OPPORTUNITIES AND CONSTRAINTS FOR MEDIUM-SCALE ORGANIC WASTE TREATMENT WITH FLY LARVAE COMPOSTING

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SUMMARY: The use of the black solider fly, *Hermetia illucens*, for conversion of organic waste streams into valuable animal protein has become a hot topic in the past decade. Large-scale protein production facilities treating up to 200 tonnes of waste per day are already in operation, with focus on protein production. On the other end of the spectrum are decentralised small-scale household composting systems focusing on waste treatment, motivated by the thought of self-sufficiency. In the middle of the scale – waste management systems treating up to 10 tonnes per day – there is of yet no alternative. There are benefits and constrains, with both large- and small-scale BSF treatment. However, by combining the advantages of the centralised large-scale protein production systems with the benefits of decentralised waste management strategies, many of the constraints can be overcome. In this paper is suggested a semi-centralised BSF-treatment approach that could bridge the lack of waste management in places current management strategies have failed. The absence of adequate organic waste management has dire health implications in low and middle-income countries and serious negative impacts on the environment all around the world. In semi-centralised BSF treatment, a centralised facility is used for fly rearing – for the production of small larvae required for the treatment – and for the refinery of the products generated from the treatment (grown larvae and residue). From the centralised BSF Rearing and Refinery (BSF R^2) facility, small larvae are sent to decentralised waste treatment units located at the place of waste production. The great volume reduction occurring in the treatment (80-85% on a wet weight basis) greatly reduce the need for transportation, while the valuable products generated from the treatment (animal protein and organic fertiliser) renders the treatment an economically viable option for the clients using the treatment units, while also allowing for business opportunities for waste management entrepreneurs operating a BSF R^2 facility. The flexibility in waste source and amounts possible to treat with BSF-technology, along with the refining of high-value products and the reduced need for transportation, can make the semi-centralised BSF-treatment approach a key player in providing organic waste treatment in areas that today are either completely lacking any service or that are not adequately treating the organic fraction. This would substantially improve the health of millions and

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considerably reduce the negative environmental impacts associated with poor organic waste management.

1. INTRODUCTION

Converting organic waste streams into insect protein and organic fertiliser with the larvae of the black soldier fly, *Hermetia illucens*, has become a hot topic over the past decade (Makkar et al., 2014; UNEP, 2010). Large scale treatment facilities, designed to treat up to 200 tonnes of organic material per day have been built in places such as the Netherlands, Canada, South Africa, China and USA.

On the other end of the spectrum there is a vast number of households, private chicken farmers and hobbyists operating black soldier fly (BSF) composting for personal use (Olivier & Hyman, 2011). This leaves a gap in the market for medium-scale BSF treatment, serving a local market. This is of great interest given the high share of organic material in the waste streams – especially in low- and middle-income countries (LMIC) – and the growing demand for locally produced animal feed. As such, BSF technology could provide an opportunity for local entrepreneurs, serving not only the aforementioned demands but also creating employment (Diener et al., 2011). The objective of this paper is to present a possible business approach which combines the advantages of centralised protein production using BSF with the benefits of decentralised waste management occurring at the neighbourhood or household level.

2. THE BLACK SOLDIER FLY TECHNOLOGY

Larvae of the black soldier fly feed on decaying organic matter. In nature this can range from rotting fruits over manure and human faeces to carcasses (Booram et al., 1977; Bradley, 1930; Dunn, 1916; Jirón & Solano, 1988). Their voracity can thus be harnessed to convert the organic fraction of waste into larval biomass. Larvae, provided a suitable feed source and adequate temperature, develop into the final larval stage (prepupae) within two to three weeks. They consist of ~35% protein and ~30% crude fat (Diener et al., 2009; Li et al., 2011; Zhou et al., 2013). In the process, the waste is reduced 60-80% and turned into larval biomass at a waste-to-biomass conversion rate of 20% based on dry matter (Diener et al., 2011; Dortmans, 2015). With constantly increasing prices for fishmeal (index mundi, 2015) – today the most common protein of animal origin in animal feed – the production of insect meal has a great potential for entrepreneurs. In particular the fairly young black soldier fly technology underwent a significant innovative boost since the turn of the millennium. About a dozen companies have already started, or are about to start, protein production with BSF and are stating a material input capacity of 200 to 1,000 tons per day.

