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Title	Is composting worm availability the main barrier to large-scale adoption of worm-based organic waste processing technologies?
Type	Article
URL	https://clock.uclan.ac.uk/id/eprint/18809/
DOI	https://doi.org/10.1016/j.jclepro.2017.06.226
Date	2017
Citation	Furlong, Claire, Rajapaksha-mudiyansela, Nalika, Butt, Kevin Richard and Gibson, Walter (2017) Is composting worm availability the main barrier to large-scale adoption of worm-based organic waste processing technologies? Journal of Cleaner Production, 164. pp. 1026-1033. ISSN 0959-6526
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It is advisable to refer to the publisher's version if you intend to cite from the work.
<https://doi.org/10.1016/j.jclepro.2017.06.226>

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Is composting worm availability the main barrier to large-scale adoption of worm-based organic waste processing technologies?

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Abstract

Organic waste is the largest typology of waste generated globally, which if untreated, can cause environmental pollution and be a public health risk. The worm-based processing of organic waste is known as vermicomposting and is recognized as a sustainable approach for the management of organic waste streams. Although this technology has been around since the 1970s and many different organic wastes have been successfully processed via vermicomposting, this technology has not been widely adopted at national or international levels. This paper explores the hypothesis that the availability of composting worms is the reason for low uptake of this technology. A market analysis of composting worm farm (vermiculture) businesses in two countries (South Africa and India) was undertaken to explore the hypothesis. It was found that the Indian market had the capacity to supply over 70,000 kg of worms per month, whilst for the South Africa market this was 3000 kg. Both markets have the capability to increase production by two-fold or more. Overall, the study concludes that worm supply is not a barrier to the scaling-up of worm-based technologies in either country. Additionally, these countries show the potential to assist development of worm-based systems in neighboring countries through export of composting worms.

Keywords: Composting worms; India; South Africa; Vermicomposting; Vermifilters; Vermiculture

1 Introduction

Organic waste is defined as any biodegradable waste that originates from animal or plant sources. Organic waste streams include sewage and fecal sludge, agricultural waste, food processing waste, and a fraction of municipal solid waste and it is the largest typology of waste generated globally. It accounts for the largest fraction of municipal solid waste; it has been estimated that globally 598 million tonnes of organic municipal solid waste are generated annually (Hoonweg and Bhada-Tata, 2012). The authors estimate that human population produces 800 million tonnes of organic waste annually, in the form of feces. This waste requires treatment to process and recycle nutrients, and to reduce the negative environmental impact when released into the environment. Additionally, unplanned release of unprocessed organic waste can pose a public health risk due to the spread of pathogens. Although difficult to quantify, it is believed that a majority of the world's organic waste goes untreated, with an estimated 350 million tonnes of untreated human feces annually discharged into the environment.¹ Therefore, there is an urgent need for the large scale adoption of sustainable organic waste processing technologies.

Worm-based processing of organic waste is known as vermicomposting, a process developed in the late 1970s. This term did not appear in scientific literature until 1980, but now an extensive body of

research now exists. Scientific interest in this organic waste processing technology has grown rapidly e.g. only seven papers were published in the 1980s, but over 338 have already been published this decade.² Vermicomposting has now been used to transform a wide range of organic wastes, from agricultural residues (Lim et al., 2015) and animal wastes (Lalander et al., 2015), plant waste (Abbasi et al., 2015) food wastes, municipal solid waste (Singh et al., 2011a) through to sewage sludge (Sinha et al., 2010; Yadav and Garg, 2011) and industrial wastes (Singh et al., 2011b).

Vermicomposting is a highly attractive approach for the treatment of organic waste due to low investment cost and the speed of processing, compared with other waste treatment technologies (Abbasi et al., 2015; Lim et al., 2016). Additionally, the nutrients in the organic waste are recycled into a high value soil amendment known as vermicompost (Lim et al., 2014, 2016; Wu et al., 2014). Recently there has been renewed interest in this technology (Abbasi et al., 2015; Jiang et al., 2016; Lim et al., 2014, 2016), this due to the inherent sustainability of the technology. Earthworms are known to sequester carbon through stabilization, hence their action mitigates climate change (Zhang et al., 2013). Furthermore, no methane is produced during vermicomposting as it is an aerobic process and greenhouse gas emissions are significantly lower compared with conventional composting (Komaketch et al., 2015).

