Vermicomposting-An Effective Technique for Paper Mill Solid Waste Utilisation and Value Addition

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A mixture of different papermill solid wastes was used to prepare vermicompost using locally available earthworms. Precomposting of raw materials without worms was found to be essential to prevent later temperature rise above 35 ^{0}C, which would be fatal for the worms. Ideal conditions were, temperature below 35 ^{0}C, pH around 7.0 and moisture content of bed 50%. Good aeration was found necessary. Vermicompost was produced in 60 days. It proved to be very useful for the growth of flowers like Marigold and Dahlia and vegetables like Ladies' Finger. The vermicompost accelerated growth, initiated early flowering and increased the number and size of flowers compared to standard cow dung-urea mixtures. Thus, various waste materials from the paper industry including sludge from effluent treatment could be converted to useful and value added vermicompost by an environmentally friendly technique. The study showed that plant and animal life could actually thrive in a vermicompost prepared from such wastes. The process is simple and effective for solid waste disposal and would be especially useful for rural and less developed areas where most of the paper mills are located. Vermicomposting could become a source of income for the rural folk and reduce environmental pollution at the same time.

INTRODUCTION

Modern India, growing at 8-9% per annum, is one of the fastest-growing countries in the world after China. However, there is a price to be paid for this. India has a large population and areas of very high population densities. This, together with growing industrialization, rising standard of living and an increasingly prevalent consumer culture, tends to produce ever-increasing quantities of solid wastes. Much of the waste is non-toxic in nature and consists of organic material. Existing methods of disposal tend to be expensive, increasing the economic burden on society.

In view of this, there is tremendous scope for solid waste utilization, preferably with some value addition. This brings with it a cleaner and healthier environment and makes life more enjoyable. Once any waste is utilized, it is transformed from a waste to a valuable resource, rather a form of wealth (1).

VERMICOMPOSTING

The paper industry generates solid wastes in many forms and offers very high potential for value addition and the manufacture of useful products. A simple and environmentally friendly method of utilizing the solid waste is through the use of earthworms, by the process of 'vermicomposting'. Earthworms are involved in one of the most critical jobs in the ecosystem (2). They recycle or reuse the basic materials that plants and animals need to survive. They can consume organic residuals very rapidly by passing them through a grinding gizzard, an organ that all earthworms posses (3). They derive their nourishment from microorganisms that grow upon the organic materials. At the same time, they promote further microbial activity in the residuals so that the fecal material, or "casts" that they produce, is much more fragmented and microbially active than what the earthworms consume. During this process, the important plant nutrients in the organic material - particularly nitrogen, potassium, and calcium - are released and converted through microbial action into forms that are much more soluble and available to plants than those in the parent compounds.

The retention time of the waste in the earthworm is short. Worms can digest several times their own weight each day, and large quantities are passed through an average population of earthworms. But in practice they biodegrade from a quarter to a half of their own weight per day. The amount of consumed substrate depends on environmental conditions and properties of substrate (pH, temperature, humidity, nutritious value of substrate etc.) (3).

While they consume biological wastes, thus decreasing the disposal problems, they are concurrently manufacturing two new products - earthworm castings known as vermicast (or vermicompost) and more earthworms.

It has been reported (4) that, continuous application of vermicompost significantly increases the organic matter content of the soil. Apart from the improvement of organic matter content and addition of nutrients, vermicompost addition improves the physical properties of soil such as porosity, soil aggregation, water and nutrient retention in the soil.

Major Processing Conditions for Vermicomposting

- Vermicomposting is an aerobic process. The earthworms, which survive only under aerobic conditions, take over both the roles of turning over the waste and maintaining it in an aerobic condition (5).
- The major constraint to vermicomposting is that, in contrast to traditional composting, which is a thermophilic process that can raise temperatures in the waste to more than 70ºC, vermicomposting systems must be maintained at temperatures below 35ºC. Exposure of the earthworms to temperatures above this, even for short periods, will kill them, and to avoid such overheating careful management of the wastes is required.
- Earthworms are active and consume organic wastes in a

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relatively narrow layer of 6-9 inches, close to the surface of a compost heap or bed. The key to successful vermicomposting lies in adding wastes to the surface of compost heaps or beds in successive thin layers, so that any heating that occurs does not become excessive, although it should be sufficient to maintain the activity of the earthworms at a high level of efficiency.

- Almost any agricultural, urban or industrial organic waste can be used for vermicomposting, but many need some form of preprocessing to make them acceptable to earthworms. Such preliminary treatments can involve washing, precomposting, macerating or mixing. Ideally, mixtures of several different wastes can be processed more readily than individual wastes, are easier to maintain aerobically, and result in a better product. Cattle and horse manures, wastes from the paper industry, and sewage solids and urban waste are particularly suitable for vermicomposting.

