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Impact of Fecal Sludge and Municipal Solid Waste Co-Compost on Crop Growth of *Raphanus Sativus* L. and *Capsicum Anuum* L. under Stress Conditions

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Abstract: Co-composted dewatered faecal sludge (FS) with organic fractions of municipal solid waste (MSW) has a high potential to be used as an agricultural resource in Sri Lanka. In addition to options for cost recovery in waste management, closing the nutrient and carbon cycles between urban and rural areas, substitution of mineral fertilizers, reduced pollution. and the restoration of degraded arable land are possible with important benefits. Up to now little is known about the usage of FS-MSW as fertilizer and it needs to be studied in order to achieve a better understanding and generate application recommendations. The aim of these experiments has been to evaluate the possibility of substituting mineral fertilization. Two field experiments were conducted on sandy loam to assess the effects of MSW compost and FS-MSW co-compost, its pelletized forms, and mineral-enriched FS-MSW on crop growth. As a short-term crop *Raphanus sativus* "Beeralu rabu" (radish) was studied for 50 days in a randomized complete block design (RCDB). Results show that, under drought conditions, FS-MSW co-compost increased the yield significantly, while MSW and FS-MSW compost enabled the highest survival rate of the plants. Similarly, the second field trial with a long-term crop, *Capsicum anuum* "CA-8" (capsicum), was planted as RCBD, using the same treatments, for a cultivation period of 120 days. Results display that during a drought followed by water saturated soil conditions co-compost treatments achieved comparable yields and increased the survival rate significantly compared to the control, fertilized with urea, triple super phosphate, and muriate of potash. Cost-benefit analysis (CBA) revealed that pelletizing decreased the monetary benefits if only fertilizer value is considered. It can be concluded that, under drought and water stress, co-compost ensures comparable yields and enables more resistance, but might not be economical viable as a one-crop fertilizer. These findings need to be validated with further trials under different climate regimes and soils.

Keywords: compost; agriculture; resource recovery and reuse

1. Introduction

Liquid and solid waste management face severe issues in Sri Lanka. The most obvious problem is urban waste disposal. In many municipalities waste services are restricted to collection and disposal only, without options for treatment or recycling, resulting in environmental pollution instead of resource recovery [1].

Furthermore, most current sanitation systems waste agricultural resources from human excreta (carbon (C), nitrogen (N), phosphorus (P), and potassium (K), as well as micronutrients) since they are either disposed of (e.g., pit latrine, ashes of incinerated sewage sludge) or enter the aquatic system, where they cause eutrophication and lead to contamination of the groundwater with human pathogenic organisms [2].

In general, these open cycles could be regarded as one cause for soil degradation and loss of soil fertility since cultivated arable land becomes increasingly deficient in essential plant nutrients when long term cropping takes place without replacement of nutrients [3].

These threats might result in a declining water and nutrient retention capacity and lower yields [4]. This trend was initially addressed by the Sri Lankan government through mineral fertilizer subsidies leading to several negative impacts on the ecosystem [5].

Co-composting of FS and MSW is considered as an appropriate low-cost technology that is capable of enhancing sanitation and waste management in low income countries. This holds especially true in urban areas where on-site storage of FS is the main sanitation option for most households, and the proper treatment of removed sludge is often lacking [6]. Since FS has a higher N content, it increases its value and possible usage as a fertilizer [7]. The thermophilic phase during the composting process is supposed to be the most reliable sanitization method for human pathogens [8].

As an option of further value adding, pelletization is discussed to reduce the bulk density and simplify field application. This technology has been used to enrich the co-compost even more by adding mineral fertilizer or other beneficial additives [9]. However, uncertainty exist regarding its effect on soil properties and plant growth as well as cost-benefit properties. MSW compost mostly positively affects physical, chemical and microbial properties of a soil. Applied on its own, it is not regarded as a fertilizer but as a soil amendment, due to its general low N content of 1–3% [10]. One of the most important beneficial impacts of compost is the return and application of organic matter to soils [11]. These practices assume that application amounts are high enough, resulting in a beneficial structural change that can last as long as nine years, or more [12]. On sandy loam, as well as on clay-textured soil, repeated applications of MSW compost consistently increased soil organic matter (SOM) content and the soil C/N ratio to levels greater than those of untreated soils [12,13]. Thus, it has been reported to improve water infiltration and retention and the available water content of soils by 58–86% [14,15].