An area which is developing rapidly and has huge potential for global impact is the use of vermicomposting in the sanitation sector. Vermicomposting of sewage sludge was one of the first wastes to be researched (Edwards, 2011) with this process being utilized selectively in the USA and Australia (Sinha et al., 2010). More recently, researchers have been exploring the use of vermifilters (biological filters containing worms) for the treatment of sewage sludge with high water content (Zhao et al., 2010) and wastewater (Jiang et al., 2016, Kadam et al., 2009; Li et al., 2009). Additionally, a small-scale vermifilter for treating fecal sludge at a household level has been developed and trialed for use in low-to middle-income countries (Furlong et al., 2014, 2015, 2016). Worm-based technologies therefore have the potential to aid the global sanitation crisis. This approach is thought to be particularly appropriate for low- and middle-income countries, as it offers a sustainable, cost effective and ecological approach for effective management of organic waste including human excreta (Zhao et al., 2010; Huang et al., 2013). Additionally, the potential markets for these technologies are huge as it is estimated that 2.5 billion people lack access to improved sanitation (WHO/UNICEF, 2012) and approximately 1.8 billion people rely on basic pit latrines (Graham and Polizzotto, 2013).

Although trials of vermicomposting organic waste have been ongoing since the 1970s, this technology has not been widely implemented. Having an appropriate worm species, or combination of species, is a key determinant for scaling-up of any worm-based organic waste processing technology. The types of worms used in these processes are known as composting worms and are naturally found in the organic soil horizon, in or near the surface litter, and feed on organic matter. There are many species of composting worms, and some of the most commonly farmed species and their characteristics are provided in Table 1.

Table 1 Selected aspects of the biology of composting worms (adapted from Dominguez and Edwards, 2011).

Parameter	Worm Species			
	<i>E. fetida</i>	<i>E. andrei</i>	<i>E. eugeniae</i>	<i>P. excavates</i>
Color	Brown and buff bands	Red	Reddish brown	Reddish brown
Adult size (mm)	4–8 × 50–100	4–8 × 50–100	5–7 × 80–190	4–5 × 45–70
Mean adult mass (g)	0.55	0.55	2.7–3.5	0.5–0.6
Time to maturity (days)	28–30	21–28	40–49	28–42
Number of cocoons/day	0.35–0.5	0.35–0.5	0.42–0.51	1.1–1.4
Incubation time (days)	18–16	18–16	12–16	18
Hatching viability (%)	70–80	72	75–84	90
Number of worms/cocoons	2.5–3.8	2.5–3.8	2–2.7	1–1.1
Life cycle (days)	45–51	45–51	50–70	40–50
Temperature range (oC)	0–35	0–35	16–30	25–37
Optimal temperature (oC)	25	25	25	>25
Moisture range (%)	70–90	70–90	70–85	–
Optimal moisture (%)	80–85	80–85	80	–

The commercial worm farming (vermiculture) industry has never been fully studied and little information is available concerning composting worm supply capabilities at a national level for any country. The aim of this research was to determine if worm supply represents a barrier to large-scale adoption or scaling-up of worm-based organic waste processing technologies. This paper evaluates the current vermiculture markets and the potential for scaling-up vermicomposting technologies in two countries, India and South Africa. It also evaluates the ability of these markets to supply composting worms for a novel worm-based technology.

2 Methodology

2.1 Country selection

India and South Africa were chosen as they are known to have a history of vermicomposting (Kale, 2011; Munroe, 2004) and therefore thought to have well-developed vermiculture industries. India is thought to be the World's largest producer of vermicompost, it is widely reported that the affiliates of the Morarka Foundation produce over 50,000 tonnes of vermicompost per year. The focus in India has been on the production of vermicompost to use in small scale agriculture, rather than waste processing. This may change as vermicomposting is being nationally promoted as an official technology for solid waste management under the Clean India Mission (Swachh Bharat Mission launched in 2014). In South Africa the focus is on vermicompost production for gardens and small scale agriculture, and small scale decentralized waste processing i.e. winery or farm waste etc. There is no national program promoting this technology in South Africa.

