10	14.13	22.47	49.01	45.39	43.13	0.83	1.07	4.70	3.52	2.86	3.93	10.33	21.36	19.99	17.19
25	30.46	48.81	94.59	75.78	42.37	15.51	17.82	21.72	15.99	11.17	4.57	13.18	32.73	22.90	19.70
40	28.39	41.01	62.69	54.56	36.73	26.53	29.45	38.92	30.46	22.46	1.20	3.06	3.12	2.58	1.07
Water logging	67.06	89.47	111.93	158.62	197.96	2.75	58.55	75.96	133.78	181.53	0.98	0.73	0.55	0.51	0.40
pH															
4.5	25.82	45.96	86.10	74.25	61.05	4.71	4.78	6.30	7.95	9.01	0.99	1.06	1.93	2.16	2.82
6.5	24.16	49.75	80.70	71.91	66.92	11.26	15.82	17.54	15.02	11.21	4.43	10.39	23.22	26.38	22.99
8.5	23.62	26.87	35.60	33.82	30.78	23.64	28.70	19.96	16.49	8.66	1.08	1.53	2.75	2.91	2.54
Control†	37.21	53.75	79.20	65.21	58.95	16.35	19.30	19.26	11.75	4.31	4.73	11.90	28.58	25.53	24.02

S_1 = First sampling ; S_2 = Second sampling, S_3 = Third sampling, S_4 = Fourth sampling, S_5 = Fifth sampling.
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Table 2 Relative Abudance (per cent occurrence) of Important Fungal Species Isolated from Decomposing Leaf Litter Incubated at Different Temperature.

Species	I	S_1				S_2				S_3				S_4				S_5			
		C	T_1	T_2	T_3	C	T_1	T_2	T_3	C	T_1	T_2	T_3	C	T_1	T_2	T_3	C	T_1	T_2	T_3
Alternaria alternata	18	06	09	03	-	01	06	01	-	-	04	01	-	-	03	-	-	-	03	-	-
Aspergillus fumigatus	-	03	-	01	39	04	04	06	54	02	01	02	68	02	01	03	54	01	01	02	49
A. nidulans	-	-	-	07	55	-	-	06	20	01	01	07	26	01	01	09	42	02	01	09	46
A. niger	05	10	02	08	01	14	09	11	01	10	04	07	01	06	02	05	-	06	02	07	01
Curvularia lunata var aeri a	09	09	14	08	-	05	08	04	-	04	07	03	-	05	06	04	-	03	05	03	-
Pestalotia macrotricha	05	10	44	17	01	08	23	12	01	05	26	07	01	10	32	14	01	11	32	11	01
Phoma hibernica	15	11	04	10	-	08	07	06	01	08	07	07	02	04	01	04	-	02	-	03	-
Robillarde phragmiti s	-	-	-	-	-	03	02	01	-	06	03	01	-	06	03	01	-	12	06	05	-
Trichoderma viride	-	05	-	04	03	07	02	07	13	02	01	02	-	01	-	-	-	-	-	-	-
Dark sterile mycelium	11	03	06	01	-	01	05	-	-	01	04	-	-	-	06	-	-	01	08	-	-
White sterile mycelium	-	01	10	-	-	-	10	-	-	01	08	01	-	01	12	-	-	01	10	-	-
'other species'	37	42	11	41	01	49	24	46	10	60	34	62	02	64	33	60	03	61	32	60	03
Total number of species isolated	17	30	17	25	08	36	27	32	11	41	31	39	12	29	24	26	05	27	21	26	06

I Initial sampling, S1 - S5 , First - Fifth sampling:
C Control (room temperature), T_1 15° C, T_2 35° C, T_3 50° C.

Table 3. Relative Abundance (percent occurrence) of Important Fungal Species Isolated from Decomposing Leaf Litter at Different Moisture Levels