- Earthworms have well-defined limits of tolerance to certain chemicals, and the wastes are processed much more efficiently under a relatively narrow range of favorable chemical and environmental conditions. If these limits are exceeded greatly, the worms may become sluggish. In particular, earthworms are sensitive to ammonia, salts and certain other chemicals. For instance, they will die quite quickly if exposed to wastes containing more than 0.5 mg of ammonia per gram of waste and more than 0.5% salts (5). However, salts and ammonia can be washed out of organic wastes readily or dispersed by precomposting.

- Earthworms do not have too many enemies except for ants, snakes, mice and mites. Proper management using nets (snakes, mice), water barriers (ants), etc can avoid the pest problem.

- The processing of organic wastes occurs most rapidly at temperatures between 15ºC and 25ºC and at moisture contents of around 50% (3). Outside these limits, earthworm activity and productivity and the rate of waste processing falls off dramatically; for maximum efficiency, the wastes should be maintained as close to these environmental limits as possible.

Earthworm Species for vermicomposting

Diversity of earthworm species varies with different types of soils and hence choosing a native species of worm for the local soil and vermicomposting is important. It has been mentioned (6) in the literature that there is no need to import earthworms from elsewhere. Local species of earthworms can be conveniently used. Common species used in India are Perionyx excavatus and Lampito mauritii.

In western countries, the two most commonly used earthworms (3) are the species Eisenia fetida and Eisenia andrei. Other species include Lumbricus rubellus, Eudrillus eugeniae and Perionyx excavatus. The latter two species are from Africa and Asia and cannot withstand low temperatures.

In this study, a mixture of local earthworm species was used - *Eisenia fetida* and *Eudrilus eugeniae.*

Solid Wastes from the Pulp and Paper Industry

The pulp and paper industry, especially a large integrated mill, produces different types of solid wastes. Some major solid wastes generated in large quantities are (1) chipper dust from the wood and bamboo chipping operations, (2) fly ash from the high-ash coal burnt in the boilers and (3) secondary sludge from the effluent treatment plant (ETP) working on the activated sludge process. Other than these, another solid waste generated in large amounts is lime sludge from the chemical recovery plant. However, this has not been considered here as it has now been made mandatory for paper mills to install rotary lime kilns for burning the lime sludge. Hence this waste will not be available in the future. For the present study, it was decided to use the solid wastes mentioned in (1) to (3) above.

Aims of the Present Study

It was decided to check the feasibility of utilizing the above-named solid wastes in preparing vermicompost by mixing in suitable proportions with or without other ingredients. This would be a preliminary study aimed at establishing the viability of the production of vermicompost from the paper mill solid wastes and was expected to lead to further studies producing improved products.

EXPERIMENTAL

Solid Waste Properties

The solid wastes taken for this study, as mentioned above, were chipper dust (CD), fly ash (FA) and ETP secondary sludge (ETPS). In addition, cow dung (CDG) was locally collected and used in admixture with the other materials. All raw materials were analysed for different parameters on receipt. The results have been reported in Table 1.

All the wastes (except FA) from the second trial onwards were precomposted individually for 2-3 weeks without earthworms so that any temperature rise due to bacterial action was over before taking for vermicomposting. This is essential as the worms cannot tolerate higher temperatures.

Vermicomposting Vessel

Plastic drums cut lengthwise were used for vermicomposting. Small holes were drilled on the sides near the bottom for aeration and for the removal of excess water. Fig. 1 shows the vermicomposting vessel. The vessel was of semi-circular cross-section with a width of 430 mm. The height and length were 300 and 650 mm respectively. During vermicomposting, two 12 mm diameter PVC tubes about 400 mm long, perforated with 3 mm holes along the length, were vertically inserted in a symmetrical manner along the centerline of the vessel for cooling and for maintaining aerobic conditions for the desired biological activity. These tubes projected about 100 mm above the vessel.

Initial Trials

Two preliminary trials were conducted where the raw materials were mixed on BD basis using the following approximate ratios:

ETPS: 30, CD: 30, CDG: 40, FA: Nil
ETPS: 35, CD: 30, CDG: 35, FA: Nil

As can be seen, FA was not used in these trials. These trials served to generate a feel for the process and to decide on the procedure to be adopted for later composting studies. Here, the raw materials were not precomposted.

The first experiments were carried out by the technique of layering. At first, a layer of 50-60 mm thickness made of coconut husk and dry leaves was laid down in the plastic container (Layer 1). Layer 2 consisted of cow dung of similar thickness as Layer 1. A layer of ETPS and CD (Layer 3) followed this while Layer 4 was again cow dung. Layer 3 composition was repeated in Layer 5 while only CDG was used for Layer 6, which was the top layer. Earthworms (150) were released on the top layer.