Additionally, both countries generate significant amounts of municipal solid waste. India generated 109,589 tonnes per day (0.3 kg/capita/day) and South Africa generated 53,425 tonnes per day (2 kg/capita/day) in 2012, with between 15% and 35% of this being organic waste (Department of Environmental Affairs, 2012; Hoonweg and Bhada-Tata, 2012). As the organic fractions are largely unmanaged this leads to significant greenhouse gas emissions. This waste stream accounts for 1% in India and 4% in South Africa of the total greenhouse gas emissions in each country (Hoonweg and Bhada-Tata, 2012). Additionally, a majority of both populations use onsite sanitation which leads to vast amounts of fecal sludge that needs to be treated before it is disposed of in the environment. South Africa alone produced 673,360 tonnes of fecal sludge in 2011, which far exceeds the amount of organic municipal waste generated in this country (Department of Environmental Affairs, 2012). Hence both were considered to be good potential markets for novel vermicomposting technologies.

Two markets (countries) were chosen so that a comparison between them could be drawn. This was made simpler as they were assumed to be independent markets; due to geographic distance they were unlikely to have an overlapping customer base. Furthermore, having examples on separate continents allowed for an assessment of the potential growth through exportation in two distinct geographical areas. Additionally, English is an official language and widely spoken in both countries, meaning that no translation was required.

2.2 Data collection

Businesses were identified through extensive web-based searches using the following terms; “vermiculture; worm farm; vermicompost; composting worm(s)” together with the country name (India or South Africa). The data collected was collated into supplier directories for each country, which included contact details for each business. A survey was then developed to gather detailed information from each company listed in the directory. It covered composting worm supply capabilities (i.e. worm species farmed, capacity, cost of worms, potential for expansion and questions on worm cocoons (egg capsules), as they are lighter and more robust, so would be easier to transport and export than live worms. The final survey amounted to three A4 pages and took approximately 20 min to complete.

Stratified sampling of all companies listed by email was employed. Due to the relatively few businesses identified in South Africa, snowball sampling was used to target other local vermiculture businesses. An electronic survey was not appropriate, due to intermittent internet connectivity and major problems with spam emails that contain suspicious links in both countries. The final survey was attached to an email, which introduced the researchers and the aim of the study. Therefore, email was chosen as the method of survey distribution, as all companies had an online presence (i.e. webpage or contact details listed on the internet) and an email address. Further email, online or telephone contact was attempted if a response was not initially gained.

The responding companies were anonymized and results presented were critically evaluated. Analysis included an assessment of each country's ability to take a novel worm-based technology to scale. As the known mass of worms is required to make this assessment, the “Tiger Toilet” (a worm-based sanitation system) was chosen as 2 kg of worms is required per unit (e.g. Furlong et al., 2016). Additionally, sustainable onsite sanitation is an issue in both countries. India has 35% improved sanitation coverage (as defined by the Millennium Development Goals 2005), while South Africa has 74% coverage (WHO/UNICEF, 2012). Therefore, both countries represent significant markets for this technology and other worm-based sanitation technologies.

3 Results and discussion

Table 2 shows that there are approximately four times as many vermiculture business in India compared with South Africa. The total land area and population of India are respectively 2.4 and 23 times higher than South Africa (The World Bank, 2015) and the survey findings and numbers clearly reflect these differences. It is believed that the reported findings significantly underestimate the capacities in both countries, although the response rate was relatively high (>50% in both countries, Table 2), only businesses that had an online presence were targeted in this study.

Table 2 Number of companies identified, contact and response rates.

Number of companies	India South Africa	
Identified via the internet	81	21
Contacted via email	48	23a
Completed the survey	26	16
Number of vermiculture businesses	15	7

a Including two businesses identified via snowball sampling.

In India only 48 of the 81 companies identified online were sent surveys, as email addresses for the remainder could not be found. Of the non-respondents (n = 22) in India, 14 confirmed by telephone that worm farming was their main business, but did not complete a survey, whilst eight companies did not respond to calls. The 15 Indian vermiculture companies that completed the survey and provided details are distributed across the country (Fig. 1).



Fig. 1 Map of India indicating the location of earthworm suppliers included in Table 3 (Source: Google Maps).

In South Africa, two companies that did not farm worms, identified two additional vermiculture businesses in their area, which were then included in the analysis. Of the total non-respondents, two companies had gone out of business and five confirmed that worm farming was their main business,

but did not complete a survey. The seven vermiculture companies that completed the survey are mainly located in Johannesburg and Cape Town (Fig. 2).



Fig. 2 Map of South Africa indicating the location of earthworm suppliers included in Table 3 (Source: Google Maps).

From this initial analysis, it appeared that the focus of the businesses contacted was predominately vermicomposting in South Africa and vermiculture in India. It was hypothesized that this was a function of market age and development. As worm-based markets develop, vermicomposting becomes an establish process which increases the demand for composting worms, therefore vermiculture becomes the dominant businesses.