Species	S_1						S_2					S_3					S_4					S_5				
	I	C	1	2	3	4	C	1	2	3	4	C	1	2	3	4	C	1	2	3	4	C	1	2	3	4
Absidia repens	—	—	01	—	—	—	—	—	—	—	—	—	—	—	—	06	—	—	—	—	10	—	—	—	—	11
Acremonium furcatum	—		01	03	01	03	—	02	02	01	05	—	03	02	03	—	05	04	04	10	—	06	07	05	13	—
Alternaria alternata	18	06	03	03	01	—	01	—	01	01	—	—	—	—	01	—	—	—	—	—	—	—	—	—	—	—
Aspergillus flavus	04	03	01	02	03	—	02	—	04	09	—	04	09	04	13	01	03	04	04	17	01	03	03	02	13	—
A. fumigatus	—	03	03	02	08	78	04	02	04	13	74	02	01	02	08	68	02	03	02	16	64	01	02	02	16	61
A. luchuensis	—	01	01	02	03	—	03	02	03	02	—	08	11	06	07	02	06	08	05	03	01	05	03	06	01	01
A. nidulans	—	—	03	01	01	—	—	02	—	—	01	01	01	02	08	01	01	01	02	13	01	02	02	03	16	04
A. niger	05	10	14	05	04	06	14	22	09	04	02	10	17	06	15	01	06	11	05	06	01	06	12	05	07	—
A. sydowi	—	—	—	—	—	05	—	—	—	01	11	—	—	—	—	10	01	—	—	—	09	—	—	—	—	08
A. terreus	—	01	—	01	01	—	01	02	01	04	—	02	01	02	03	—	02	01	02	05	01	01	—	02	10	—
A. variecolor	03	02	03	03	12	01	02	01	01	05	01	02	02	03	05	—	02	02	03	08	—	01	02	02	06	—
Penicillium brevicompactum	—	01	01	06	11	—	—	—	01	02	—	—	—	01	—	—	—	—	02	—	—	—	—	01	—	—
Pestalotia macrotricha	05	10	06	05	06	—	08	09	09	07	—	05	07	06	08	—	11	10	09	09	—	11	17	10	12	—
Phoma hibernica	15	11	01	05	07	—	08	11	08	04	—	08	09	07	01	—	04	08	05	—	—	02	—	02	—	—
Robillarda phragmitis	—	—	—	03	—	—	03	01	03	—	—	06	02	04	—	—	06	05	06	—	—	12	08	06	—	—
Dark sterile mycelium	11	03	03	01	01	—	01	—	—	02	—	01	—	01	—	—	—	—	—	—	—	01	—	—	—	—
'Other species'	39	48	57	60	39	10	51	46	55	38	11	48	38	53	22	11	51	43	51	13	12	49	44	54	06	15
Total number of species isolated	17	30	28	40	34	06	36	20	40	28	08	41	29	44	27	12										

I Initial sampling, S_1 - S_5, First - Fifth samplings

C Control (25-30% moisture content), 1 10% moisture content, 2 25% moisture content, 3 40% moisture content, 4 water logging.

regularly supplied with sterile distilled water to maintain the moisture content of the litter at approximately 10, 25 and 40% on oven dry weight basis. Excess of sterile distilled water was added to the pots to maintain water-logging condition throughout the study. For the effect of pH the leaf litter was adjusted initially at pH 4,5, 6.5 and 8.5 using dilute acid or alkali. The pots kept as control, were treated with same amount of sterile distilled water.

The pots were incubated at room temperature (26-33 C) and regularly supplied with sterile water to maintain 25-30% moisture except mentioned otherwise as in the case of experiments set to study the effects of temperature and moisture. The experiments were performed in 5 replicates and the microbial population and activity of the leaf litter were estimated by the method described below:

Isolation of microorganisms The microorganisms were isolated from the decomposing litter at monthly interval. The first isolation was made from the freshly fallen litter which was considered as the 'initial' sample. Subsequent isolations were made from the treated and untreated leaf litter of the pots until 5 months. Dilution plate technique (Parkinson *et al* 1971) was employed for the isolation of fungi, bacteria and actinomycetes from the leaf litter (Rai & Srivastava, 1982b). Czapek-Dox + 0.05% yeast extract agar, Thornton's agar and starch casein agar medium supplemented with mycostatin at 50 µg ml-1, were used for isolation of fungi, bacteria and actinomycetes, respectively. The fungi were assessed qualitatively and quantitatively after 1 week of incubation at 25±2°C. The bacterial and actinomycete flora were estimated only quantitatively after 4 and 10 days of incubation at 35±2C; 28±C respectively.

Estimation of microbial activity in terms of CO_2 evolution The rate of CO_2 evolution from the treated and untreated decomposing litter of the pots was determined monthl by inverted box method (Witkamp, 1966). The first estimation of CO_2 evolution was made from the treated and control leaf litter immediately after their dispersion over the soil surface of the pots and was considered as the 'initial' sample. The subsequent estimations were done for 5 months.