Dewatered faecal sludge (FS), on the other hand, increases the N content and, therefore, provides a possible fertilizer resource for agricultural practices because of its higher N content of 3–6%, if added to the composting process [6].

While co-composting processes have been studied over the last decades, little is known about its effects in the context of FS-MSW on plant growth, yield, and soil impact.

2. Materials and Methods

2.1. Co-Compost Production

The co-composting process was conducted at the compost site of the municipal council Kurunegala, Sri Lanka. The main share of the initial feedstock of 90% consists of on-site segregated organic fractions of municipal solid waste, collected from households. Dewatered faecal sludge, collected in Kurunegala, was added and mixed with the organic waste fractions for co-composting. Open windrow composting with weekly turning procedures was conducted for 10 weeks, with an additional four weeks of maturation. Afterwards, the compost was analysed for plant nutrients

(Table 1). An analysis of the potentially-harmful trace elements lead (Pb), cadmium (Cd), and arsenic (As) was done by high-pressure aqua regia extraction [7].

While Cd and As had been underneath the detection limit of 1 mg/kg dry matter (DM), Pb was measured as 22.82 (±1.82) mg/kg DM, complying with international standards for compost [7].

Table 1. Treatments for agricultural trials, groups and total N, P, and K contents adapted from [7].

Treatment	Fertiliser Type	N	P	K	C_{org}
		(% FM)			
Control	Control (Mineral)	45.00 (Urea)	7.84 (TSP)	49.80 (MoP)	-
MSW	Organic	1.37	0.09	2.43	12.48
MSW-P	Organic	1.37	0.09	2.43	12.48
FS-MSW	Organic	2.22	0.63	1.11	15.5
FS-MSW-P	Organic	2.22	0.63	1.11	15.5
FS-MSW-Pas	Mineral-Organic	5.00	0.54	0.94	7.62
FS-MSW-Pr	Organic	2.15	0.62	1.07	10.73
FS-MSW-Pasr	Mineral-Organic	5.00	0.52	0.91	9.26

Control: mineral fertilization recommendation by the Department of Agriculture, Sri Lanka. MSW: Municipal solid waste compost as powder. MSW-P: pelletized municipal solid waste compost, FS-MSW: municipal solid waste and dewatered faecal sludge co-compost as powder. FS-MSW-P: pelletized MSW-FS co-compost. FS-MSW-Pas: MSW-FS pelletized co-compost, enriched with ammonium sulphate. FS-MSW-Pr: pelletized FS-MSW co-compost with 3% vol. rice flour. FS-MSW-Pasr: pelletized MSW-FS co-compost enriched with ammonium sulphate to 5% N/kg FM and 3% vol. rice flour.

2.2. Fertilizer Treatments

Compost was used in a sieved form (4 mm) (MSW) and in its pelletised form (MSW-P). A co-compost setup prior to the experiment with 10% FS added to the initial feedstock was similarly used in sieved (FS-MSW) and pelletised form (FS-MSW-P). As a further option to increase the nitrogen content FS-MSW co-compost was enriched with ammonium sulphate (AS) to achieve 5% TN in the fresh matter (FM) of the co-compost and pelletised afterwards (FS-MSW-Pas).

Preliminary trials lead to the conclusion that pellets require a binding agent to increase their stability, therefore, rice flour was mixed in FS-MSW co-compost (FS-MSW-Pr) and the enriched version (FS-MSW-Pasr) prior to pelletising.

The control (Control) represented the amount and timing of mineral fertilisation, recommended by the Department of Agriculture (DoA) in Sri Lanka for radish and capsicum in the intermediate agroecological zone [16].

All treatments were analysed on nitrogen, phosphorus, and potassium (Table 1) to calculate the application rates [7]. These were based on the amount of N applied by the control (Table 2).

2.3. Trial Setup

The capsicum cultivar "CA-8" (green capsicum variety) was nursed in coconut coir potting mixture up to the phenological growth stage of four developed leaves prior to planting. A RCDB with four replicates and guard rows were set up. The plot size was 4.2 m^2 with four rows of plants, with a spacing of 60 to 45 cm.

The radish cultivar "Beeralu rabu" (white tuber variety) was used for the short-term trial which was set up as RCDB with four replicates and guard rows. Each plot was 1.6 m^2 and was planted with a spacing of 10 to 20 cm in rows.