The South African businesses were easier to contact, due to more internet-focused business strategies. Most of the large companies in both countries included a web-based communication strategy e.g. Skype, Facebook, Twitter. However, some companies had limited internet access and were not using these types of communication effectively, which was thought to have negatively influenced the current survey response rate. It was assumed that language was not a barrier for this survey, however some problems occurred when contacting companies in rural India by telephone, but his was overcome through clear communication.

These results confirm that there are sizable vermiculture markets in both India and South Africa. They therefore represent potentially favorable countries for the large-scale adoption of worm-based organic waste processing technologies, but only if their composting worm supply capabilities are large enough.

3.1 Market analysis

The hypothesis being explored in this paper is that the availability of composting worms is the reason for the lack of adoption of worm-based organic waste processing technologies. The supply capabilities in both countries were therefore explored via market analysis.

3.1.1 Indian market

In India, all of the vermiculture companies (n = 15) were classified as large-scale i.e. were able to supply >50 kg live worms per month (Table 3). Their worm production capacity varied from 100 to 50,000 kg per month, whilst 11 companies stated that they could supply 1000 kg or more per month. Except for one, all companies had been trading for between five and 19 years.

Table 3 Summary of questionnaire survey results from India and South Africa. (A dash indicates that information was not supplied). The geographical location of each company within India and South Africa is mapped in Figs. 1 and 2.

Company	Earthworm species	Species availability (single/mixed)	Production capacity (Kg/month)	Cost (US\$/Kg)	Cocoon availability	Export experience
India						
A	Ef, Ee	Single/Mixed	1000	–	Yes	No
B	Ef, Pe	Mixed	100	15	Yes	No
C	Ef	Single	50,000	8	Yes	No
D	Ee	Single	9000	5–40	Yes	No
E	Ef	Single	–	8.30	No	No
F	Ef	Single/Mixed	1000 (500 from each species)	10	No	–
G	Ef	Single	2000	41.50	No	No
H	Ee	Single	Limitless	8.30	No	Malaysia, Japan
I	-	–	Depends on the request	15	Yes	No
J	Ee, Ef	Single/Mixed	300	10	No	–
K	Ef	Single	1000	8.50	Yes	No
L	Ef	Single	3000	4.25	No	Afghanistan
M	Ee, Ef	Single/Mixed	1000	9	Yes	Malaysia, Singapore, Italy, Thailand
N	Ef	Single	>1000	5.80	No	No
O	Ef, Lr	–	1000 (500 from each species)	16	No	–
South Africa						
P	Ef	Single	–	47–66	–	–
Q	Ef	Single	20	56	Yes	Botswana

Company	Earthworm species	Species availability (single/mixed)	Production capacity (Kg/month)	Cost (US\$/Kg)	Cocoon availability	Export experience
India						
R	Ef	Single	50	90	Yes	Namibia, Botswana, Zambia
S	Ef	Single	50	90	Yes	No
T	Ef	Single	200	56	No	Tanzania, Botswana, Namibia, Lesotho, Ugandan
U	Ef, Ee	Single	500	25	No	No
V	Ef	Single	2300	15	Yes	Zambia, Nambia, Tanzania

Earthworm species: *E. fetida* (Ef), *E. eugeniae* (Ee), *P. excavatus* (Pe), *L. rubellus* (Lr)

Eisenia fetida was the most widely supplied species; the other species available were *Eudrilus eugeniae*, *Perionyx excavatus* and *Lumbricus rubellus* (Table 1). Eight companies sold single species, whilst four companies stated that they could provide worms as single or mixed species, depending on request. One company farmed only mixed, whilst a further two companies did not provide details of the types of worms available. Eleven companies stated that their worms have been independently verified by experts. The species of worms farmed is not surprising as it is known that *E. fetida*, *E. eugeniae* and *P. excavatus* have been used successfully for vermicomposting in India for over 30 years (Kale, 2011). The cost of the worms varied from US\$ 4.25 to 41.50 per kg, with five companies charging less than US\$ 10 per kg. Seven companies were able to supply cocoons, whilst only two of these were able to provide details of their production capacity, which were 5 and 9 kg per month. Also, three companies gave a price for their cocoons, which varied from US\$ 1 to 40 per g.

