Bioresources for Sustainable Plant Nutrient Management

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Chapter 5

Vermicomposting: Recycling Wastes into Valuable Manure for Sustained Crop Intensification in the Semi-Arid Tropics

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1. INTRODUCTION

Producing more food sustainably from the limited and scarce land and water resources to feed ever-growing population of 9 billion people in the world by 2050 is a challenge for the human kind in the 21st century. Neither the quantity of available water or land has increased since 1950, but the availability of water and land per head has declined significantly due to increase in global human population. For example in India per capita arable land availability has decreased from 0.39 ha in 1951 to 0.14 ha in 2001 due to increased population from 361 million in 1951 to 1.02 billion in 2001 which is expected to rise to 1.39 billion by 2025 and 1.64 billion by 2050 with associated decrease in per capita land availability 0.1 ha in 2025 and 0.08 ha by 2050. Distribution of land varies differently in different countries and regions in the world and also the current population as well as anticipated growth which is expected to grow rapidly in developing countries.

Large fraction of the global expansion in the total crop land since 1900 onwards is rainfed (Figure 1). Native vegetation like forest and wood lands were converted into crop lands mostly into rain-fed agriculture and grass lands, which produced more staple food and animal protein but also under gone severe land degradation, depletion of soil nutrients and loss of

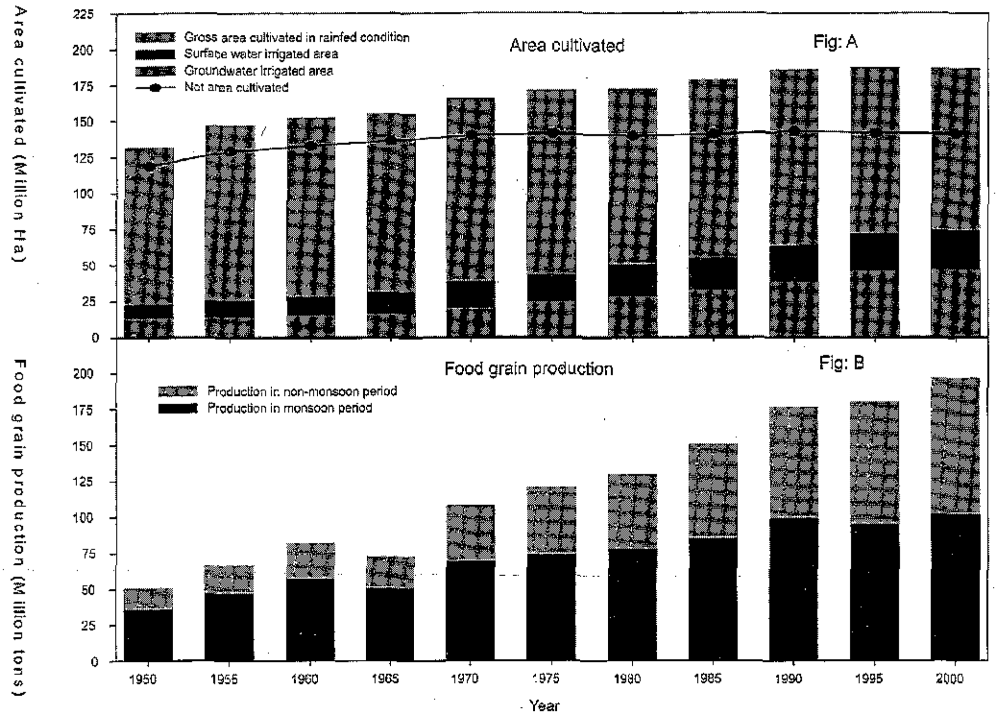


Fig. 1: a) Gross area cultivated in rainfed and irrigated groundwater and surface water irrigated area) crop lands and net cultivated area in India;
b) Total food production during monsoon and post-monsoon period) in India Data source: Centre water commission, 2005).

biodiversity which resulted into poor productive status and lost in system resilience and ecosystem services Gordon *et al.*, 2005). Most countries in the world depend primarily on rain-fed agriculture for its grain food and in many developing countries, a great number of poor families in Africa and Asia still face poverty, hunger, food insecurity and malnutrition, where rain-fed agriculture is the main agricultural activity. These problems are exacerbated by adverse biophysical growing conditions and the poor socioeconomic infrastructure in many areas in the arid, semiarid tropics SAT and the sub-humid regions (Wani *et al.*, 2011a).

Even in tropical regions, particularly in the subhumid and humid zones, agricultural yields in commercial rain-fed agriculture exceed 5-6 t/ha (Rockström and Falkenmark, 2000; Wani *et al.* 2003a, 2003b) (Figure 2). At the same time, the dry subhumid and semiarid regions have experienced the lowest yields and the weakest yield improvements per unit land. Here, yields oscillate between 0.5 to 2 t/ha, with an average of 1 t/ha in sub-Saharan

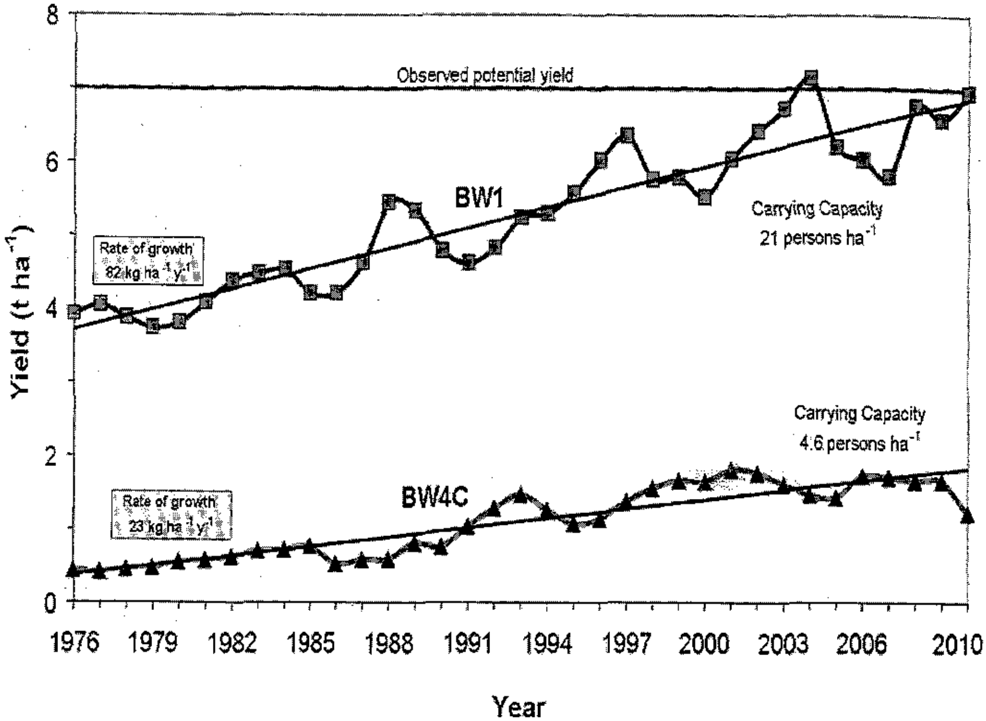


Fig. 2: A comparison of harvested grain yield by implementing IWRM techniques in BW1 Vertisol Heritage watershed at ICRISAT with traditional farmer's practices at BW4C; results are shown since 1976 onwards