Large-scale facilities focus on protein production rather than on waste management. Homogenous and pure input materials such as brewery waste, pre-consumer food waste, chicken manure, and slaughterhouse waste allow for a controllable and stable production of high value animal protein. However, competition with biogas or composting plants can have a negative influence on the availability and thus the price of these resources. The other extreme of the spectrum regarding the scale is the great variety of household based BSF-treatment reactors mostly developed and promoted by enthusiastic hobbyists. Designs and gained experiences are being spread through blogs and discussion forums on the internet. A wide range of designs of great creativity can be found online (example: http://blacksoldierflyblog.com/). The motivation often comes from the thought of self-sufficiency: the desire of treating one's own waste, while producing chicken or fish feed for one's own animals. Although most of the individual experiences published on the internet origin from northern countries, the on-site technologies using BSF are often brought up as a low-tech and low-cost solution when discussing organic waste management in LMIC where municipal solid waste (MSW) consists up to 80% of organic material (UN-HABITAT, 2010).

3. SOLID WASTE MANAGEMENT

The challenges concerning organic waste handling differ somewhat between LMIC and high-income countries (HIC), however, similar solutions can still be applied. The difficulties in providing an accurate level of public waste management service in the urban centres in LMICs are often attributed to the poor financial status of the managing municipal corporations (Sharholy et al., 2008). The question is: why are cities in LMIC not drowning in solid waste even when public services fail? The informal sector takes a great share of the waste management by diverting valuables from the waste stream, bringing it back in circulation. In Delhi, 150,000 waste pickers divert 25% of the total solid waste (UN-HABITAT, 2010) and in a selected urban area belonging to Mexico City with 1.7 million inhabitants, the informal waste sector not only generates an income of USD 12 million per year but also save the municipality USD 2.6 million for collection services (Medina, 2005). The informal waste business is flourishing but recovery of waste is limited to sellable recyclables such as glass, metal, paper and plastics. The organic fraction is still not being recycled, but rather discharged in landfills or in more or less illegal dumps (Komakech et al., 2014), creating an olfactory nuisance that poses a serious health risk. In HIC the solid waste is collected to a great extend (>76%); albeit the degree and selection of treatment differ greatly between countries.

The solid waste comprise on average to 28% of organic material in HIC; 70% of the solid waste is landfilled in Australia, 26% in Norway and 66% in Ireland, while nearly no solid waste is landfilled in Japan, Sweden and Switzerland (Hoornweg & Bhada-Tata, 2012). The organic waste fraction comprise of food-, garden- and market waste, and also to a greater or lesser extend different animal manures (Asomani-Boateng & Haight, 1999). Animal manures are a source of pathogenic bacteria, virus and parasites (Pell, 1997), while rodents and flies, known vectors of disease transmission, are attracted to rotting food and manures. In conjunction to the health risk associated with inadequate organic waste management, major environmental issues can be expected: an increased green-house gas emissions from partially anaerobic decomposition of organic material (UNEP, 2010) and eutrophication of water bodies as the nutrients contained in the organic fraction leach out (Sharpley et al., 1994). The health related impacts are greater in LMIC, where a great proportion of the organic fraction of the waste is discharged untreated in urban environment where many people move around (Komakech et al., 2014), while the negative environmental impacts are of great concern in LMIC as well as in HIC (Hoornweg & Bhada-Tata, 2012).

With a technology at hand which turns the organic fraction of municipal solid waste into valuable products, its collection will become more attractive. Precondition will be, just as it is with other recyclables, a reliable purchaser and an attractive price. However, unlike plastic or paper, organic waste cannot be stored until a large bulk for shipping has accumulated or until the reselling price is right. The putridness of the material along with the risk of disease transmission requires prompt processing and treatment. The collected waste needs thus either to be treated on spot or has to be moved to the centralised treatment site daily.