The general practice of sowing was modified because of a poor germination rate of approximately 65%. Two seeds were sown per planting hole at a depth of 3 cm. As soon as the first seedling successfully completed its germination with two unfolded cotyledons, the second seedling was thinned out.

Field cultivation of both trials started in February 2016 and lasted 120 days for capsicum and 60 days for radish, respectively (Figure 1). Both trials had been irrigated daily when needed.

Table 2. Application rates and timing of nutrient inputs for capsicum and radish trials adapted to mineral fertilisation, recommended by the Department of Agriculture Sri Lanka [16].

Capsicum	Application Rate and Timing (kg/ha)			
	Initial	1 MAP	2 MAP	3 MAP
Control (Urea, TSP, MoP)	100 215 65	100 0 65	100 0 65	100 0 65
MSW	3357	3357.66	3357	3357
MSW-P	3357	3357.66	3357	3357
FS-MSW	2071	2071.26	2071	2071
FS-MSW-P	2071	2071.26	2071	2071
FS-MSW-Pas	920	920.00	920	920
FS-MSW-Pr	2135	2135.32	2135	2135
FS-MSW-Pasr	920	920.00	920	920
Radish	**Initial**		**3 WAP**	
Control (Urea, TSP, MoP)	85 110 65		85 0 65	
MSW	2854		2854	
MSW-P	2854		2854	
FS-MSW	1760		1760	
FS-MSW-P	1760		1760	
FS-MSW-Pas	782		782	
FS-MSW-Pr	1815		1815	
FS-MSW-Pasr	782		782	

TSP: Triple Super Phosphate, MoP: muriate of Potash, MAP: months after planting, WAP: weeks after planting.

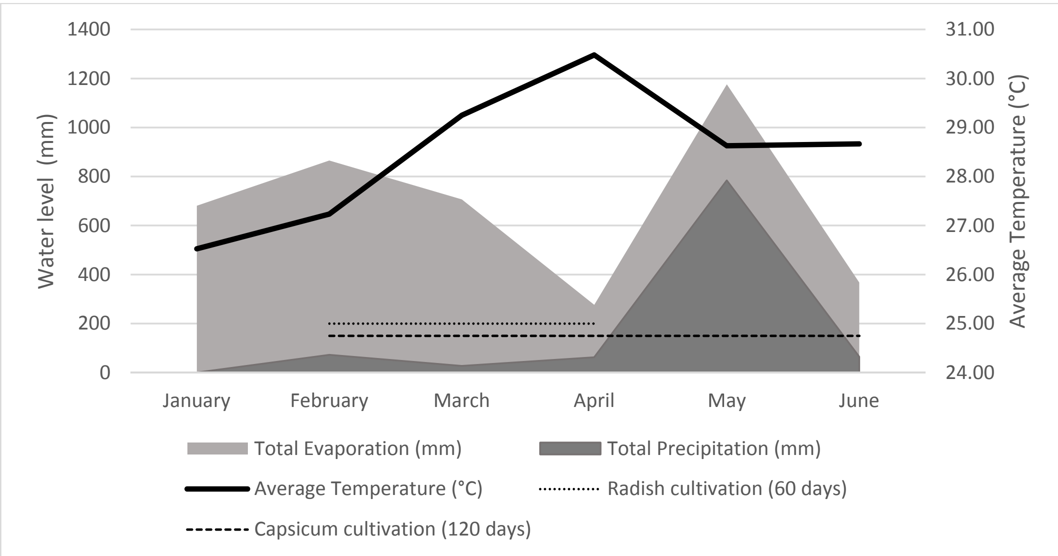


Figure 1. Total monthly evaporation (mm), total monthly precipitation (mm) and average monthly temperature (°C) over the six-month growing period.

2.4. Trial Site

The trial site is situated in the Kurunegala District of Sri Lanka and belongs to the Regional Agricultural Research and Development Centre. The area is defined as a low land intermediate agroecological zone.

The soil of the field site is a sandy loam and characterized as epidystric Luvisol with a pH of 4.22 and a low SOM content of 1.63% [17].

Weather data was recorded by the on-site station. The district faced a severe drought from January–April 2016, followed by high daily precipitation during May, causing water saturation of the soil and temporary water levels of up to 40 cm below ground (Figure 1). Both weather extremes created undesirable growing conditions but reflect the challenges agricultural systems will need to adapt in this climate zone in the course of climate change [18].