Effects of temperature, moisture and pH on the rate of litter decomposition. Rate of litter decomposition was measured on the basis of loss of dry weight of the litter in small nylon litter bags (Rai & Srivastava, 1982b). Five 15 x 15 cm nylon bags (4 mm sieve), each containing 10 g leaf litter discs, were placed over each pot containing 2 kg forest soil. The litter discs were obtained by cutting different portions of leaves of different tree species with the help of a cork-borer (5 mm diam). To study the effects of temperature, moisture and pH the experiments were set up by the methods described earlier. Five such sets were prepared for each treatment and control .Five litter bags (one from each replicated pot) from each set were sampled at monthly interval until 5 months. The samples were oven dried at 80 C for 24 h and percentage weight remaining at each sample was calculated.

RESULTS Effect of temperature, moisture and pH on the microbial population. The fungal population was least at 15 C and the highest at 50 C. Bacterial count was low at 15 C during early samplings but it increased later on. The litter supported a fairly high bacterial population at 35 C. The population of actinomycetes was lowest at 50 C and the highest at 35 C (Table 1)

The fungal population was low at 10% and high at 25% moisture content of the litter becoming lower at 40%. Exceptionally highest fungal population was recorded under waterlogged condition due to predominance and heavy sporulating nature of *Aspergillus fumigatus* (Table 3). At 10% moisture level the bacterial population was reduced considerably. There was a regular increase in the bacterial count with increase in moisture. A sizable increase of the bacterial population in the litter was recorded under water-logged condition. The actinomycetes count also declined at 10% and 40% moisture levels. However, the most detrimental effect was noticed under water-logged condition (Table 1).

The fungal population was slightly low at pH 4.5 and 6.5 at the beginning but enhanced in the successive samples. Fungal population was markedly low at pH 8.5 count was low at pH 4.5 and 6.5 except in the last few samples but pH 8.5 enhanced the bacterial population. Actinomycetes count was reduced due to acid and alkaline treatments whereas it showed values similar to control at pH 6.5 (Table 1).

Effects of temperature, moisture and pH on qualitative nature of the litter mycoflora Less number of fungal species was isolated from the litter incubated at 15 C and 50 C (Table 2). Only a few fungi withstood 50 C. There was a little variation in the number of fungal species between the litter incubated at 35 C and room temperature (26-33 C). *Alternaria alternata, A. tenuissima, Curvularia lunata* var. *aeria, Pestalotia macrotricha,* and fungi with dark and white sterile mycelia were favoured while *Aspergillus* spp. were suppressed at 15 C. *A fumigatus* and *A. nidulans* were most dominant species in the litter at 50 C (Table 2).

Table 4 Relative Abundance (per cent occurrence of Important Fungal Species Isolated from Decomposing Leaf Litter Adjusted Initially at Different pH

Species	S_1					S_2				S_3				S_4				S_5			
	I	C	1	2	3	C	1	2	3	C	1	2	3	C	1	2	3	C	1	2	3
Acremonium furcatum	—	01	02	01	—	02	02	01	—	03	03	02	01	05	03	05	08	06	02	06	10
Alternaria alternata	18	06	09	03	02	01	02	01	—	—	02	—	—	—	03	—	—	—	—	—	—
Aspergillus candidus	—	—	—	01	02	—	—	—	01	—	02	01	—	—	06	02	—	—	11	02	—
A. flavus	04	03	02	05	02	02	02	03	12	04	06	11	12	03	—	—	—	03	—	—	—
A. fumigatus	—	03	01	02	02	04	19	12	09	02	04	02	01	02	—	—	—	01	—	—	—
A. luchuensis	—	01	—	01	01	03	01	05	21	09	07	14	21	06	05	09	22	05	03	06	12
A. nidulans	—	—	01	01	18	—	01	01	01	01	01	01	01	01	—	01	13	02	—	01	13
A. niger	05	10	05	05	14	14	06	08	30	10	05	08	25	06	03	04	30	06	03	04	30
A. variecolor	03	02	02	13	16	02	02	08	07	02	03	05	01	02	—	04	02	01	—	06	03
Penicillium citrinum	—	01	—	20	22	01	—	02	04	03	03	05	01	04	06	04	—	06	05	05	—
Pestalotia macrotricha	05	10	12	03	01	08	07	06	03	05	07	08	10	10	15	13	12	11	18	12	15
P. mangiferae	—	—	—	—	—	01	02	01	—	03	04	03	—	05	08	03	—	10	20	10	04
Phoma hibernica	15	11	13	05	01	08	08	06	01	08	07	05	01	04	06	06	02	02	—	03	—
Robillarda phragmitis	—	—	—	—	—	03	—	04	—	06	—	03	—	06	—	06	—	12	—	11	—
Trichoderma harzianum	—	—	01	—	—	06	16	05	01	04	01	01	—	06	15	03	—	02	08	02	—
Dark sterile mycelium	11	03	04	01	—	01	—	01	—	01	—	01	—	—	—	—	—	01	01	01	—
'other species'	39	49	48	61	18	44	32	36	10	39	38	29	26	40	30	40	11	32	27	31	13
Total number of species isolated	17	30	27	30	18	36	30	32	18	41	33	35	17	29	18	29	11	27	16	26	10