Decentralised municipal organic waste treatment using BSF thus have the potential to incentivise collection and treatment of municipal organic waste, which could contribute to improved health-related quality of life in LMIC, and greatly reduce the negative environmental impact of poor organic waste management.

Five key attributes make BSF-technology an attractive treatment option for organic waste:

I) A waste reduction up to 80% on wet weight basis have been demonstrated (Dortmans, 2015). If applied locally, costs for waste transport and space requirements for landfills can thus be reduced drastically. It could furthermore reduce the risk for open dumps that often appear in LMIC. While the material is reduced, most nutrients contained in the organic waste (apart from nitrogen that is partially evaporated) remain in the residues, which can be seen as a concentrated organic fertiliser, simplifying the recycling of plant nutrients from the organic waste back to arable land (Lalander et al., 2015).

II) At the same time the biomass is being converted into high quality animal protein, an important resource for local chicken and fish farmers. In Kampala, Uganda, for example, chicken farmers, as result of limited trust in the feed industry and the quality of their products, buy small dried fish on the market and, after grinding, mix it together with grains to produce their own feed (Diener et al., 2014).

III) A high waste-to-biomass conversion rate of up to 23% on wet weight basis (Banks et al., 2014) has been demonstrated, which would results in a satisfactory output quantity even for medium waste quantities.

IV) The technology has been proved to inactivate zoonotic bacteria such as *Salmonella* spp. (Lalander et al., 2013). That means that the risk of disease transmission between animals and between animals and humans is reduced if using this technology on farm level or when treating waste of animal origin in general (*e.g.* chicken manure or slaughterhouse waste).

V) As from a socio-economic point of view, given a suitable waste collection scheme, the locally operated BSF treatment facility could act as a collection point for the informal waste collection sector. Similar to middle men of plastic or glass recycling, the operator of a BSF treatment facility may buy organic waste from either waste pickers or from farmers, thus generating an income while at the same time reducing negative environmental impact of inadequate organic waste and manure management (UN-HABITAT, 2010).

4. COMBINING THE PROTEIN BUSINESS WITH WASTE MANAGEMENT

Besides their beneficial aspects, both, the BSF-driven centralised large-scale protein production and the decentralised waste treatment BSF-technologies are facing obstacles when it comes to handling organic waste (

A business model which combines the advantages of the industrial BSF systems with the flexibility and waste treatment potential of the decentralised BSF facilities could contribute both to local economic growth and wide-ranging organic waste management.

A segregation of tasks seems promising: operation of a centralised BSF Rearing and Refinery (BSF R^2) facility serving a number of decentralised, robust treatment units may facilitate the uptake of the BSF waste treatment technology (Figure 1). The critical processes, where skilled labour and specialised equipment is needed, are located at the BSF R^2 facility. The treatment of the waste happens where the material is generated, *e.g.* at a poultry or pig farm, or in a LMIC perspective, at a collection point where waste pickers deposit their pickings and get paid. Treatment devices, each capable of treating 200-1,000 kg per day, are dispersed over an area which is reachable by a courier within a reasonable time. The courier delivers the young larvae required for the treatment and in return collects the products of the treatment process (grown larvae and residue). The products are post-processed and prepared for sale at the BSF R^2.

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Table 1: Large-scale BSF production *versus* on-site BSF treatment systems

Centralised BSF production: Industrial scale, processing several tons of homogenous waste per day with focus on protein production.	
Advantages	*Disadvantages*
• Homogeneous waste source guarantees steady operational conditions • Economy of scale • Specialised in-house know how • Big quantities of products allows supply contracts with animal feed industry • Professional quality control • Emissions can be centrally controlled	• Competition for pure waste sources with other processes (*e.g.* biogas) increases price for the raw material • Large investment needed • Conveyance of large quantities results in high transportation costs • Little flexibility to adapt the process if waste source or market changes.
Decentralised stand-alone waste treatment with BSF: Household or neighbourhood facilities, processing up to 100 kilograms of mixed waste per day with focus on waste treatment.	
Advantages	*Disadvantages*
• Waste is for free • Waste can be treated where it is produced • Allowing for waste treatment in areas hard to access (urban slum areas, rural farms) • Short transport ways for bulky material • Can react to demographic change with multiplication • Technology and operational procedures adapt to the local context (waste characteristics, market for products)	• Requires waste segregation at source and/or sorting before treatment • Low degree of efficiency or even risk of system failure due to unskilled personnel • No established and guaranteed market for products • Little product quality control • Little control over hygiene standards