Africa, and 1-1.5 t/ha in South Asia, Central Asia and West Asia and North Africa for rain-fed agriculture (Rockström and Falkenmark, 2000; Wani *et al.*, 2003a, 2003b). Data on long-term experiment at ICRISAT's Heritage Watershed site (Figure 3) has explained that due to integrated IWRM interventions average crop yield is five folds higher compare to traditional farmer's practices (Wani *et al.*, 2003a, 2011a, 2011b). Similar results are also recorded at Kothapally watershed where implementing IWRM interventions enhanced crop yields almost two to three times as compared to before such interventions in 1998 (Wani *et al.*, 2003a; Sreedevi *et al.*, 2004).

To achieve the goal of sustainable food production with limited land and water resources where is need to sustainably intensify the agriculture. The green revolution in India increased food production through intensification of irrigated areas with the use of fertilizers responsive, dwarf genotypes of wheat and rice.

Past few decades have seen high levels of indiscriminate and imbalanced use of chemical fertilisers in agriculture which is now manifesting as degradation of soil health. The loss of soil health and fertility due to heavy nutrient mining, nutrient imbalances and loss of soil structure and biota are compromising the ability of the production systems to produce more to feed the burgeoning population. Along with water scarcity soil fertility management in particular need to be paid due attention alongside water stress management in view of the fragile nature of the soil resource base (Wani *et al.*, 2009; Sahrawat *et al.* 2010a, 2010b). Moreover, it is commonly believed that at relatively low yields of crops in the rainfed systems, the deficiencies of major nutrients, especially N and P are important for the SAT soils (El-Swaify *et al.*, 1985; Rego *et al.*, 2003; Sharma *et al.*, 2009) and little attention is devoted to diagnose the extent of deficiencies of the secondary nutrients such as S and micronutrients in various crop production systems (Rego *et al.*, 2005; Sahrawat *et al.* 2007, 2010a, 2011) on millions of small and marginal farmers' fields. Since 1999, ICRISAT and its partners are conducting systematic and detailed studies on the diagnosis and management of nutrient deficiencies in the semi-arid regions of Asia with emphasis on the semi-arid regions of India under the integrated watershed management program (Wani *et al.* 2009). These studies revealed wide spread deficiencies of multiple nutrients including micro-nutrients like boron, zinc and secondary nutrient sulfur in 80-100% of farmers' fields (Rego *et al.* 2005, Sahrawat *et al.* 2007, 2010b, 2011).

Role of soil organic matter in improving and sustaining soil health is well documented. In addition to its' importance for sustainable crop production, low soil organic matter in tropical soils is a major factor contributing to their poor productivity (Lee and Wani, 1989, Syers *et al.*, 1996, Katyal and Rattan, 2003; Bationo and Mokwunye, 1991; Edmeades, 2003; Harris 1999; Bationo *et al.*, 2008; Ghosh *et al.*, 2009; Materechera, 2010). Management practices that augment soil organic matter and maintain at a threshold level are needed. Sequestration of carbon in soil has attracted the attention of researchers and policy makers alike as an important mitigation strategy for minimizing impacts of climate change (Lal, 2004, Velayutham *et al.*, 2000, ICRISAT, 2005, Bhattacharya *et al.*, 2009., Srinivasarao *et al.* 2009) which also serves the purpose of enhancing soil moisture storage. Agricultural soils are among the earth's largest terrestrial reservoirs of carbon and hold potential for expanded C sequestration (Lal, 2004).

Now there is a growing realization that the adoption of ecological and sustainable farming practices can only reverse the declining trend in the global productivity and environment protection (Aveyard, 1988; Wani and Lee, 1992; Wani *et al.* 1995). It is great maladies that on the one side tropical soils are deficient in carbon and essential plant nutrients and on the other large quantities of carbon and nutrients contained in domestic wastes and agricultural byproducts are wasted. It is estimated that in cities and rural areas of India nearly 700 million t organic wastes is generated annually which is either burned or land filled (Bhiday, 1994). In this context, vermicomposting is a biotechnological process which can convert problem posing organic wastes into a valuable manure rich in essential nutrients to increase productivity of soils through environment friendly manner (Wani, 2002).

2. WHAT VERMICOMPOSTING MEANS?

Vermiculture or vermicomposting is derived from the Latin term vermis, meaning worms. Vermicomposting is a simple process of composting with the help of earthworms to produce a better enriched end product. It is one of the easiest methods to recycle wastes to produce quality compost in a short span of time. Vermicomposting differs from composting in several ways (Gandhi *et al.*, 1997). In vermicomposting, during the process earthworms consume biomass and break it into small pieces which expose raw waste biomass to intensive microbial decomposition. Moreover, after passing through the earthworm gut, resulting earthworm castings (worm manure) are also rich in microbial activity to hasten the composting process. While the raw biomass passes through earthworm gut (Coelom), coelomic fluid which has plant growth promoting properties, is also mixed with it. Therefore, earthworm castings (worm manure) in contrasts to ordinary compost are rich in plant nutrients including micronutrients (Table 1) growth regulators, promoting plant growth and fortified with pest repellence attributes as well! In short, earthworms, through a type of biological alchemy, are capable of transforming garbage into 'gold' (Vermi Co, 2001; Tara Crescent, 2003; Nagavallemma *et al.*, 2004).