2.5. Parameters

As parameters for the radish trial, survival rate (proportion of survived plants) and plant height (longest leaf per plant) were measured. After a cultivation period of 50 days, plots were harvested and the weight of bulbs was recorded as fresh matter (FM) in Mt/ha. Six randomly-selected tubers per plot were dried to determine dry matter (DM) and to calculate DM yield.

To assess phenological growth of capsicum, the survival rate and average plant height were recorded. The survival rate was measured weekly as survived plants in percentage (%). The plant height was measured from ground level to the terminal growing point of the main stem at 19 WAP. Pods of marketable size were harvested every three days and results were recorded as picks per week and over all FM (Mt/ha). DM determination was done by drying six randomly-selected pods per plot weekly to calculate the DM yield.

2.6. Fertilizer Cost-Benefit-Analysis

Costs per treatment application were calculated based on input materials and processing (Table 3). The control treatment, consisting of urea, TSP, and MoP, were taken from the fixed subsidised prices given by the DoA Sri Lanka. The price for MSW displays an average of wholesale prices of 15 compost sites in Sri Lanka. FS-MSW, as well as the costs for pelletizing, were adapted from ongoing projects in Ghana and are still subject of research in Sri Lanka. The incorporated amendments were calculated by market prizes. To generate the revenue, market prices for radish and capsicum were monitored.

This comparison is focussing only on fertiliser costs and, therefore, does not consider transport and application costs, as well as a potential residual nutrient effect on the following crop.

2.7. Statistical Analysis

Datasets have been analysed using SPSS Statistics for Macintosh, Version 22.0. (IBM, Armonk, NY, USA). Descriptive analyses, and tests for normality and homogeneity of variances have been conducted prior to one-way analyses of variances (ANOVA). Treatment means which were found to be significantly different from each other were separated by Duncan tests.

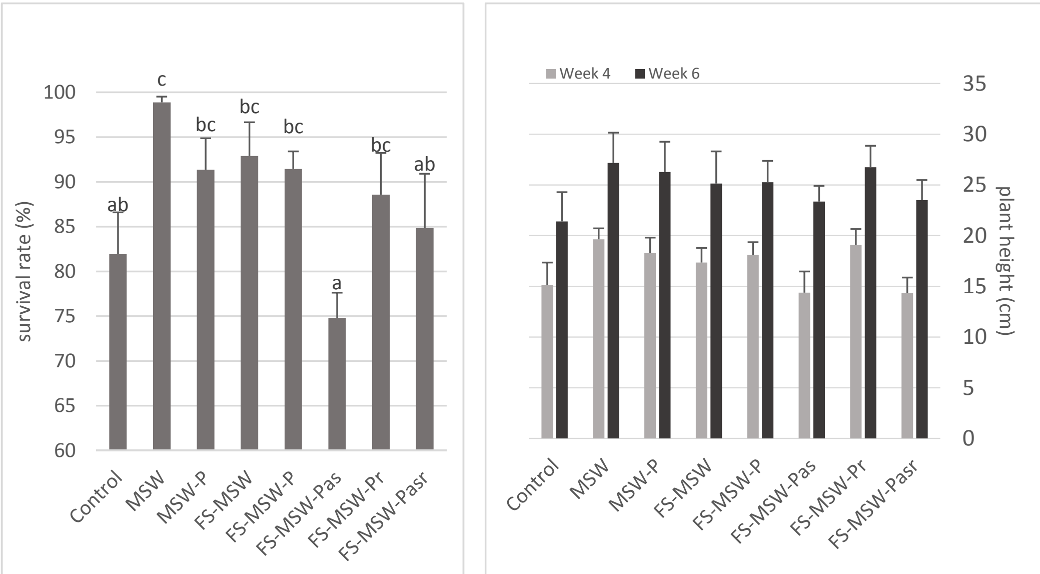
Table 3. Baseline dataset for cost-benefit-analysis; components of the treatments, amounts, and component costs per kg and per hectare.