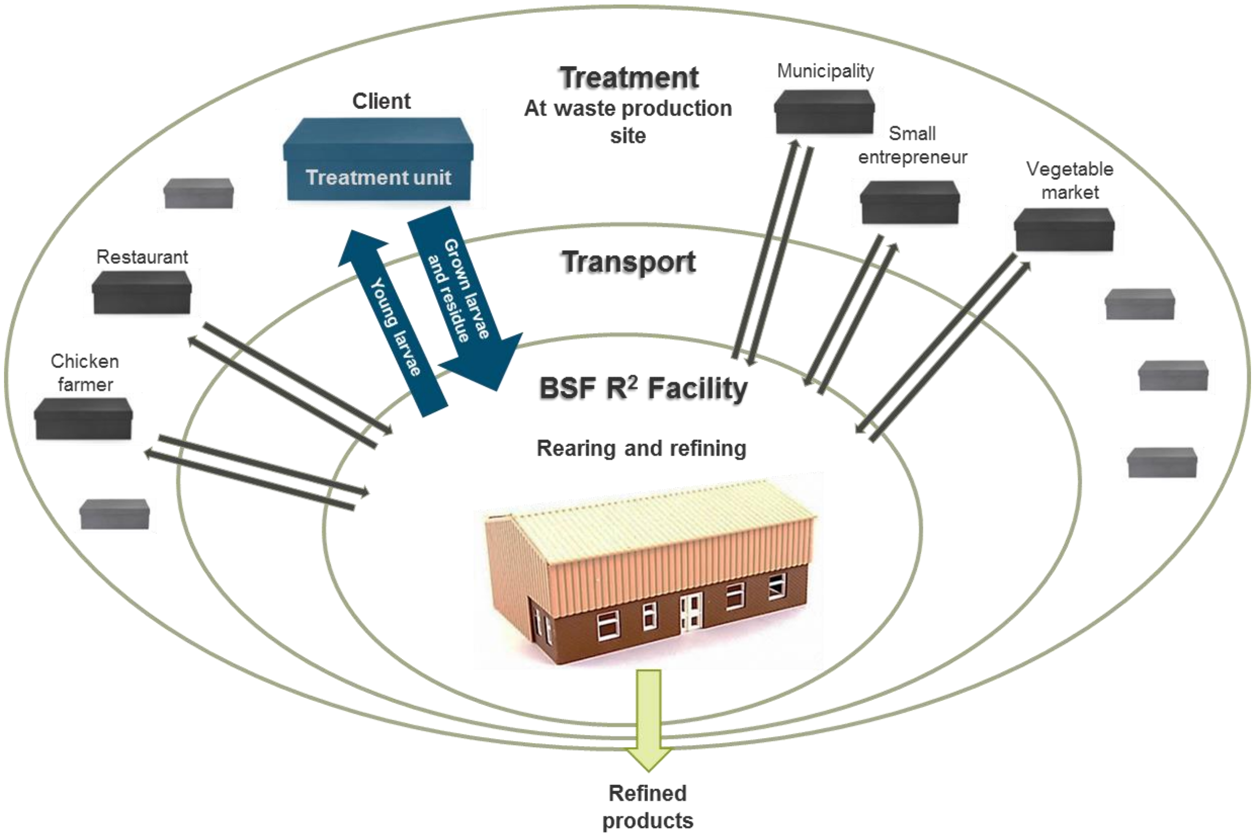

Figure 1: Centralised BSF Rearing and Refinery facility with outsourced treatment units

The process requires a high number of young fly larvae to be added to the system and a well-operated rearing facility is therefore key for a well-functioning BSF-system. Thanks to the scale of the centralised facility, the fly colony can be operated by skilled workers who react on sudden fly population fluctuations or outbreaks of diseases. Another advantage of the combined facility is that the degree of capacity utilisation for the equipment for sanitisation, refining and packaging of the products is much higher. The investment will thus amortise faster. Furthermore, with the refinery processes happening under the same roof, quality control can be ensured much easier following standard protocols and using calibrated checking devices.