Table 1: Nutrient composition of vermicompost and garden compost

Nutrient element	Vermicompost %)	Garden compost %)
Organic carbon	9.8–13.4	12.2
Nitrogen	0.51–1.61	0.8
Phosphorus	0.19–1.02	0.35
Potassium	0.15–0.73	0.48
Calcium	1.18–7.61	2.27
Magnesium	0.093–0.568	0.57
Sodium	0.058–0.158	<0.01
Zinc	0.0042–0.110	0.0012
Copper	0.0026–0.0048	0.0017
Iron	0.2050–1.3313	1.1690
Manganese	0.0105–0.2038	0.0414

Source: Nagavallemma *et al.*,(2004)

Going by its simplicity and numerous benefits, vermicomposting is being practised on a large scale in countries like India, Canada, Italy, Japan, Philippines, and United States (Asha *et al.*, 2008). Vermicomposting is being proposed as a technique globally for stabilizing the natural as well as anthropogenic wastes like sewage sludge, industrial sludge, plant-derived wastes, agro-industrial solid waste, household waste, animal dung, etc (Suthar, 2007).

3. PRE-REQUISITES OF VERMICOMPOSTING

3.1 Earthworms

There are nearly 3600 types of earthworms in the world and they are mainly divided into two types: 1) burrowing; and 2) non-burrowing. The burrowing types (*Pertima elongata* and *Pertima asiatica*) live deep in the soil. They come onto the soil surface only at night. These make holes in the soil up to a depth of 3.5 m and produce casts by ingesting 90% soil and 10% organic waste. The burrowing types are pale, 20 to 30 cm long and live for around 15 years. On the other hand, the non-burrowing types live in the upper layer of soil surface and eat 10% soil and 90% organic waste materials. This property of non-burrowing earthworms is used to convert the organic waste into vermicompost. *Eisenia fetida* and *Eudrilus eugenae* species of earthworms are consistently used in vermicomposting for their high multiplication rate (1 cocoon in every 3 days) and efficacy to convert organic matter into vermicompost (~200kg/1500 worms/2 months). Worms hatch from cocoon after an incubation period of 20-22 days and attain maturity in 50-55 days. The non-burrowing types are red or purple in colour and 10 to 15 cm long and their life span is only 28 months. They have relatively high tolerance to environmental variations and can tolerate temperatures ranging from 0 to 40°C but the regeneration capacity is more at 25 to 30°C.

A rapid multiplication of earthworm population is desired in converting large quantities of raw biomass into vermicompost. For developing understanding, a multiplication trial was conducted at the International Crops Research Institute for the Semi-Arid Tropics ICRISAT), Patancheru, Andhra Pradesh with three kinds of earthworm cultures (*Eisenia fetida, Eudrilus eugenae* and *Perionyx excavatus*) using wheat straw, chickpea straw, tree leaves (*Peltophorum* sp.) and *Parthenium mixed* with cow dung as feed materials (Nagavallemma *et al.*, 2006). There was an increase in earthworm population and size during incubation for 90 days. The three types of earthworms multiplied 12 to 18 times when grown individually using legume tree leaves and cow dung mixture as raw material (Table 2). However, mixed culture of all three species showed higher multiplication rate (27 times) than the individual species. Further studies on earthworm multiplication were also conducted at ICRISAT using tree leaves and *Gliricidia* stems mixed with cattle

Table 2: Multiplication trial of earthworm species at ICRISAT, Patancheru, India in 2000[1].

Earthworm species	Initial population	Final population	Increase (%)
Mixed culture	900	15950	1612 (27)
Eisenia fetida	90	1036	1051 (12)
Eudrilus eugenae	55	1007	1731 (18)
Perionyx excavatus	85	1192	1302 (14)

1. Mixture of legumes tree leaves and cow dung was used as substrate
2. Values in parentheses indicate increase in number of times at 90 days after incubation

Source: Nagavallemma *et al.* 2006

manure as feed material (Table 3). The earthworm population decreased when grown in mixture of *Gliricidia* stems and cattle manure. These results indicated that *Gliricidia* loppings could not be used for multiplication of earthworms. *Gliricidia* bark is known to possess toxic properties as it is used as rat poisoning bait. In another multiplication study at ICRISAT, there was maximum increase in earthworm population (570%) and weight (109%) when grown in a feed material containing tree leaves (3 kg) and cow dung (6 kg). In contrast,

Table 3: Multiplication trial of earthworms using different organic materials at ICRISAT, Patancheru, India during 2000-02

Earthworm species	Feed material	*Initial*		*Final*[1]	
		Population	Weight (g)	Population	Weight (g)
Eisenia fetida	Tree leaves (15 kg)	345	20	2510	207
	Cattle manure (15 kg)	510	207	1159	207
	Cattle manure (3 kg)+ Gliricidia stem (6 kg)	1255	101	1000	50
Eudrilus eugenae	Tree leaves (15 kg)	311	21	2986	334
	Cattle manure (15 kg)	2986	334	1522	216
	Cattle manure (3 kg)+ Gliricidia stem (6 kg)	2707	230	2249	100
Perionyx excavatus	Tree leaves (15 kg)	409	29	2707	230
	Cattle manure (15 kg)	2707	230	2650	187
	Cattle manure (3 kg)+ Gliricidia stem (6 kg)	3356	365	1000	50

1. At 90 days after incubation

Source: Nagavallemma *et al.* 2006

mortality of earthworms about (7 to 22%) was observed by growing them in a feed material containing soil (Table 4).

All these studies indicated that *Gliricidia* and tobacco leaves are not suitable for multiplication of earthworms. Perhaps the alkaloids and other principal compounds present in these leaves may effect the survival of earthworms. Also, soil and rabbit manure should not be mixed with earthworm feed material.

Table 4: Multiplication trials of mixed culture of earthworms using soil and other organic substrates at ICRISAT, Patancheru, India, 2002-02

Feed material	Initial		Final		Increase[1] (%)	
	No.	Wt. (g)	No.	Wt. (g)	No.	Wt. (g)
Cow dung (15 kg)	500	89	750	163	50	83
Tree leaves (3 kg) + cow dung (3 kg)	500	95	1545	125	21	32
Tree leaves (3 kg) + cow dung (6 kg)	500	110	3351	230	570	109
Pigeon pea leaves + pod shells + tree leaves (2 kg)+ cow dung 2 (kg)	500	98	2230	187	346	90
Pigeon pea leaves pod shells + tree leaves (2 kg) + cow dung	500	115	1490	193	198	68
(4 kg) Soil (5 kg)+ cow dung (5 kg)	1000	90	784	87	-22	-3
Soil (5 kg) + cow dung (5 kg) + pigeon pea leaves (1 kg)	1000	75	1023	241	2	223
Soil (5 kg) + cow dung (5 kg) + tree leaves (1 kg)	1000	160	929	170	-7	-6