I Initial sampling, S_1-S_5, First - Fifth samplings

C Control, 1 pH 4.5, 2 pH 6.5, 3 pH 8.5

Table 5. Effect of Temperature, Moisture and pH on the rate of CO_2 evolution from decomposing leaf litter (μg g^{-1} dry litter hr^{-1})

Treatment	S_1	S_2	S_3	S_4	S_5
Initial sampling			92		
Temperature (°C)					
15	95	114	152	197	225
35	172	217	335	185	87
50	199	257	297	128	45
Moisture Content (%)					
10	124	136	248	137	88
25	164	182	331	204	80
40	132	128	101	99	99
Water-logging					
pH					
4.5	110	142	205	195	86
6.5	118	164	248	171	87
8.5	104	131	196	117	60
Control	125	164	274	160	89

S_1 - S_5, First - Fifth sampling.

Table 6. Effect of Temperature, Moisture and pH on per cent Weight remaining of Decomposing Leaf Litter

Treatment	I	S_1	S_2	S_3	S_4	S_5
				Per cent Weight		
Temperature (°C)						
15	100	99.	94.	85	77	65
35	100	95.	85	60	40	22
50	100	96.	90	74	62	55
Moisture content (%)						
10	100	96	91	73	60	47
25	100	94	87	61	42	27
40	100	98	94	82	63	58
Water-logging	100	99	95	87	77	68
pH						
4.5	100	98.	90	77	62	49
6.5	100	96.	91	70	59	36
8.5	100	99.	96	85	72	65
Control	100	96	90	67	41	32.

I Initial sampling : S_1 - S_5 , First - Fifth samplings .

The number of fungal species was less in the litter at low moisture content (10%). The diversity in fungal composition increased by increasing moisture content of the litter to 25%. Further increase in moisture content i.e., 40% caused a decline in fungal species (Table 3). Waterlogging caused a marked reduction in the number of fungal species and the dominant species isolated was *A.fumigatus*. In addition, *Absidia butleri*, *A. repens*, *A. scabra*, *Aspergillus sydowi* and *Cunninghamella echinulate* were also well represented (Table 3).

Alteration in pH of the litter caused reduction in the number of fungal species. The most significant effect was recorded at pH 8.5 and the least at pH 6.5 (Table 4). *Alternaria alternate*, *Pestalotia* spp. and *Trichoderma harzianum* were abundant at pH 4.5. At pH 8.5, Aspergillus spp., particularly *A. luchuensis*, *A. nidulanes* *A. nigar* and *A variecolor*, were most abudant in the litter.

Effects of temperature, moisture and pH on CO_2 evolution from the litter Carbon dioxide evolution from the decomposing leaf litter under different temperature, moisture and pH is presented in Table 5. The rate of CO2 evolution was low at 15 C in the first three samples but increased subsequently. Incubation of litter at 35 C enhanced the rate of CO_2 evolution. The rate of CO_2 evolution at 50 C was high in the first two samples but declined sharply later on showing values even less than the litter at room temperature (26-33 C).

CO_2 evolution at 10% moisture content was low. Moisture content at 25% favoured CO_2 evolution except in the last sample. Further increase in moisture content (40%) reduced the rate of CO_2 evolution except in the first and last samples. Water logging of the litter resulted in the minimum rate of CO_2 evolution.

Alteration in pH of the litter lowered the rate of CO_2 evolution and the least rate was recorded at pH 8.5. However, the rate was high for the fourth samples at pH 4.5 and 6.5.

Effects of temperature, moisture and pH on weight loss of the litter. The litter lost maximum weight (78%) at 35 C and the minimum (35%) at 15 C (Table 6). The maximum weight loss of litter was recorded at 25% (72%) followed by 10% moisture content (53%). The minimum loss of litter weight occurred under water-logged condition (31.97%). The litter adjusted at pH 4.5, 6.5, and 8.5, lost less weight compared with the control. The minimum weight loss of the litter was recorded at pH 6.5.