The treatment itself is a predictable, hands-on process. Given the right conditions, larvae will feed on the waste and can be collected after they have done the job. However, there is a risk of system collapse if the treatment units are not operated adequately. To prevent this, the treatment devices have to be without frills, robust and have to come with clear and simple instructions for operation and maintenance.

5. DIFFERENT SCENARIOS FOR THE TREATMENT

The treatment can be located wherever a client accumulates waste on a regular basis; be it a chicken farmer, a restaurant or a small entrepreneur who collects organic waste for this purpose alone. By outsourcing the treatment, a great share of the transport costs can be cut. Material treated with larvae of the black soldier fly is being reduced by up to 80% on wet weight basis: 1,000 kg of organic material is thus converted into 200 kg of residue and 200 kg of larval biomass; transportation can thus be reduced by 60%.

There are several possible scenarios regarding ownership of the treatment device(s) and who is responsible for operation, maintenance and harvest. Depending on the skills and needs of a client, the treatment device can be bought or hired from the company who runs the BSF R^2 facility. Operation should be up to the client itself but certain maintenance tasks could be part of a service contract. The quality and quantity depends on the input waste material, but also on the operation of the treatment unit. A purchase commitment for the products should thus be linked to a certain minimum quality requirement.

Establishing a semi-centralised BSF treatment operation requires:

- development of a robust treatment unit which withstands mal-operation and which can cope with extreme environmental conditions (*i.e.* temperature and moisture);
- build-up of a healthy fly colony, able to generate sufficient larvae on a regular basis;
- develop and evaluate different business models for context-specific optimisation of semi-centralised BSF treatment;
- assessment of different logistics models for larvae distribution and product collection to identify the limiting factors.

However, successful projects need to be flexible in design, adaptable and operational in ways that best meet current social, economic and environmental conditions, which are also likely to change over time and vary depending on the geographic area of the project (Zurbrügg et al., 2012).

6. FINAL REMARKS

With the conversion of organic waste into valuable products, the flexible scalability and the reduced need for transportation; semi-centralised BSF-technology has the potential to play a key role in improving the health conditions of many in LMIC and reducing the negative environmental impact of inadequate or insufficient organic waste management in LMIC as well as HIC. Due to the great plasticity in source and amounts of waste possible to treat, the BSF-technology can serve and benefit a public toilet entrepreneur in a bustling urban centre of an African city, a medium-scale pig-producer operating in a rural area of North America and an organic waste manager in an Asian food market.

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REFERENCES

Asomani-Boateng, R., Haight, M. 1999. Reusing organic solid waste in urban farming in African cities - A challenge for urban planners. *Third World Planning Review*, **21**(4), 411-428.

Banks, I.J., Gibson, W.T., Cameron, M.M. 2014. Growth rates of black soldier fly larvae fed on fresh human faeces and their implication for improving sanitation. *Tropical Medicine and International Health*, **19**(1), 14-22.

Booram, C.V., Newton, G.L., Hale, O.M., Barker, R.W. 1977. Manure as a substrate for protein production via *Hermetia illucens* larvae. *Proceedings of the Cornell agricultural Waste Management Conference*. pp. 599-604.

Bradley, G.H. 1930. *Hermetia illucens* L. A pest in sanitary privies in Louisiana. *Journal of*

Economic Entomology, **23**, 1012-1013.

Diener, S., Semiyaga, S., Niwagaba, C.B., Murray Muspratt, A., Gning, J.B., Mbéguéré, M., Ennin, J.E., Zurbrugg, C., Strande, L. 2014. A value proposition: Resource recovery from faecal sludge—Can it be the driver for improved sanitation? *Resources, Conservation and Recycling*, **88**(0), 32-38.

Diener, S., Studt Solano, N.M., Roa Gutiérrez, F., Zurbrugg, C., Tockner, K. 2011. Biological Treatment of Municipal Organic Waste using Black Soldier Fly Larvae. *Waste and Biomass Valorization*, **2**(4), 357-363.