Although a majority of their business was in the local area, 11 of the Indian companies had experience of transporting live earthworms to other cities or regions. Three companies had previously exported worms to other countries such as Malaysia, Japan, Afghanistan, Singapore, Italy and Thailand. Although these companies had exported beyond Asia, there was no shared customer base with the South African companies (Section 3.1.2), meaning each market studied was independent of the other. The respondent companies stated that it would take between 48 h and 10 weeks to fulfil an order of 20 kg. A majority of the responding companies (60%) stated that production capacity could be increased depending on demand. Five companies predicted that production could be doubled, whilst one company projected to increase their production by 2.5 times. A further three companies projected to increase production by three-fold or more. The survey results from India are summarized and presented in Table 3.

3.1.2 South African market

Vermiculture businesses in South Africa were a mixture of small scale producers (four could supply 50 kg per month) and large-scale producers (three companies). These companies had been trading for between five and thirty years. This is approximately the same as in India, so it would seem that a business focus on vermicomposting is not a function of the age of the market, but is demand driven. The large-scale vermiculture businesses supply capacity varied from 200 to 2300 kg per month, with

only one company able to supply over 1000 kg per month. In small scale vermiculture business, the cost of worms varied from US\$ 47 to 90 per kg, compared with US\$ 15 to 57 per kg for large-scale producers, which demonstrated economies of scale. Additionally, companies offered a discount for large orders, although this was not explored in the survey.

E. fetida was also the most common worm species grown in South Africa (Table 1). One of the large suppliers produces a mixture of *E. fetida* and *E. eugeniae*, whilst the other two companies supply only *E. fetida* (Table 1). All earthworm species were reported to have been independently verified by experts. All companies were able to supply cocoons, although none were able to provide a price for this. Two of the small scale and two of the large-scale producers had experience of exporting to neighboring African countries such as Botswana, Lesotho, Namibia, Tanzania, Uganda and Zimbabwe. Of the larger companies, two were able to supply cocoons at a cost of US\$ 25 per kg mixed with vermicompost, whilst another stated that it would cost US\$ 10 per 100 g of cocoons. These companies projected that they could increase their worm production by two to ten-fold depending on demand. The survey results from South Africa have been summarized and presented in Table 3.

3.1.3 Comparison of markets

The price of worms was lower in India compared with South Africa. Five companies in India charged less than US\$ 10 per kg of worms, whilst the lowest price recorded in South Africa was US\$ 15 per kg of worms. This difference was possibly due to the strength of their currencies compared to the US\$ and the differences in the cost of living in each country. Both countries showed similar international export experience of worms. Overall, this study suggests that India has a larger vermiculture market compared with South Africa, whilst vermiculture businesses have been longer established in South Africa. This is thought to be due to the length of time each country had been exposed to this technology. In India, research on worms and their importance in nutrient cycling started over five decades ago (Nijhawan and Kanwar, 1952). However, the first efforts to use earthworms for waste management in India begin in 1978 at the University of Agricultural Science, Bangalore (Kale, 2011). Thereafter, numerous studies were conducted (e.g. Kale et al., 1982; Kale, 2004; Kaushiik and Garg, 2004; Garg et al., 2006; Suthar and Singh, 2008; Suthar, 2009) and awareness of vermiculture and vermicomposting was rapidly developed throughout the country allowing India to become one of the major vermicompost producers in the world (Kale, 2011). South Africa was another pioneering country in terms of vermicomposting (Munroe, 2004) and the current survey confirms that there is at least a 30-year history of vermiculture. Compared with India, less literature-related evidence is available for the South African vermicompost industry and its development. However, the vermiculture industry in South Africa has grown considerably in recent years, particularly in relation to the production of worms for waste management (DWAF, 2010; Voua Otomo et al., 2013).

The predominant worm species grown in both countries was *E. fetida* (Table 3) and as a majority of the worm farmers in both countries (>70%) reported to have independently verified the worm species grown, this statement is thought to be correct. This is not surprising as *E. fetida* is commonly reported to be the most widely used vermicomposting worm (Domínguez and Edwards, 2011), therefore this study supports this statement. The reasons for the extensive use of this worm is that it is globally abundant, it can tolerate a large temperature range (0 °C–35 °C) (Domínguez and Edwards, 2011), it reproduces rapidly through maturing quickly and producing high numbers of worms per cocoon (Table 1) and it tolerates handling and rough treatment (Munroe, 2004).