Treatments	Components	Amount (kg/ha)	Cost (USD/kg)	Cost (USD/ha)
Capsicum				
Control	Urea	400.00	0.33	132.89
	TSP	215.00	0.33	71.43
	MoP	260.00	0.33	86.38
MSW		13,430.64	0.06	805.84
MSW-P	pelletized	13,430.64	0.13	1745.98
FS-MSW		8285.04	0.12	994.20
FS-MSW-P	pelletized	8285.04	0.19	1574.16
FS-MSW-Pas	Pelletized	3135.36	0.19	595.72
	AS	544.64	0.29	157.95
FS-MSW-Pr	pelletized	8285.04	0.19	1574.16
	rice flour	256.24	1.05	269.05
FS-MSW-Pasr	pelletized	3030.76	0.19	575.84
	rice flour	93.56	1.05	98.24
	AS	555.68	0.29	161.15
Radish				
Control	Urea	170.00	0.33	56.48
	TSP	110.00	0.33	36.54
	MoP	130.00	0.33	43.19
MSW		5708.02	0.06	342.48
MSW-P	pelletized	5708.02	0.13	742.04
FS-MSW		3521.14	0.12	422.54
FS-MSW-P	pelletized	3521.14	0.19	669.02
FS-MSW-Pas	Pelletized	1332.53	0.19	253.18
	AS	231.47	0.29	67.13
FS-MSW-Pr	pelletized	3521.14	0.19	669.02
	rice flour	108.90	1.05	114.35
FS-MSW-Pasr	pelletized	1288.00	0.18	231.84
	rice flour	39.84	1.05	41.83
	AS	236.16	0.29	68.49

3. Results

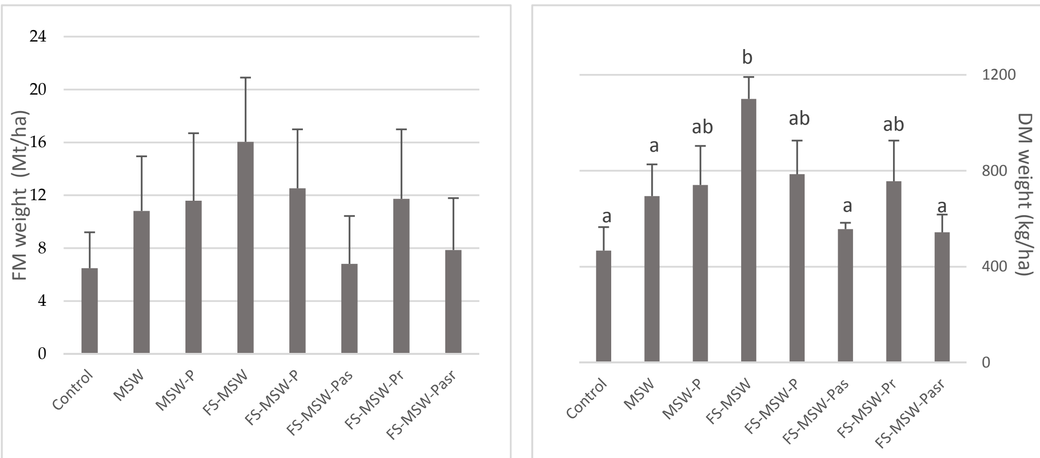
3.1. *Raphanus sativus*

Regarding the survival rate (Figure 2a), MSW treated plots were significantly higher ($p = 0.007$) than mineral and partly mineral fertilized treatments namely: Control, FS-MSW-Pas, and FS-MSW-Pasr. Average plant height did not significantly differ between treatments. Therefore, results are presented as means of groups of treatments (Figure 2b). Taking the results of the survival rate into account, regrouped treatments are compared according to their type (Table 1) as Control, Mineral-Organic (FS-MSW-Pas, FS-MSW-Pasr), and Organic (MSW, MSW-P, FS-MSW, FS-MSW-P). It can be observed that organic treatments had a significantly ($p = 0.02$) higher plant height than the control (Table 4). FM-Yield between treatments did not show significant differences which is why results are presented as average across the treatments (Figure 3a). DM-Yield revealed significant ($p = 0.03$) differences across the treatments. FS-MSW achieved the highest DM yield by 1.09 ± 0.18 Mt/ha, while the lowest was measured on the control plots with 0.47 ± 0.19 Mt/ha (Figure 3b).



(**a**) (**b**)

Figure 2. (**a**) Survival rate of *Raphanus Sativus* after 50 days; means ± standard deviation, different letters indicate significant differences between treatments at $p \leq 0.05$; and (**b**) plant height of *Raphanus sativus*; means ± standard deviation.