DISCUSSION A change in temperature, moisture and pH will alter the species composition of the active flora and at the same time will have a direct influence on each organism within the community in terrestrial ecosystem (Alexander, 1977). Our results indicate that the optima of temperature, moisture and pH lie somewhere near 35C, 25% and 6.5, respectively, for microbial growth in the litter. However, the reason for an exceptional highest fungal population at high temperature and under water-logged condition might be attributed to predominance and rich sporulation of *Aspergillus fumigatus* and *A.nidulans* in the case of former and only *A. fumigatus* in case of the latter. The dominance of these two species under adverse situation and at high temperature has been reported by other workers (Evans, 1971; Tiwari, 1975 and Upadhyay 1987). The bacterial population was recorded higher under water-logged condition as obligate and facultative anaerobic bacteria might have grown under such condition. The relaxation in number of species at these extremes might be considered a factor for some of the microbes to grow.

The optima of the three factors for growth of microorganisms corresponded with the optima of microbial metabolic activity. Edwards (1975) found a strong relationship between CO_2 evolution and mean daily litter temperature. The microbial activity was slow at 15C but rapid at 35 C. The CO_2 evolution declined at temperature above 35 C except in case of thermophilic microbial activity. Adequate moisture (i.e. 25% moisture content of the litter) might have induced greater microbial activity in the litter. The pH also influences the type of microorganisms associated with the carbon cycle or any habitat (Alexander, 1977). Therefore, reduction in microbial activity in the litter at altered pH was apparent. The rapid decomposition of the litter occured at pH 6.5 which is in accordance with the pH optimum for microbial count and CO_2 evolution. The lowest rate of decomposition was recorded at pH 8.5 which might be attributed to the adverse effect of alkaline reaction on fungi.

REFERENCES

ALEXANDER M 1977 *Introduction to Soil Microbiology*. Wiley London.

BUNNELL F L, DEAN TAIT, P W FLANGAN & K VAN CLEVE 1977 A Microbial respiration and substrate loss I. A general model of the influences of variables *Soil Biol Biochem* 9 33-40.

DAUBENMIRE R & D C PRUSSO 1963 Studies on the decomposition rates of tree litter *Ecology* 44 589-592.

EDWARDS N T 1975 Effects of temperature and moisture on carbon dioxide evolution in a mixed deciduous forest *Proc Soil Sci Am* 39 361-365.

EVANS H C 1971 Thermophilous fungi of coal spoils tips I. Taxonomy *Trans Br Mycol Soc* 57 241-254.

MEENTEMEYER U 1978 Microclimate and lignin control of litter decomposition rates *Ecology* 59 465-472.

PAL D & F E BROADBENT 1975 Influence of moisture on the straw decomposition in soil *Soil Sci Am Proc* 39 1975.

PARKINSON D, T R G GRAY & S T WILLIAMS 1971 Isolation of microorganisms, in *Methods for Studying the Ecology of Soil Microorganisms*. I.P.B.Handbook No. 19, Blackwell London.

RAI B & A K SRIVASTAVA 1982A Decomposition of leaf litter in relation to microbial populations and thier activity in a tropical dry mixed deciduous forest, *Pedobiologia* 24 151-159.

RAI B & A K SRIVASTAVA 1982B Microbial decomposition of leaf litter as influenced by fertilizers *Plant Soil* 66 195-204.

TIWARI V K 1975 Effect of soil amendments on qualitative and quantative nature of mycoflora Ph.D thesis Banaras Hindu University, India

UPADHYAY R S 1987 Tolerance to higher temperature by *Aspergillus nidulans* and its possible implication in biological control of wilt disease of pigeon pea *Plant Soil* 97 273-277.

WICKLOW D T & V MOORE 1974 Effect of incubation temperature on the copriphilous fungal succession *Trans Br. Mycol Soc* 62 411-415.

WILDUNG R E, T R GARLAND & R L BUSCHOM 1975 The interdependent effects of soil temperatire and water content on soil respiration rate and plant root decomposition in arid grassland soils *SoilBiol Biochem* 7 373-378.

WILLIAM S T & T R G GRAY 1974 Decomposition of litter on the soil surface, in *Biology of Plant Litter Decomposition* (C.H.Dickinson & C.J.E.Pugh, Eds.) vol.2, pp. 611-632 Academic Press, London.

WITKAMP M 1963 Microbial population of leaf litter in relation to environmental conditions and decomposition. *Ecology*, 44, 370-377.

WITKAMP M 1966 Rates of carbon dioxide evolution from the forest floor. *Ecology* 47 492-494.

WITKAMP M DRIFT VANDER J 1961 Breakdown of the forest litter in relation to environmental factors. *Plant Soil* 15, 295-311.