1.At 90 days after incubation

Source: Nagavallemma *et al.* 2006

3.2 Organic Raw Biomass

Various sources of wastes like crop residue (Bansal and Kapoor, 2000; Talashilkar *et al.*, 1999) cattle waste (Chan and Griffiths, 1988; Hand *et al.*, 1998; Mitchel, 1997; Reeh, 1992), dairy sludge (Elvira *et al.* 1998; Gratelly *et al.*, 1996; Kavian and Ghatneker, 1991), sewage sludge (Diaz Burgos *et al.*, 1992; Benitez *et al.*, 1999), brewery yeast (Butt 1993), vine fruit industry sludge (Atharasopoulous, 1993), textile mill sludge (Kaushik and Garg, 2003), sugarcane industry wastes like pressmud, bagasse and trash (Bansal and Kapoor, 2000), kitchen and agro wastes (Garg *et al.*, 2006), paper waste and sludge (Butt, 1993; Elvira *et al.*, 1997; 1998; Gajalakshmi *et al.*, 2001; 2002) are being converted into valuable organic manures using earthworms. The micro flora of earth worm gut are highly potential in digesting the organic materials as well as polysaccharides like cellulose, sugars, chitin, lignin, starch and polylactic acids (Aira *et al.*, 2007; Vivas *et al.*, 2009; Zhang *et al.*, 2000). However, the sludges produced like from paper and dairy industries cannot be used alone as a feeding media to the earthworms (Butt, 1993; Gratelly *et al.*, 1996), but are mixed with organic residues in order to balance the nutrients before feeding the earthworms (Grately *et al.*, 1996). Some examples of widespread agricultural wastes comprise sorghum straw and rice straw after feeding cattle, dry leaves of crops and trees, pigeonpea (*Cajanus cajan*) stalks, groundnut (*Arachis hypogaea*) husk, soybean residues, vegetable wastes, weed (*Parthenium* spp.) plants before flowering, fiber from coconut (*Cocos nucifera*) trees and sugarcane (*Saccharum officinarum*) trash which can be converted into vermicompost. In addition poultry wastes, food industry wastes, municipal solid wastes, biogas sludge etc. also serve as good raw materials for vermicomposting.

Studies even revealed that waste water sludge can be used in vermicomposting which decreases the organic, inorganic contaminates and pathogens in it and the vermicompost so produced is a very rich source of nutrients which can significantly improve crop grain yields (Correa *et al.*, 2005; Cordovil *et al.*, 2007).

In general cowdung is the most preferred food for earthworms and so it is best to mix it with other raw biomass. Further, phosphorus content of the end product vermicompost can be significantly increased by mixing low cost rock phosphate which is converted into soluble form by microbial action during composting process (Nagavallema *et al.*, 2006). The quantity of raw materials required using a cement ring of 90 cm in diameter and 30 cm in height or a pit or tank measuring 1.5 m × 1 m × 1 m is given below:

- Dry organic wastes (DOW) 50 kg
- Dung slurry (DS) 15 kg
- Rock phosphate (RP) 2 kg
- Earthworms (EW) 500–700
- Water (W) 5 L every three days

The various ingredients are used in the ratio of 5:1.5:0.2:50–75:0.5 of DOW:DS:RP:EW:W. In the tank or pit system 100 kg of raw material and 15–20 kg of cow dung are needed for each cubic meter of the bed.

3.3 Environmental and other requirements

3.3.1 Moisture

Earthworms breathe through their skins and therefore must have a moist environment in which to live. If a worm's skin dries out, it dies. The bedding must be able to absorb and retain water fairly well if the worms are to thrive. Moisture content in the bedding of less than 50% is dangerous. With the exception of extreme heat or cold, nothing will kill worms faster than a lack of adequate moisture. The ideal moisture-content range for materials in conventional composting systems is 45-60% (Rink et al., 1992). In contrast, the ideal moisture-content range for vermicomposting or vermiculture processes is 70-90% (Georg, 2004).

3.3.2 Aeration

Worms are oxygen breathers and cannot survive anaerobic conditions defined as the absence of oxygen). Anaerobic conditions will kill the worms very quickly. Not only are the worms deprived of oxygen, they are also killed by toxic substances (e.g., ammonia) created by different sets of microbes that bloom under these conditions.

3.3.3 Temperature

Eisenia can survive in temperatures as low as 0°C, but they don't reproduce at single-digit temperatures and they don't consume as much food. It is generally considered necessary to keep the temperatures above 10 °C (minimum) and preferably 15 °C for vermicomposting efficiency and above (15 °C minimum) and preferably 20 °C for productive vermiculture operations. In general, warmer temperatures above 20 °C) stimulate reproduction. *Eisenia* can survive having their bodies partially encased in frozen bedding and will only die when they are no longer able to consume food. Above 35 °C will cause the worms to leave the area. If they cannot leave, they will quickly die. *Eudrilus eugenae* can tolerate high temperature than *Eisenia foetida* in a condition of more humidity but has a very narrow temperature range and cannot survive at temperatures of below 7°C (Misra *et al.*, 2003).

3.3.4 Shade

Earthworms dislike sunlight; therefore cool and shade is the first and foremost requirement for vermicomposting. Therefore a place under a tree may be an ideal place for vermicomposting or otherwise construction of a shed is a pre-requisite for successful vermicomposting.

3.3.5 pH

Worms can survive in a pH range of 5 to 9 (Edwards, 1998). Most experts feel that the worms prefer a pH of 7 or slightly higher. Some studies found that the range of 7.5 to 8.0 was optimum (Georg, 2004).

3.3.6 Salt Content

Worms are very sensitive to salts, preferring salt contents less than 0.5% (Gunadi *et al.*, 2002). If saltwater seaweed is used as a feed and worms do like all forms of seaweed then it should be rinsed first to wash off the salt left on the surface.

4. PRECAUTIONS

Different feeds can contain a wide variety of potentially toxic components. Prominent among them are de-worming medicine in manures, particularly horse manure. Most modern deworming medicines break down fairly quickly and are not a problem for worm growers. Application of fresh manure from recently de-wormed animals could prove costly. Harmful detergent cleansers, industrial chemicals and pesticides can often be found in feeds such as sewage or septic sludge, paper-mill sludge, or some food processing wastes. Some naturally occurring tannin in trees like as cedar and fir can harm worms and even drive them from the beds. Gunadi *et al.* 2002) point out that pre-composting of wastes can reduce or even eliminate most of these threats. However, pre-composting also reduces the nutrient value of the feed, so this is a definite trade-off.