(**a**) (**b**)

Figure 3. (**a**) Yield of *Raphanus Sativus* after 50 days as FM in Mt/ha, means ± standard deviation; and (**b**) yield of *Raphanus Sativus* after 50 days as DM kg/ha; different letters indicate significant differences between treatments at $p \leq 0.05$, means ± standard deviation.

Table 4. Plant height of *Raphanus sativus* after four and six weeks; different letters indicate significant differences between treatments at $p \leq 0.05$.

Groups of Treatments	Treatment Code	Plant Height (cm)	
		4 WAP	**6 WAP**
Control	Control	15.11 ab	21.23 a
Mineral-Organic	FS-MSW-Pas, FS-MSW-Pasr	14.35 a	23.14 ab
Organic	MSW, MSW-P, FS-MSW, FS-MSW-P, FS-MSW-Pr	18.49 b	26.01 b
Duncan		0.019	0.029

3.2. Capsicum anuum

The treatments had a significant effect (p = 0.009) on the survival rate of the planted capsicum seedlings, ranging between the lowest with 73.6% (±3.0) of the control and the highest with 91.95% (±2.29) of FS-MSW, as shown in Figure 4a.

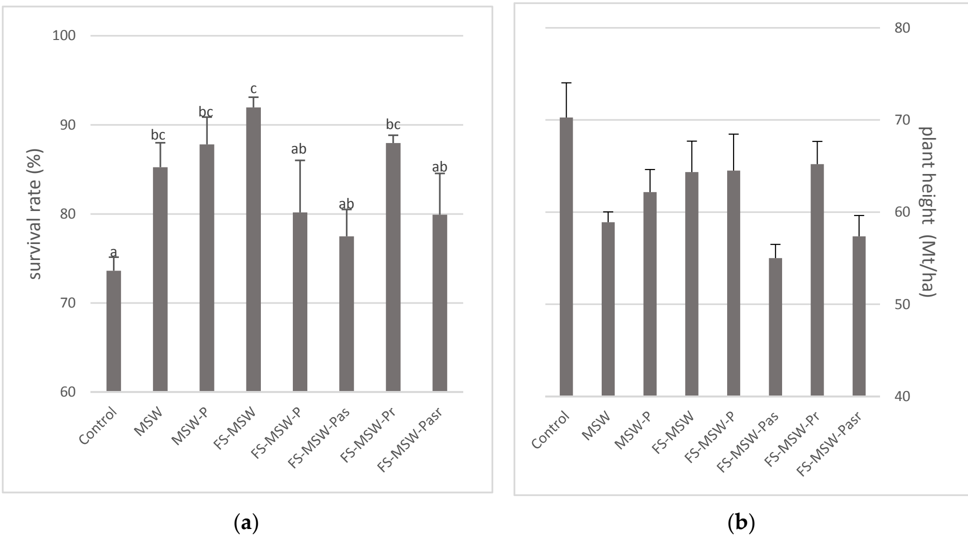


Figure 4. (**a**) Survival rate after 160 days as a percentage; means ± standard deviation, different letters indicate significant differences between treatments at $p \leq 0.05$; and (**b**) plant height; means ± standard deviation.

However, measurements of plant height in week 19 after planting revealed significantly (p = 0.017) higher plants fertilized by the control (70.26 cm ± 7.50) compared to FS-MSW-Pasr, FS-MSW-Pas, and MSW (Figure 4b).

The recorded differences in growth and survival rate did not result in significant differences in overall FM and DM yield per treatment, ranging between 26.95/2.71 (±9.90/1.00) FM/DM Mt/ha of FS-MSW-Pasr and 14.67/1.54 (±3.87/0.41) FM/DM Mt/ha of FS-MSW-P (Figure 5a,b). Further investigation of the number of leaves, harvested fruits per week, number of bunches, and developed flowers did not find significant differences regarding fertilizer type or pelletization (data not shown).