The composting was done for 60 days. During this period, the bed was kept moist with water and the bed temperature was regularly monitored. The bed pH was checked frequently and generally kept under observation for the development of smells, pests, etc. After 60 days, the product of composting was screened through a 7 mm sieve to separate large solids and worms. The vermicompost was analysed for different parameters and the results are given in Table 2.

The product was used for growing 'Ladies' Fingers' in comparison with normal cow dung. For this purpose, garden soil was mixed with 40% cow dung and 40% vermicompost in two pots and the seeds planted. The growth of the plants was regularly monitored, including height, leaf size, etc. Flowering and fruiting times and size of the crop were also noted.

TABLE 1
ANALYSIS OF RAW MATERIALS (AS RECEIVED)

S. NO.	PARTICULARS	UNITS	ETP SECONDARY SLUDGE	CHIPPER DUST	FLY ASH	COW DUNG
1.	Moisture	% w/w	70	53	1.3	36
2.	pH#	-	6.8	6.7	7.2	8.4
3.	Bulk Density (As Received)	Kg/m^3	729	357	849	839
4.	Bulk Density (BD)	Kg/m^3	219	168	838	537
5.	Electrical Conductivity#	μMhos/cm	690	120	320	1200
6.	Ash	%	42.7	4.0	-	68
7.	Organic Matter	%	54	95	3.2	39.3
8.	Organic Carbon	%	31.3	55.2	2.2	22.9
9.	Kjeldahl N_2	%	3.2	0.4	0.5	1.2
10.	C:N Ratio	-	9.8	138.1	4.8	19.2
11.	Phosphorus	%	1.4	0.7	0.6	1.1
12.	Potassium#	%	1.2	0.6	0.6	1.3
13.	Calcium#	%	0.4	0.4	2.5	1.5
14.	Magnesium#	%	0.6	0.2	1.8	1.0
15.	Sodium#	%	0.2	0.04	-	0.08
16.	Chloride#	%	0.2	0.07	0.0014	0.4

Using a 5% solution after filtration

TABLE - 2
ANALYSIS OF VERMICOMPOST FROM THE FIRST TRIAL

S. NO.	PARTICULARS	UNITS	VALUE
1.	Moisture	%	50
2.	pH	-	7.6
3.	Electrical Conductivity	μSiemens/cm.	$6.3x10^2$
4.	Organic Matter	%	46.7
5.	Organic Carbon	%	27.1
6.	Kjeldahl Nitrogen	%	1.1
7.	C:N Ratio	-	24.6

Further Trials

Moisture and Bulk Density: The moisture and bulk density of individual raw materials were determined immediately after collection and are reported in Table 3.

TABLE - 3
MOISTURE & BULK DENSITY

S. NO.	PARTICULARS	MOISTURE, % W/W	*BULK DENSITY (AS SUCH) KG/M^3	*BULK DENSITY (BD) KG/M^3
1.	Effluent Sludge(ETPS)	70	729	219
2.	Cow Dung(CDG)	36	839	537
3.	Chipper Dust(CD)	53	357	168
4.	Fly Ash(FA)	1.3	849	838

*Average of 2 readings   Note: BD = Bone Dry

All raw materials were precomposted without earthworms for 4 weeks. The raw materials including fly ash were mixed in the following ratio on BD basis:

ETPS: 30 %
CD: 30 %
CDG: 25 %
FA: 15 %

The above composition gave a calculated C:N ratio of 30:1, which has been recommended (8) for composting. The mixed raw materials were brown in colour with moisture content of 54%. The bulk density was found to be 610 kg/m^3 on 'as such' basis and 281 kg/m^3 on BD basis. The mixture was tested for various parameters. The results are given in Table 4.

Vermicomposting

The above mixture was taken for vermicomposting in the plastic container prepared as given above. The layer method was not followed in this case due to troubles experienced in the previous trials. Instead, the entire mass, about 10-15 Kg BD was taken for composting and gradually added over a bed of 50-60 mm thick layer of coconut husk.

About 300 worms were cast on the top of the bed. Since the worms tend to remain active near the top of the bed, the mixture starts turning into vermicompost from the top downwards. The appearance of the converted material changes to a dark blackish colour and is fairly easy to

TABLE - 4
ANALYSIS OF RAW MATERIAL MIXTURE AND VERMICOMPOST

NOTE : RATIO OF RAW MATERIALS MIXED ON BD BASIS:
ETPS: 30, CD: 30, CDG: 25 AND FA: 15

S. NO.	PARTICULARS	UNITS	RAW MATERIAL MIX	VERMICOMPOST
1.	Moisture	%	54.0	50
2.	PH	-	7.5	7.0
3.	Organic Matter	%	54.6	28.6
4.	Organic Carbon	%	31.6	16.6
5.	Kjeldahl Nitrogen	%	1.13	1.43
6.	C:N Ratio	-	27.96	11.16
7.	Phosphorus as P	%	0.96	1.13
8.	Potassium as K	%	1.2	1.16
9.	Bulk Density :	Kg/m^3		
	As such		610	410
	BD basis		281	205