Materials of animal origin such as eggshells, meat, bone, chicken droppings, etc are not preferred for preparing Vermicompost. *Gliricidia* loppings and tobacco leaves are also not suitable for rearing earthworms. The material to be organic. Vermicompost should be free from plastics and glass pieces as they damage the worms' gut. After completion of the process, the Vermicompost should be removed from the bed at regular intervals and replaced by fresh waste materials, because earthworm casts are toxic to their population. The earthworms should be protected against birds, termites, ants and rats.

5. METHODS OF VERMICOMPOSTING

Vermicompost can be prepared in underground pits or aboveground heaps. Underground pits for vermicomposting should ideally be 1 m deep and 1.5 m wide and the length may vary as required. In vermicomposting in aboveground heaps, the waste material is spread on the ground surface. Sunitha *et al.*, (1997) compared the efficacy of pit and heap methods of preparing vermicompost under field conditions. Considering the biodegradation of wastes as the criterion, the heap method of preparing vermicompost was better than the pit method probably due to better aeration in heap method. Earthworm population was high in the heap method, with a 21-fold increase in *Eudrilus eugenae* as compared to 17-fold increase in the pit method. Biomass production was also higher in the heap method (46-fold increase) than in the pit method (31-fold). Consequent production of vermicompost was also higher in the heap method than in the pit method.

For regular and large scale production of vermicompost, it is desirable to construct tanks above the ground. The important criteria to fix dimensions is to have a width to facilitate reach to each and every part of the unit and the height should not be more as it creates problems in moisture maintenance. Following structure types are suited for different needs.

5.1. Cement Rings

Vermicompost can be prepared above the ground by using cement rings (Figure 3). The size of the cement ring should be 90 cm in diameter and 30 cm in height. Such small units are very suited for small scale production at household level. The details of preparing vermicompost by this method have been described in a later section. This method of vermicomposting at household level in community watersheds is popular in India. This is also a popular method of vermicomposting in Cuba (Cracas, 2000).

Fig 3: Cement ring model for vermicomposting at ICRISAT

5.2 Commercial Model

The commercial model for vermi-composting developed by ICRISAT consists of four chambers enclosed by a wall (1.5 m width, 4.5 m length and 0.9 m height) (Figure 4). The walls are made up of different materials such as normal bricks, hollow bricks, shabaz stones, asbestos sheets and locally available rocks. This model contains partition walls with small holes to facilitate easy movement of earthworms from one chamber to another (Figure 5). Providing an outlet

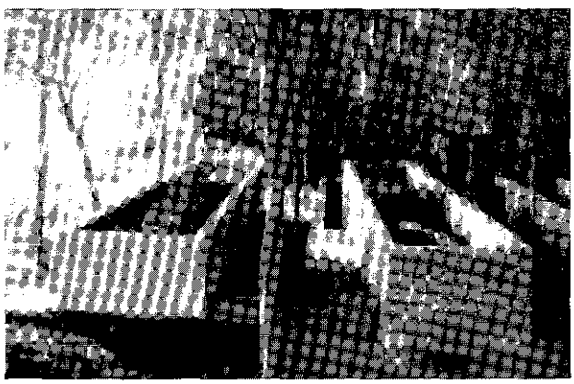


Fig 4: Commercial model for vermicomposting

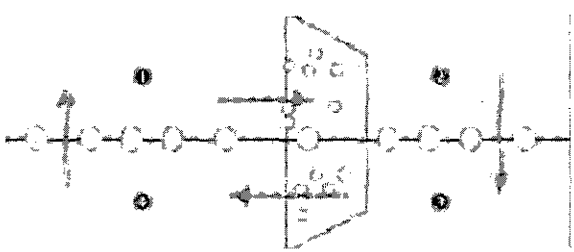


Fig 5: Diagrammatic representation of the commercial model with four chambers for vermicomposting

at one corner of each chamber with a slight slope facilitates collection of excess water, which is reused later or used as earthworm leachate (vermin wash) for spraying on crop. The outline of the commercial model is given in Figure 5. The four components of a tank are filled with plant residues one after another. The first chamber is filled layer by layer along with cow dung and then earthworms are released. Then the second chamber is filled layer by layer. Once the contents in the first chamber are processed the earthworms move to chamber 2, which is already filled and ready for earthworms. This facilitates harvesting of decomposed material from the first chamber and also saves labor for harvesting and introducing earthworms. This technology reduces labor cost and saves water as well as time.

6. BENEFITS OF VERMICOMPOST

6.1 Balanced plant nutrient source

The final nutrient composition of the vermicompost depends on the type of raw biomasss used in composting. It is always better to know the chemical composition of the waste to be converted into vermicompost as the knowledge of structural polysaccharides as well as the nitrogen content in the waste will help us to develop a proportional ratio to obtain a stable end product suitable for agricultural use (Elvira *et al.*, 1997). Vermicompost, however, is in general rich in nutrients than other compost due to better decomposition of it. Earthworms consume various organic wastes and reduce the volume by 40-60%. The moisture content of castings ranges between 32 to 66% and the pH is around 7.0. A mature vermicompost contain 9.8 to 13.4% organic carbon, 0.51 to 1.61% nitrogen, 0.19 to 1.20% phosphorus and 0.15 to 0.73% potassium, and other plant nutrients (Table 1) Nagavallemma *et al.* (2004), in addition to secondary and micronutrients like sulphur, calcium, magnesium, boron, zinc, copper, iron, manganese, molybdenum chlorine and nickel (Manivannan *et al.* 2009). Vermicompost has high cation exchange capacity (Manivannan *et al.* 2009) to hold plant nutrients which is useful in increasing nutrient use efficiency.

6.2 Source of enzymes and plant growth promoters

The digestive epithelium of the simple straight tubular gut of worms is known to secrete cellulase, amylase, ureaes, invertase, protease, phosphatase (Ranganathan and Vinotha, 1998) and so vermicompost becomes rich in these enzymes. Humic acid (Atiyeh *et al.*, 2002) plant growth regulators like auxins, gibberellins and cytokinins (Tomati *et al.*, 1988) are the major components of vermicompost, which help plant in increasing growth as well as yields. These components are mainly produced by the action of soil micro organisms like bacteria, fungi, actinomycetes and earthworms.