Diener, S., Zurbrügg, C., Tockner, K. 2009. Conversion of organic material by black soldier fly larvae – Establishing optimal feeding rates. *Waste Management & Research*, **27**, 603-610.

Dortmans, B. 2015. Valorisation of Organic Waste - Effect of the Feeding Regime on Process Parameters in a Continuous Black Soldier Fly Larvae Composting System. in: *Department of Energy and Technology*, Vol. MSc, Swedisch Agricultural University SLU, pp. 41.

Dunn, L.H. 1916. *Hermetia illucens* Breeding in a Human Cadaver (Dipt.). *Entomological News*, **17**(2), 59-61.

Hoornweg, D., Bhada-Tata, P. 2012. What a Waste - A Global Review of Solid Waste Management. World Bank.

index mundi. 2015. Fishmeal Monthly Price - US Dollars per Metric Ton. http://www.indexmundi.com/commodities/?commodity=fish-meal.

Jirón, L.F., Solano, M.E. 1988. Notes on the eclectical feeding preferences of the black soldier fly *Hermetia illuscens* (Diptera: Stratiomyidae) in Costa Rica. *Brenesia*, **30**, 101-103.

Komakech, A.J., Banadda, N.E., Kinobe, J.R., Kasisira, L., Sundberg, C., Gebresenbet, G., Vinnerås, B. 2014. Characterization of municipal waste in Kampala, Uganda. *Journal of the Air and Waste Management Association*, **64**(3), 340-348.

Lalander, C., Diener, S., Magri, M.E., Zurbrugg, C., Lindstrom, A., Vinneras, B. 2013. Faecal sludge management with the larvae of the black soldier fly (Hermetia illucens) - From a hygiene aspect. *Sci Total Environ*, **458-460C**, 312-318.

Lalander, C.H., Fidjeland, J., Diener, S., Eriksson, S., Vinnerås, B. 2015. High waste-to-biomass conversion and efficient Salmonella spp. reduction using black soldier fly for waste recycling. *Agronomy for Sustainable Development*, **35**(1), 261-271.

Li, Q., Zheng, L., Cai, H., Garza, E., Yu, Z., Zhou, S. 2011. From organic waste to biodiesel: Black soldier fly, *Hermetia illucens*, makes it feasible. *Fuel*, **90**, 1545-1548.

Makkar, H.P.S., Tran, G., Heuzé, V., Ankers, P. 2014. State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, **197**(0), 1-33.

Medina, M. 2005. Serving the unserved: informal refuse collection in Mexico. *Waste Management & Research*, **23**(5), 390-397.

Olivier, P., Hyman, T. 2011. Making Waste our Greatest Resource - The Small-Scale Production of Food, Fuel, Feed and Fertilizer.

Pell, A.N. 1997. Manure and microbes: Public and animal health problem? *Journal of Dairy Science*, **80**(10), 2673-2681.

Sharholy, M., Ahmad, K., Mahmood, G., Trivedi, R.C. 2008. Municipal solid waste management in Indian cities - A review. *Waste Management*, **28**(2), 459-67.

Sharpley, A.N., Chapra, S.C., Wedepohl, R., Sims, J.T., Daniel, T.C., Reddy, K.R. 1994. Managing Agricultural Phosphorus for Protection of Surface Waters: Issues and Options. *J. Environ. Qual.*, **23**(3), 437-451.

UN-HABITAT. 2010. *Solid waste management in the world's cities*. Earthscan, London and

Washington, DC.

UNEP. 2010. Waste and Climate Change: Global trends and strategy framework. United Nations Environmental Programme.

Zhou, F., Tomberlin, J.K., Zheng, L., Yu, Z., Zhang, J. 2013. Developmental and waste reduction plasticity of three black soldier fly strains (Diptera: Stratiomyidae) raised on different livestock manures. *Journal of Medical Entomology*, **50**(6), 1224-1230.

Zurbrügg, C., Gfrerer, M., Ashadi, H., Brenner, W., Küper, D. 2012. Determinants of sustainability in solid waste management - The Gianyar Waste Recovery Project in Indonesia. *Waste Management*.