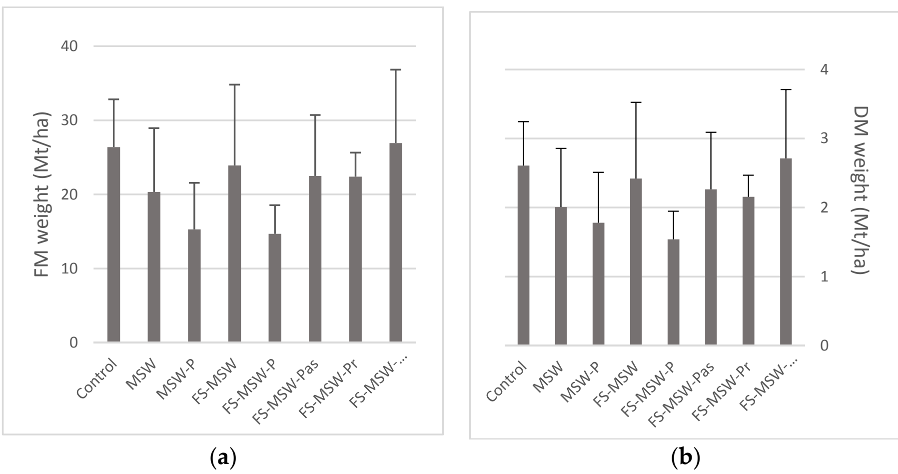


Figure 5. (**a**) Capsicum yield as FM in Mt/ha, means ± standard deviation; and (**b**) capsicum yield as DM Mt/ha, means ± standard deviation.

3.3. Cost-Benefit Analysis

For capsicum, co-compost based fertiliser costs (994.20 USD/ha), compared to the control (290.70 USD/ha), had been more than double as much for MSW (805.84 USD/ha) and FS-MSW-Pr (1843.21 USD/ha) (Table 3). Therefore, the generated benefits from fertiliser inputs had been highest using the control, leading to monetary benefits of 20,580 USD/ha (Table 5). However, similar achieved yields of FS-MSW-Pasr led to a comparable marginal benefit of 99.9%. It can be observed that pelletisation without mineral amendments leads to highest fertiliser costs and lowest benefits, as being observed for MSW-P and FS-MSW-P, resulting in approx. 50% marginal benefits.

Co-compost-based fertilisers for radish (MSW 805.84 USD/ha; FS-MSW-Pr 1843.21 USD/ha), similar to the capsicum treatments, compared to the control (136.21 USD/ha), were more expensive by at least double the price of the mineral fertilization. However, other than capsicum, all compost-based treatments tend to increase the FM-yield. The highest organic matter application correlates with the highest yields, leading to marginal benefits compared to the control of, e.g., 238.46% marginal benefit by FS-MSW. Only FS-MSW-Pas reduced the benefit by 15.88%. These results (taking the weather situation into account) reflect the assessment of growth and harvest data, showing that the increase of SOM results in increased economical yield as well.

As in the capsicum evaluation, pelletising leads to decreased benefits compared to the same treatments un-pelletised.

Table 5. Cost-benefit analysis results including price of treatment in USD/ha, FM yield Mt/ha, revenue as market prices (capsicum 0.8 USD/kg, radish 0.16 USD/kg), and calculated benefit 000 USD/ha; means ± standard deviation.

Treatments	Price	Yield FM	Revenue	Benefit	Benefit Marg.
	USD/ha	**Mt/ha**	**000 USD/ha**	**000 USD/ha**	**%**
Capsicum					
Control	290.70	26.37 (±6.45)	20.87 (±7.22)	20.58	-
MSW	805.84	20.34 (±8.61)	16.10 (±9.64)	15.29	74.32
MSW-P	1745.98	15.29 (±6.27)	12.10 (±7.01)	10.35	50.30
FS-MSW	994.20	23.91 (±10.89)	18.93 (±12.19)	17.93	87.14
FS-MSW-P	1574.16	14.68 (±3.88)	11.62 (±4.34)	10.04	48.81
FS-MSW-Pas	753.66	22.49 (±8.22)	17.80 (±9.20)	17.04	82.81
FS-MSW-Pr	1843.21	22.39 (±3.25)	17.72 (±3.64)	15.88	77.15
FS-MSW-Pasr	835.23	26.93 (±9.90)	21.31(±11.08)	20.47	99.49
Radish					
Control	136.21	6.48 (±2.72)	1.07 (±0.63)	0.93	-
MSW	342.48	10.82 (±4.14)	1.78 (±0.96)	1.44	154.59
MSW-P	742.04	11.59 (±5.10)	1.91 (±1.19)	1.17	125.40
FS-MSW	422.54	16.04 (±4.86)	2.65 (±1.13)	2.22	238.46
FS-MSW-P	669.02	12.53 (±4.46)	2.07 (±1.04)	1.40	149.80
FS-MSW-Pas	320.31	6.81 (±3.62)	1.12 (±0.84)	0.80	86.12
FS-MSW-Pr	783.36	11.73 (±5.25)	1.93 (±1.22)	1.15	123.54
FS-MSW-Pasr	342.15	7.86 (±3.92)	1.30 (±0.92)	0.95	102.28