6.3 Soil Conditioner

Studies on vermicompost indicate that it increases soil pore space, water holding capacity, organic carbon, and reduces particle and bulk density (Manivannan *et al.,* 2009; Marinari *et al.,* 2000). Vermicompost favourably affect soil physical structure and so improves soil tilth which facilitates easy germination for seeds and a good root growth.

6.4 Soil Health

Compared to conventional composts, vermicompost is much richer in microbial diversity, populations and activities (Subler *et al.,* 1998). The application of vermicompost so increases the beneficial populations of microorganisms in the soil (Jeyabal and Kupuswamy, 2001; Manivannan *et al.,* 2009), microbial respiration, microbial biomass C and N and relatively higher fungal population (Pramanik *et al.,* 2010; Nagavallemma *et al.,* 2006). Increases in microbial populations and activities are key factors influencing rates of nutrient cycling, production of plant growth-regulating materials, and the build-up of plant resistance or tolerance to crop pathogen and nematode attacks (Arancon *et al.,* 2006). Arbuscular mycorrhiza fungi (AMF) colonization which is important in nutrient uptake in the plant in exchange of carbon compounds from the host is also increased (Cavender et al., 2003). In addition, vermicompost also reduces the proportion of water-soluble chemical species, which cause possible environmental contamination (Mitchell and Edwards, 1997). In field study Sarangi and Lama (2013) found that application of vermicompost increased soil moisture in 0-15 cm layer by 3.06%, soil organic carbon by 0.39% while pH changed from acidic to neutral. Addition of vermicompost prepared with 5% lime also increased the soil microbial biomass carbon by 147%. The beneficial effect of vermicomost on soil chemical and physical properties have also been reported (Niranjan *et al.,* 2010; Nada *et al.,* 2011; Mahmoud and Ibrahim, 2012).

6.5 Disease and pest suppression in plants

Some studies have demonstrated the suppression of soil borne plant pathogens by vermicompost (Hoitink and Fahy, 1986; Szczech *et al.,* 1993), or disease suppression in the presence of earthworms (Stephens and Davoren 1997; Stephens *et al.,* 1994). Application of vermicompost suppresses the growth of pathogenic fungi like *Pythium, Rhizoctonia* and *Verticillium* (Hoitink and Fahy, 1986) and populations of parasitic nematodes (Arancon *et al.,* 2006). Disease suppression by compost may be attributed to the activities of competitive or antagonistic microorganisms as well as the antibiotic compounds present in the vermicompost.

Similarly, vermicompost have been found effective to suppress the incidence of insect pests like leaf miner (*Aproaerema modicella*) in groundnut

(Ramesh, 2000), *Heteropsylla cubana* in *Leucaena* (*Leucaena lecocephala*) (Biradar *et al.*, 1998), caterpillars (*Pieris brassicae* L.) in cabbage (*Brassica oleracea* L.), mealy bugs in tomato (*Lycopersicon esculentum*), aphids (Myzus persicae Sulz.) in pepper (*Capsicum annuum* L.) (Biradar *et al.*, 1998) and cucumber beetles (*Acalymma vittatum* and *Diabotrica undecimpunctata*) etc. (Yardim *et al.*, 2006).

6.6 Cost cut on chemical fertilisers

The escalating cost of chemical fertilisers in addition to deleterious effects of their imbalanced use is another reason to trigger a search for integrated nutrient management options. Vermicompost is a potential alternative rich in essential nutrients to cut cost on chemical fertilisers along with other multifarious benefits. In addition, it increases the efficiency of applied chemical fertilisers by way of adsorbing nutrient ions on extensive adsorption sites on organic colloids and which are slowly released in due course of time.

6.7 Other miscellaneous benefits

Vermicompost has numerous miscellaneous benefits. It reduces pressure on landfills and is an environment friendly option. It also opens opportunities for livelihoods based on sale of vermiculture or vermicompost and it may be a highly profitable proposition for farmers having dairy units. Vermicomposting is a low cost easily adoptable technology.

7. VERMICOMPOSTING AS LIVELIHOOD ENTERPRISE

Vermicompost has a high potential value, but that potential has not been realized in most areas. Potential income diversification opportunities exist in the sale of vermicompost and worms in addition to its use by farmers in their own fields. Any farmer wishing to go into the business of making and selling vermicompost or worms need to assess local market need before venturing into it. ICRISAT has promoted and established vermicomposting as a livelihood micro enterprise for women in various watersheds like Adarsha Watershed, Kothapally, Andhra Pradesh Rural Livelihood Program (APRLP) watersheds etc.

Women's tenacity in house holding is remarkable. In the watershed villages, women's propensity to work against all odds is shown in the management of household consumption and production under conditions of increasing poverty. Lakshmi, a poor resident of Kothapally village, Andhra Pradesh, India, eked her livelihood as a farm labourer until she was introduced to vermicomposting, i.e. converting degradable garbage, weeds and crop residues into valuable organic manure using earthworms. She earned US$ 36 per month from this activity. She has also inspired and trained 300 peers in

Fig 6: Vermicomposting by women SHGs

50 villages of Andhra Pradesh. Lakshmi has also achieved a singular recognition by becoming a Fellow of the Jamsetji Tata National Virtual Academy for Rural Prosperity for her achievement of empowering women members.

After training of women from Kistapur at ICRISAT on vermicompost preparation and technical support at village two SHGs have started with two vermi-compost units in the village. At the moment they are able to produce large quantities of vermicompost out of two units. The vermicompost produced by them is used for Pongamia nursery raising. Now SHG member want to produce more vermicompost by strengthening and expanding the already existing facility in the village. Looking at the success some more groups are also showing interest to start the activity soon Figure 6).

Similarly women members in Powerguda also initiated this activity in a small scale. At the same time the women farmers in Behranguda are also motivated by training at ICRISAT on vermi-composting. They also started producing good quality vermicompost in large quantities by having very big unit with four chambers 10′ x 10 ′ x 2 ′). The women in all three villages have built confidence in making good quality vermicompost and its use in different crops. At the moment they have become trainers to train the women in other villages.

8. VERMICOMPOSTING PROCESS

Vermicomposting involves the following steps (Nagavallemma *et al.*, 2006) which are depicted in Figure 7(a–k):

1. Cover the bottom of the cement ring with a layer of coconut husk or slowly decomposable biomass (Fig. 7a).
2. Spread 15–20 cm layer of organic waste material on the surface (Fig. 7b). Sprinkle rock phosphate powder if available (it helps in improving nutritional quality of compost) on the waste material and then sprinkle cow dung slurry (Fig. 7c and d). Fill the ring completely in layers as described. Paste the top of the ring with soil or cow dung (Fig. 7e). Allow the material to decompose for 15 to 20 days.