TABLE 5
TOXICITY TESTING

S. NO.	PARAMETERS	RESULTS	* MAXIMUM LIMIT
1.	Chromium (vi)	0.02 mg/gm	50 mg/kg (0.05 mg/g)
2.	Lead	0.015 mg/gm	5000 mg/kg (5 mg/g)
3.	Nickel	0.002 mg/gm	5000 mg/kg (5 mg/g)
4.	Cadmium	0.001 mg/gm	50 mg/kg (0.05 mg/g)
5.	AOX	0.00	-
6.	LC50	The LC50 value was found at 30% (W/V) leachate concentration in a 48 hr study in which the test species Rita rita, which is a cat fish was taken as the test organism	-

* As per the Notification (2000) of the Ministry of Environment and Forests, Schedule-II.

distinguish from the original mixture. This converted material was removed every seven days starting from 15 days after starting the vermicomposting. After removing the top layer, the whole mass was taken out and mixed well before putting back in the container. This ensured good aeration. For additional air uptake, 12 mm PVC tubes were inserted vertically into the mass as described above. The total composting period was 8 weeks. During this period, the temperature was regularly monitored and water sprinkled on the bed whenever the temperature showed signs of increasing.

At the end of the composting period, the remaining vermicompost was screened through a 7 mm sieve to separate the worms from the compost. The moisture content and bulk density of the compost were measured. The prepared vermicompost was also analysed for different parameters. The results are given in Table 4 together with the raw material mixture test results.

A number of trials were carried out on the above basis and selected results have been reported.

Field Trials

Field trials were carried out on different flowers in equal sized beds prepared either with vermicompost (on the basis of 1-2.5 tonnes/hectare) and soil or with the normally used cowdung and urea mixture. The results obtained with Dahlia and Marigold flowers have been reported here. The heights of the Dahlia and Marigold plants and the number of flowers observed at different times of growth with vermicompost and with cow dung have been shown in Figs. 2-6. The field trials were continued for 4-5 weeks, which represented peak growth for both species.

Toxicity Testing

A sample of the vermicompost was sent to the independent institute "Centre for Environmental Studies and Analysis", Bhubaneswar, for the testing of toxicity parameters like the content of heavy metals chromium, lead, nickel and cadmium, LC_{50} and AOX (adsorbable organic halides). The results are given in Table 5.

OBSERVATIONS

Initial Studies by the Layer Method Without Precomposting

Some problems were experienced during these studies:

- The bed temperature remained high even after sprinkling water. The temperature range was 29 37 ^{0}C. This was too high for successful vermicomposting as the worms became lethargic and did not move much after initial exposure to high temperature. Some worms died.
- The pH of the bed increased gradually. Starting from 7.8, it went up to 8.5 and then to 8.9. Acetic acid was added to neutralize the alkalinity and bring the pH to 7.0.
- Foul smell developed in the bed from time to time. The process became anaerobic at some point because of insufficient aeration. It was not possible to manually turn the bed over in order to avoid disturbing the layers.
- With all the above problems, the bed was only partially converted to vermicompost even after 60 days.

The following points emerged from the above observations:

- Precomposting is essential to avoid temperature rise to high levels during vermicomposting.
- The layer method was not working well because of aeration problems. It was not possible to aerate the bed without disturbing the layers. On the other hand, it was essential to maintain aerobic conditions.
- Drying of the bed and excessive moisture (soggy bed) are both to be avoided. All attempts should be made to maintain 50% moisture in the bed, which is considered optimum.

In spite of the above problems, the trial with growing Ladies' Fingers in pots containing soil and vermicompost on the one hand and soil and cow dung on the other, gave interesting results. The quantities of compost and cow dung added to the soil are given below:

Vermicompost added : 20% (V20) and 40% (V40) of the soil quantity.

Cow dung added: same proportion as above. Code: C20 and C40.

Fig. 1: Vermicomposting Vessel (Not to scale)