3.2 Worm supply capacity

Results suggest that capacity of worm production in India is over 70,000 kg per month, with the capacity to increase production to 150,000 kg per month. In South Africa, the capacity for worm production was over 3000 kg of worms per month, with an ability to increase this to 11,000 kg per month. All responding companies in India were large-scale worm suppliers, whilst more than half of those in South Africa were small-scale suppliers. Eleven companies in India stated that they could supply 1000 kg or more worms per month, whilst only one company in South Africa was able to fulfil that target.

Six to seven companies in both countries stated that they could supply worm cocoons, if there is a demand. However, the cocoon production capacity and prices were less established in both countries and only two to three companies could provide figures for this. The disadvantage of using cocoons in the bioconversion of organic waste, is that it takes time for them to hatch and to reach maturity. This means that there would be a lag-phase in the processing of waste typically of 45 days for *E. fetida*. An advantage of using cocoons is that they would be easier to transport due to their initial weight and robustness. It should be noted that none of the companies in either country had experience in transporting or supplying earthworm cocoons.

3.3 Potential of scaling-up

The initial aim of this study was to determine if worm supply would impact the scaling up of worm-based technologies, such as the Tiger Toilet. Assuming that an individual Tiger Toilet requires 2 kg of worms (e.g. Furlong et al., 2016), the survey results suggested that the Indian worm industry currently has the capacity to supply composting worms for 35,000 Tiger Toilets per month (420,000 per year), whilst South Africa has the current capacity to supply worms for 1500 Tiger Toilets per month (18,000 per year).

The 3000 kg of worms from South Africa have the ability to process the fecal waste from 15,000 people which equates to approximately 4 tonnes of feces per day and the current worm supply capacity in India could support processing of around 23 tonnes of fecal waste per day. Both countries have the potential to increase production of worms immediately, this would lead to the capacity to supply composting worms for 75,000 Tiger Toilets in India per month (900,000 Tiger Toilets per year) and 5500 Tiger Toilets per month in South Africa (66,000 per year). Currently 195 million households in India practice open defecation and 24 million households in South Africa practice either open defecation or have unimproved sanitation (based on the figures published by The World Bank, 2015; WHO/UNICEF, 2012). Both countries are huge potential markets for such a system. Furthermore, many of the companies in these countries have a history of exporting worms internationally, which means there is the potential for the global scaling-up of worm-based technologies from these markets.

The majority of the respondent companies (in both countries) stated that they have successfully transported worms to other regions of their country. However, live earthworm transport is a major concern and it should be undertaken rapidly to prevent undue stress and mortality. When introducing worm-based technology or taking one to scale, consideration of geographical location and local supply is highly recommended. Regarding cocoon production, limited information was gained from the current survey, due to the novelty of the product. Therefore, further research is required to assess this products business potential in the vermiculture world. It has been calculated from data provided by Domínguez and Edwards (2011) for *E. fetida* (the most common species identified in this study), that 100 g of cocoons could potentially yield 16 kg of adult worms, however, this process could take over 45 days (Table 1). The authors feel that cocoon production could be a novel business proposition in this market, which could lead to the accelerated global expansion of

worm-based technologies due to ease of transport. This area still needs development in terms of separation methods, packaging and knowledge of cocoon hatchability, survival rate and time to reach maturity of the earthworm species of interest.

4 Conclusions

Even with the limited sample size in this study, it can be concluded that worm supply is not a barrier to either scaling-up or large-scale adoption of worm-based technologies in India and South Africa. It would appear that there is scope for worm production to assist development of worm-based systems throughout these and other countries in Asia and Africa. Although most companies could supply cocoons, currently this is less developed commercially. Yet, there is great potential to increase demand by encouraging cocoon production. Further studies are recommended to investigate the national vermiculture market in emerging economies such as China, and low-to middle-income countries where there is a huge potential for worm-based organic waste processing technologies.

Although this paper concluded that worm supply was not a barrier to large-scale implementation of worm-based technologies in these countries, it does not address why there has been limited uptake of vermicomposting as an organic waste management technique, further research is therefore required in areas such as technology transfer and appropriate business models.

Acknowledgements

The authors acknowledge the support of the Technology Strategy Board (United Kingdom) through an Innovation Voucher Round 6 and the International Federation of the Red Cross and Crescent, Geneva for funding this work.

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Footnotes

1 Calculated using figures of 300 g feces generated per person per day, 42% of the global population using unimproved sanitation and a current world population of 7.5 billion.

2 Web of Science search on 3/12/2016 search terms used was vermicomposting.

Accepted Date: 26 June 2017