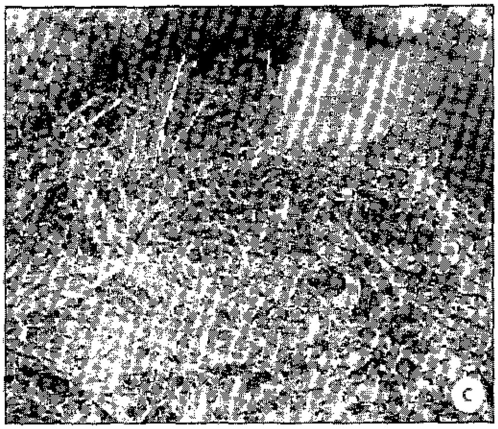
3. When the heat evolved during the decomposition of the materials has subsided (15–20 days after heaping), release selected earthworms 500 to 700) through the cracks developed (Fig. 7f).
4. Cover the ring with wire mesh or gunny bag to prevent birds from picking the earthworms.
5. Sprinkle water every three days to maintain adequate moisture and body temperature of the earthworms (Fig. 7g).
6. The vermicompost is ready in about 2 months if agricultural waste is used and about 4 weeks if sericulture waste is used as substrate(Fig. 7h).
7. The processed vermicompost is black, light in weight and free from bad odor. Identification of exact maturity of the vermicompost is an important component as the excess time leads to loss of nitrogen, polysaccharides as well as immobilization of nutrients like N and P (Meunchang *et al.*, 2005). Moreover, the application of non matured vermicompost to the soils can cause harmful effects to the soil due to incomplete stabilization of the compounds (Deportes *et al.*, 1995).
8. When the compost is ready, do not water for 2–3 days to make compost easy for shifting. Pile the compost in small heaps and leave under ambient conditions for a couple of hours when all the worms move down the heap in the bed (Fig. 7i). Separate upper portion of the manure and sieve the lower portion to separate the earthworms from the manure (Fig. 7j). The culture in the bed contains different stages of the earthworm's life cycle, namely, cocoons, juveniles and adults. This culture may be transferred to fresh half decomposed feed material by keeping aside it the harvested vermicompost for 20-22 days (Hatching period for cocoons). The excess as well as big earthworms can be used for feeding fish or poultry. Pack the compost in bags and store the bags in a cool place (Fig. 7k).
9. Prepare another pile about 20 days before starting the process and repeat the process by following the same procedure as described above.

9. VERMICOMPOST USE IN CROP PRODUCTION

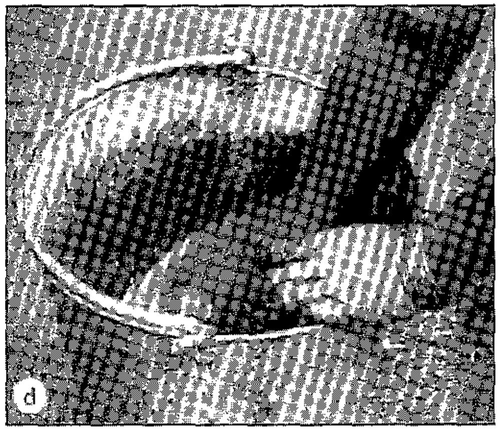
Vermicompost can be used for all crops: agricultural, horticultural, ornamental and vegetables at any stage of the crop. For general field crops and vegetables, around 3-4 t ha^{-1} vermicompost is used by mixing with seed at the time of sowing or by row application when the seedlings are 12–15 cm in height. For vegetable and flower crops vermicompost is applied around the base of the plant. It is then covered with soil and watered regularly. Normal irrigation is followed. For vegetables for raising seedlings to be transplanted,

Plastic sheet placed below the ring

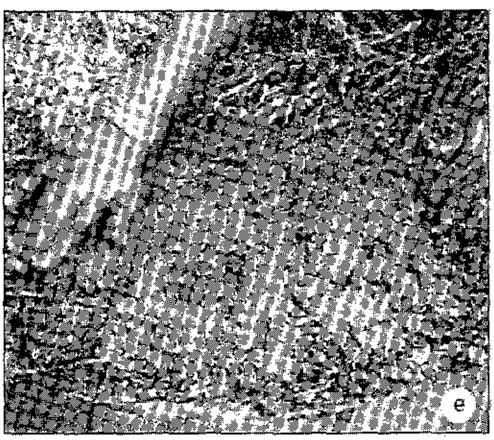
Layer of raw material placed on polythene sheet



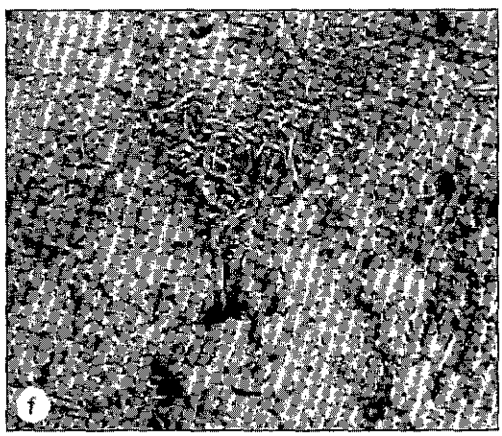
Rock phosphate powder sprinkled on organic material