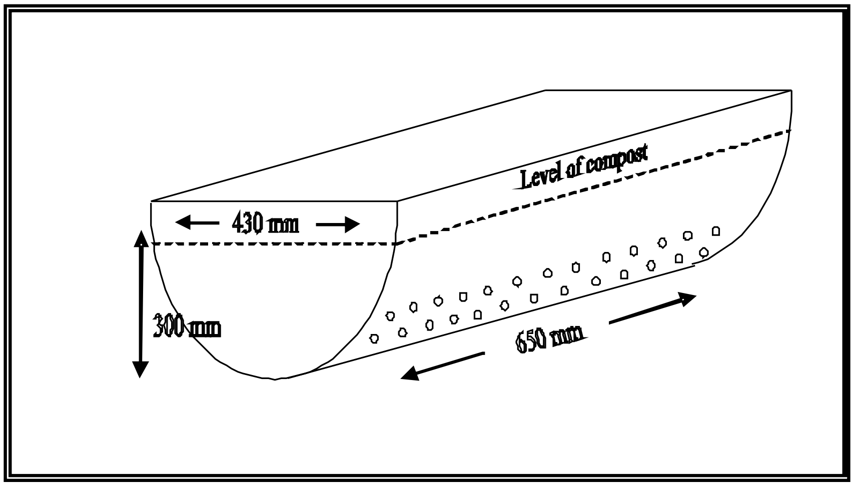


Fig. 2: Growth of Marigold Plants (Height, cm)

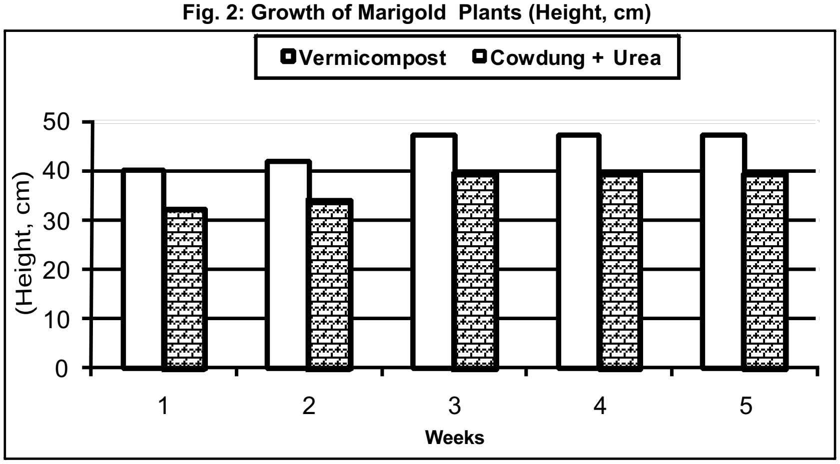
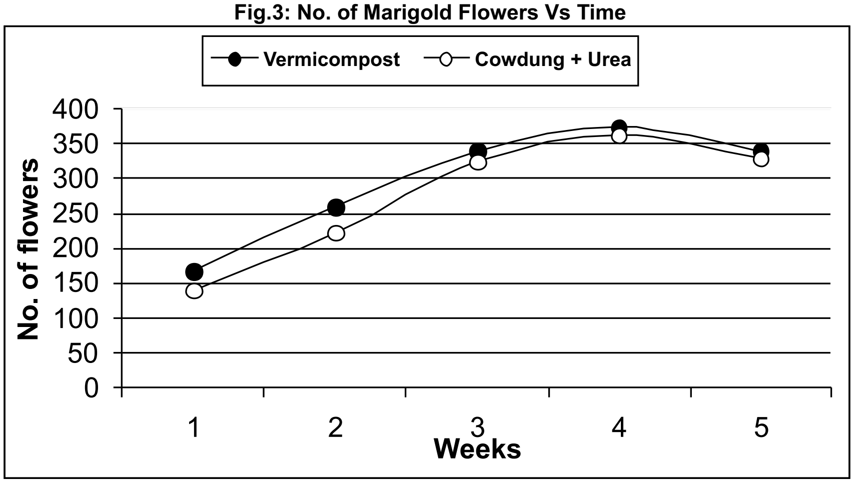


Fig.3: No. of Marigold Flowers Vs Time



It was observed that the plant grew faster with the vermicompost mixture. After 7 weeks, the height of the V40 plant was 64 cm compared to 56 cm for the C40 plant. In another pot, it was 57 cm for V40 against 46 cm for C40. Similar trends were observed for the 20% blends also. As expected, the height was greater when more vermicompost or more cow dung were used. For example, V40 plants were taller than V20 plants at the same age and it was the same with C40 and C20 plants. However, whatever the ratio, the plants grown with vermicompost were always taller than their cow dung counterparts.

Thus, vermicompost seemed to accelerate growth. With regard to sprouting and flowering, the seeds sown on the same day were found to sprout on the same day, whether vermicompost or cow dung was used. Also the size of the leaves in both cases was the same as was the start of flowering.

Other Trials With Vermicomposting

Subsequent trials were conducted with the inclusion of fly ash in the composting mixture. Fly ash is an industrial waste which is generated in very large quantities by the paper mill coal-fired boilers. Fly ash is known to contain trace metals which serve as micronutrients for plants providing essential minerals. According to the Tata Energy Research Institute (TERI), fly ash contains (7) several macro and micro nutrients which are essential for plants and the soil. The fly ash used in these studies was subjected to detailed analysis at the "Centre for Environmental Studies and Analysis", Bhubaneswar and the results are given in Table 6. The analysis shows the rich mineral content of fly ash, especially trace elements like Zinc, Copper and Boron.

With the inclusion of fly ash, there were now 4 materials for vermicomposting. These were:

- ETP Sludge (ETPS)
- Chipper Dust (CD)
- Fly Ash (FA)
- Cow Dung (CDG)

Table 1 shows that the pH of the raw materials ranges from 6.7 to 8.4. This shows that the materials are neither strongly acidic nor alkaline they are close to neutrality. The moisture content was very high in the fresh ETPS 70%. FA had the lowest moisture content of 1.3%. The heaviest material was fly ash with a dry bulk density of 838 kg/m^3 while the lightest was CD at 168 kg/m^3. The electrical conductivity of CDG was the highest (1200), indicating the presence of soluble mineral matter. The ETPS also had high conductivity (690).

After precomposting for 4 weeks, all raw materials were mixed in the ratio as given above, i.e., ETPS 30: CD 30: CDG 25: FA 15. As mentioned earlier, the composting period was 8 weeks. At the end of the above period, when the worms were separated, it was observed that the original 300 had increased to

TABLE 6
DETAILED ANALYSIS OF FLY ASH

S. NO.	PARAMETERS	UNITS	RESULTS
1.	Moisture	%	6.05
2.	Conductivity(0.5% water Extract)	μS/cm	54.0
3.	L.O.I. at 950 ^{0}C.	%	4.5
4.	Al_2O_3	%	22.2
5.	SiO_2	%	56.4
6.	Fe_2O_3	%	5.3
7.	CaO	%	1.5
8.	MgO	%	0.76
9.	Na_2O	%	0.25
10.	P_2O_5	%	0.23
11.	K_2O	%	0.45
12.	TiO_2	%	0.65
13.	Cu	mg/kg	29.4
14.	Cr	mg/kg	22.0
15.	Co	mg/kg	4.5
16.	Zn	mg/kg	44
17.	Pb	mg/kg	48.8
18.	B	mg/kg	2.5
19.	Mn	mg/kg	586

TABLE 7
NUMBER OF FLOWERS

No. of Weeks	No. of Flowers - Compost Bed	No. of Flowers - Normal Bed
1	168 (+19%)	141
2	261 (+17%)	223
3	339 (+ 4%)	325
5	340 (+ 3%)	330
The % figures in brackets show the difference between the compost bed and the normal bed		

TABLE - 8
HEIGHT OF MARIGOLD PLANTS (cm)

S. NO.	NO. OF WEEKS	VERMICOMPOST	COWDUNG + UREA
1.	1	40	32
2.	2	42	34
3.	3	47	39
4.	4	47	39
5.	5	47	39

700 worms. There were also numerous cocoons indicating vigorous multiplication during vermicomposting. The analysis of the raw material mixture and final vermicompost has been presented in Table 4.

It may be observed that the vermicompost had 50% moisture and was neutral at 7.5 pH. The organic matter content, as expected, had come down from 54.6% to 28.6%. Corresponding to this, the organic carbon content was 31.6% in the beginning and 16.6% at the end. The nitrogen content increased from 1.13% to 1.43% while the C:N ratio went down from 27.96 to 11.16. There was a slight increase in the phosphorus content while the potassium content was practically constant.

Field Trial Results

The field trial results are given in Tables 7-12 and Figs. 2-6. It was first observed that, on applying vermicompost, the soil became black and more porous. The water retention also improved. Some earthworms were noticed in the compost beds after a few days although no worms had been introduced. These could have come from the cocoons which were mixed with the compost.

In the case of Marigold flowers, 30 plants were selected at random from each bed. The height of the plant, total number of flowers and the number of flowers in the 6-10 cm diameter range was measured at intervals of one week. The average weekly numbers were calculated from the data. It was observed (Figs. 2-4) that:

- The growth of the plants in the compost bed was more than in the normal bed.
- Budding and flowering were also observed first in the compost bed.
- The size and total number of flowers was also higher in the compost bed.

The plant height increased in both cases (Fig. 2) upto 3 weeks and did not increase thereafter. The height of the plants in the compost bed was found to be consistently more than in the normal bed. The maximum height of the Marigold plants in the compost bed was 47 cm compared to 39 cm in the normal bed or 20% higher in the former case.

Figs. 3-4 show the situation with the number and size of flowers. It can be observed from Fig. 3 that the number of flowers was always higher in the compost bed compared to the normal bed. However, the difference was higher in the beginning, and reduced thereafter as shown in Table-7.

However, the above does not tell the complete story because the larger flowers were more abundant in the compost bed. Fig. 4 shows the difference. It may be seen that the number of larger flowers of 6-10 cm size were greater in number right from the beginning and the difference increased upto 4 weeks growth period. The maximum difference was at 4 weeks - 298 flowers in the compost bed against 188 in the normal bed or about 59% more with vermicompost.