Cow dung slurry



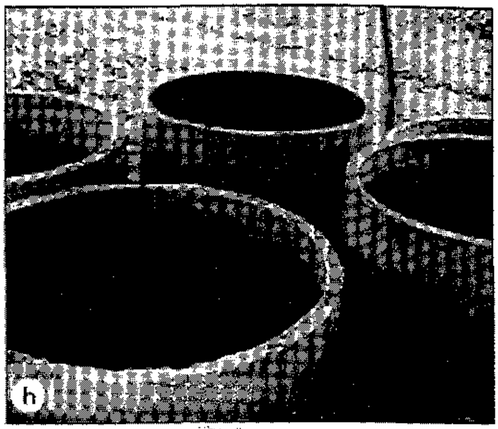
Cement ring sealed with cow dung



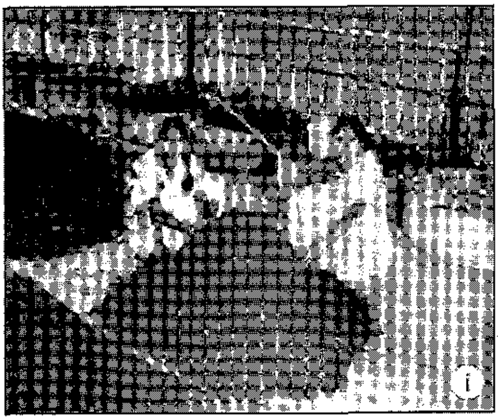
Earthworms are released near cracks

Fig. 7(a-f): Vermicomposting process

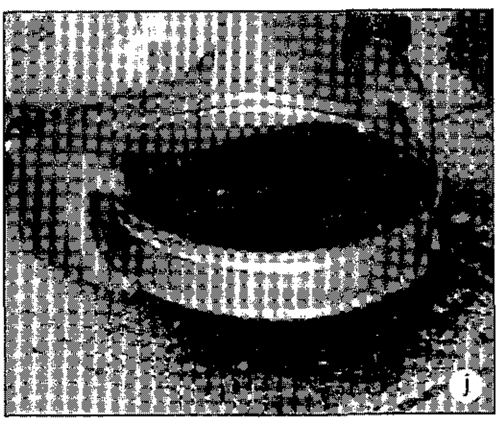
Cement ring covered with gunny bag



Processed vermicompost



Heaping of vermicompost



Compost sieved

Bag filled with vermicompost

Fig. 7(g-k): Vermicomposting process vermicompost at 1 t ha^{-1} is applied in the nursery bed. This results in healthy and vigorous seedlings. For fruit trees the amount of vermicompost ranges from 5 to 10 kg per tree depending on the age of the plant. For efficient application, a ring (15–18 cm deep) is made around the plant.

9.1 Effects on crop productivity

A large number of studies were conducted on cereals and legumes (Buckerfield and Webster, 1998; Chan and Griffiths, 1998; Jayabal and Kupuswamy, 2001; Mba, 1996), vegetables (Atiyeh *et al.*, 1999; 2000b; Subler *et al.*, 1998; Gutierrez-Miceli *et al.*, 2007; Sarangi and Lama, 2013), ornamental and flowering plants (Atiyeh *et al.*, 2000), and fruit plants (Singh *et al.*, 2008). These scientific evidences proved that vermicompost can influence favourably the plant growth as well as productivity significantly (Edward, 1998). Sarangi and Lama (2013) reported an increase in grain and pod yields of upland rice and groundnut,by 120% and 107% respectively, over control following application of vermicompost prepared with 5.0% lime.

ICRISAT has also evaluated the role of vermicompost in integrated nutrient management (INM) in on-farm trials. The vermicompost produced on-farm is promoted for use to enhance soil quality in crop production and to cut cost on the chemical fertilisers. INM trials were conducted on soybean in Madhya Pradesh, India, based on soil test analysis to demonstrate the benefits of using vermicompost along with mineral fertilisers for sustaining productivity. The vermicompost was added to meet the 50% P requirement of the soybean crop. Applications of S, B, Zn and vermicompost were made as basal at sowing of the crop. The findings revealed that, the soil test based balanced nutrition including S, B and Zn increased soybean grain and straw yield over the farmers practice (Table 5). Interestingly, the substitution of 50% of chemical fertilisers with vermicompost either maintained yield level or increased it over the balanced nutrition with nutrients applied solely through chemical fertilisers. The integrated approach of applying 50% of the recommended chemical fertilisers plus vermicompost increased grain yield significantly over the soil test based balanced nutrition through chemical fertilisers by 14% in Shajapur district and by 10% in Guna district. The grain yields with integrated approach were however statistically at par with balanced nutrition through chemical fertilisers in Raisen and Indore districts.

Similarly, on-farm trials were also conducted in Rajasthan on the use of vermicompost as a source of organic matter and plant nutrients by partially replacing chemical fertilisers. Vermicompost was added to replace 50% of N requirement in non-legumes and 50% of P requirement in legumes. The balanced nutrition (BN) increased grain yield of crops by 6 to 52% and straw yield by 1 to 56% as compared to farmer's practice (Table 6). Interestingly,

Table 5. Effects of balanced nutrient management BN, nutrients added through chemical fertilisers) and INM on yield of soybean under rainfed conditions in various districts of Madhya Pradesh in 2010 rainy season

District	No. of trials	Grain yield kg ha^{-1})			CD 5%)	Straw yield kg ha^{-1})			CD 5%)
		FP	BN	50% BN+VC		FP	BN	50% BN+VC	
Raisen	30	1360	1600	1600	115	1920	2100	2180	109
Shajapur	15	1900	2120	2410	69	1610	1650	1750	87
Indore	15	1680	1700	1720	27	1760	1790	1850	33
Guna	12	1270	1440	1580	34	2130	2380	2570	250
Anandpur	7	1300	1580	1500	445	1630	1990	1950	815
Vidisha	2	1130	1410	1700	640	1650	1900	1950	130

Table 6: Effects of farmer's practice FP), balanced nutrient management BN) and INM 50% BN + VC) treatment on crop yield in three districts of Rajasthan, 2010 rainy season

District	No. of trials	Crop	Grain yield kg ha^{-1})			CD 5%)	Straw yield kg ha^{-1})			CD 5%)
			FP	BN	50% BN+ VC		FP	BN	50% BN+VC	
Banswara	15	Maize	2850	3390	3620	780	4060	4820	5230	727
Bhilwara	15	Maize	4410	5420	5520	710	5230	6770	6910	843
Jhalawar	15	Soybean	1700	1810	2020	82	1490	1510	1540	128
Tonk	7	Groundnut	820	960	1060	107	1030	1240	1330	153
	3	Pearl millet	2210	2560	2800	325	2740	3200	3370	611
	5	Maize	2840	3350	3560	280	3580	4170	4430	464
Swai Madhopur	9	Pearl millet	1410	1590	1700	234	1680	1930	2050	291
	1	Black gram	330	500	560	-	390	610	670	-
	2	Maize	1560	2180	2530	268	1860	2610	2830	298

the inclusion of vermicompost in the INM approach not only reduced cost on chemical fertilisers, but also increased grain and straw yield over and above the balanced nutrition treatment nutrients supplied solely through chemical fertilisers. The increase in grain yield using INM approach over the BN treatment varied from 2 to 16% in maize, 12% in soybean, 10% in groundnut, and 7 to 9% in pearl millet and 12% in groundnut. Similar increase in straw/ stover yield was also observed (Table 6).

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