Thus, it may be concluded that

Fig.4: Variation in the Number of Larger Marigold Flowers (6-10 cm) Vs Time

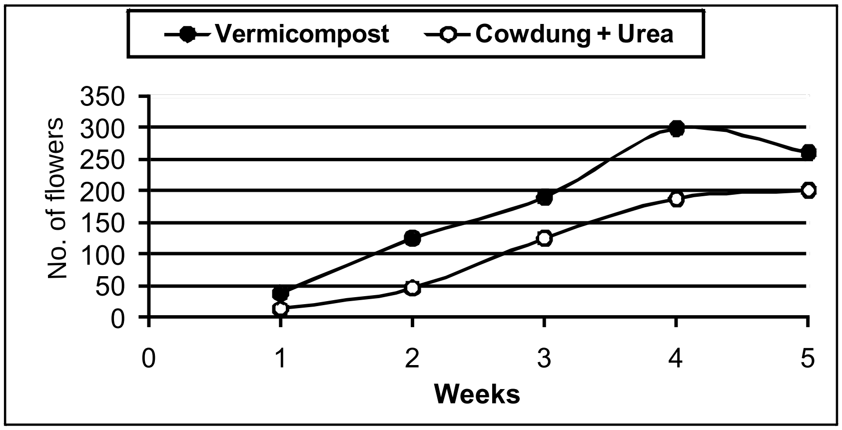


Fig. 5: Growth of Dahlia Plants (Height, cm)

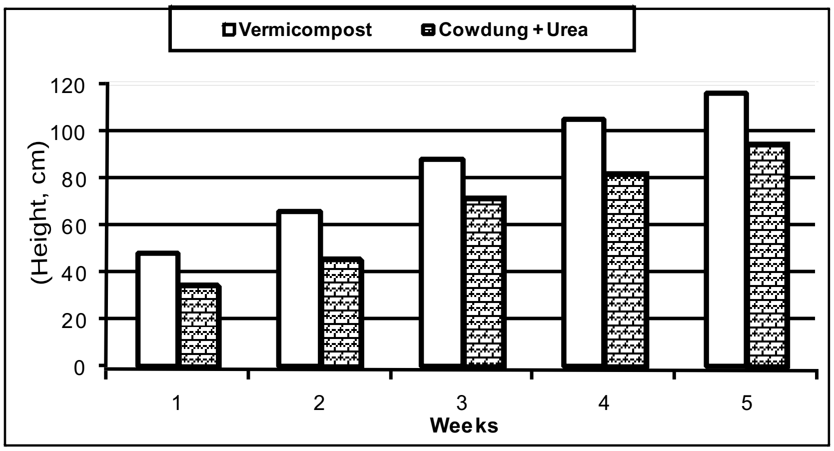
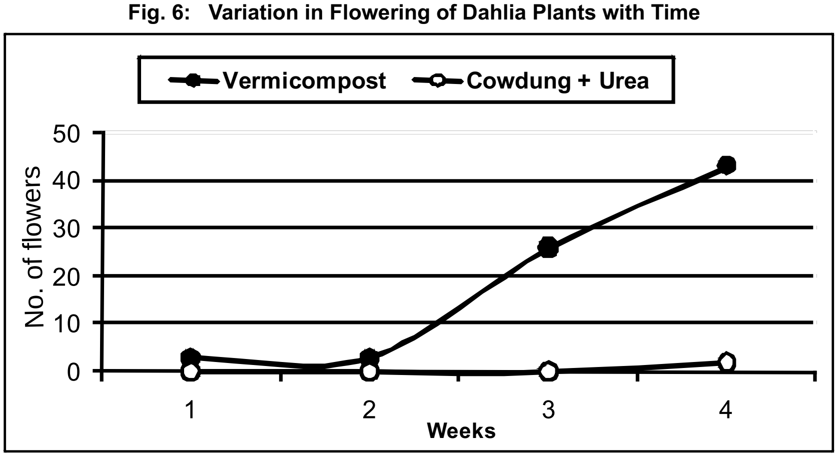


Fig. 6: Variation in Flowering of Dahlia Plants with Time



vermicompost promotes the growth of larger Marigold flowers (almost 60% more in number) compared to urea and cowdung mixture in addition to producing a slightly higher number of flowers.

In the case of the field trial with Dahlia flowers, the total number of plants taken for observation in each bed was 13. The plant height and number of flowers were measured between 1-5 weeks of growth. Fig. 5 and 6 show that the plant height increases continuously for both beds upto 5 weeks but the compost bed plants were always taller than the normal bed. After 4 weeks, the height of the plants in the compost bed was 28% more than the ones in the normal bed.

With regard to the number of flowers, buds started opening after 1 week in the compost bed whereas nothing happened in the normal bed (except budding) upto 3 weeks, by which time there were 26 flowers in the compost bed. After 4 weeks, there were 43 flowers in the compost bed and only 2 in the normal bed.

Thus, it may be observed that vermicompost promotes early and rapid flowering in Dahlia plants. This is definitely a point in its favour because early flowering is always desirable from a pure horticultural and also from a commercial point of view.

The field trials with Marigold and Dahlia flowers thus showed that vermicompost is a good soil amendment and compares favourably with urea and cow dung mixtures.

Toxicity Test Results

The test data given in Table 5 show that heavy metals like chromium, lead, nickel and cadmium were all within permissible limits. There was no AOX present. The LC_{50} value was found to be acceptable at 30% (W/V) leachate concentration in a 48 hour study in which a catfish species *Rita rita* was used as a test organism.

CONCLUDING REMARKS

- It has been found possible to use solid wastes from a wood and bamboo based large integrated pulp and paper mill to produce vermicompost using locally available earthworms.
- Temperatures in the composting material were kept below 35 ^{0}C and the moisture content around 50%. Temperatures above 35 ^{0}C were found detrimental to the worms. The beds were turned and aired frequently. Under these conditions, the pH of the bed remained near neutral. In the method adopted, layers of vermicompost were scraped off the top of the bed every 7 days.
- The layer method of vermicomposting was tried but abandoned as it was found to become anaerobic and was difficult to aerate without disturbing the layers.
- The vermicompost produced was tried as a soil amendment for horticultural applications, in beds of Marigold and Dahlia flowers. Small trials were also made for growing vegetables like Ladies'

TABLE 9
NUMBER OF MARIGOLD FLOWERS

S. NO.	NO. OF WEEKS	VERMICOMPOST	COWDUNG + UREA
1.	1	168	141
2.	2	261	223
3.	3	339	325
4.	4	375	363
5.	5	340	330

TABLE 10
NUMBER OF MARIGOLD FLOWERS OF 6-10 cm SIZE

S. NO.	NO. OF WEEKS	VERMICOMPOST	COWDUNG + UREA
1.	1	38	14
2.	2	126	45
3.	3	190	125
4.	4	298	188
5.	5	260	200

TABLE 11
HEIGHT OF DAHLIA PLANTS (cm)

S. NO.	NO. OF WEEKS	VERMICOMPOST	COWDUNG + UREA
1.	1	48	35
2.	2	66	46
3.	3	88	72
4.	4	105	82
5.	5	116	95

TABLE 12
NUMBER OF DAHLIA FLOWERS

S. NO.	NO. OF WEEKS	VERMICOMPOST	COWDUNG + UREA
1.	1	3	0
2.	2	3	0
3.	3	26	0
4.	4	43	2

Fingers. Cow dung and urea mixture was used for comparison. The results showed that the growth of all the plants was accelerated by the vermicompost and was significantly more than that of plants grown with cow dung and urea. It was also noticed in the case of the Ladies' Fingers that, increasing the amount of vermicompost immediately increased the growth rate of the plant. This was applicable to cow dung-urea mixture also but the difference was always maintained between the two.

- For both Marigold and Dahlia flowers, budding and flowering were first noticed in the compost bed. The total number of flowers was also higher with vermicompost for both species. This was especially true for Dahlia where, after 4 weeks, there were 43 flowers in the compost bed compared to only 2 in the cow dung-urea bed. In the case of Marigold, the size of the flowers was significantly higher with vermicompost.

- This preliminary study has shown that vermicompost prepared from different papermill solid wastes can be used in the growth of vegetables and flowers. It accelerates growth, initiates early flowering, increases the number of flowers and produces larger flowers in greater numbers.

- No toxic effects were noticed in this study, either to the earthworms or to the plants which grew in the vermicompost beds. Thus, plant and animal life were supported by the vermicompost. Hence, it is evident that vermicomposting can be considered as a method of utilizing sludge from the effluent treatment plant of a paper mill after suitably mixing with other solid wastes. Toxicity studies conducted in an independent laboratory also did not show any alarming results. There was no AOX content in the vermicompost, The LC50 result was acceptable and heavy metals tested (chromium, lead, nickel and cadmium) were within specified limits.

- Thus, this study has shown that the wastes can be converted into useful and safe soil amendments using the simple, environmentally friendly technique of vermicomposting. The process automatically adds value to the waste materials as the vermicompost can be easily sold to various end users or through supermarkets, etc. Also, one of the greatest advantages is that vermicomposting can be done anywhere in the country, even in the remote, rural areas where most to the papermills are located.

- Further studies are being planned to change the composition of the composting mixture, improving the current composting techniques, trying out vermicompost on different plants and also improving the vermicompost quality further by mixing certain other nutrients with it.

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