000 USD: thousand (1000.00) US Dollars.

4. Discussion

The poor survival rate of radish plants of FS-MSW-Pas (Figure 2a) was attributed to the lower input of organic matter (Table 1) compared to plots treated without further amended co-compost treatments. MSW applications had the highest mass applied among all treatments (because of its low total N content) and resulted in the best survival rate. Especially in the first four weeks of the growth period in March 2016, when the trial faced a severe drought with high daily temperatures (Figure 1), organic matter is suspected to be an important growth factor, since numerous studies have proven that it increases the field capacity on sandy loams [14,19]. This observation could be supported by comparing the treatments according to their composition. Therefore, organic treatments resulted in significantly higher plants than the control group.

The DM yield results, taking the weather conditions into account, indicate that nutrients had been more available when treated with FS-MSW compared to the control or treatments with additional AS.

When evaluating the capsicum trial, it was observed that the drought conditions at the beginning and the water saturated soil at the end of the trial influenced the crop growth. The survival rates of the treatments had similar results as observed in the radish trial. All treatments with mineral fertilizer (FS-MSW-Pas, FS-MSW-Pasr), as well as the control, had the lowest survival compared to FS-MSW. Pelletizing, however, does not seem to affect the survival rate. Thus, earlier studies can be supported that during the early plant development, facing a drought, the higher organic matter application leads to a higher drought tolerance by increasing the field capacity [19].

Plant height of the control was the highest. This was attributed to the low survival rate of 73.6% ($\pm$3.0), leaving more space and providing access to nutrients for the individual plants to develop.

After 19 weeks of cultivation the differences in vegetative growth seems to be marginalized considering the overall FM and DM yields of pods. No significant differences were detected, leading to the assumption that that MSW, FS-MSW treatments, pelletized, as well as amended versions are achieving comparable yields.

Constraints regarding harmful trace elements being present in MSW compost from the research site can be reduced, but need to be monitored constantly because of the general risk that delivered household waste could be contaminated with light bulbs, paint chips, or other sources of contamination [20]. This holds true not only for trace elements, but especially for human pathogens.

Even if the aerobic composting process is being regarded as a cost effective method to eliminate the human pathogens due to considerably high temperatures during the thermophilic phase, careful processing is needed to achieve a pathogen-free end product [21,22]. Focusing on the final CBA evaluation, the average yield achieved on the radish trial of FS-MSW led to the highest benefit compared to the other treatments. The increase in yield recovers even the estimated production costs of the co-compost. Furthermore, it can be noticed that the control and the mineral organic treatments FS-MSW-Pas and FS-MSW-Pasr result in lowest benefits.

However, the CBA also revealed that, for capsicum, the control and the AS-amended treatment FS-MSW-Pasr achieved the highest benefits. Both trials show that pelletizing without mineral fertiliser amendments result in decreased benefits if only its fertilizer value is considered.

These results demonstrate that the benefit of pelletizing lies within the reduction of transport costs, which was not considered, and within the possibility to amend the co-compost with cheaper mineral plant nutrient sources. Finally, it is noted that the conducted CBA does not include an assessment of relevant co-benefits for soil health and ecosystem services. Likewise, positive long-term effects related to the increase of SOM and microbial life are not reflected, but may significantly increase the overall value of applied organic fertilizers.

5. Conclusions

This study was conducted under drought and water stress conditions and, therefore, displays a climate scenario becoming more and more present in the intermediate agro ecological zone of Sri Lanka [18]. Under those circumstances, the hypothesis, that co-compost derived from FS and MSW is able to substitute mineral fertilization, can be confirmed. Short-term crops, like radish, seem to benefit even more from an initially higher organic matter content and nutrient availability during severe droughts. Long-term crops, that are capable of balancing out droughts and heavy rains better than short term crops, do not react as sensitive whereas the impact on the survival rate seems similar to short-term crops.

However, the CBA focusing on fertilizer properties only shows that pelletizing without initial cost-reducing additives like mineral nitrogen in the form of AS, increases costs, but show no effect on yields, resulting in decreased monetary benefits.

To verify the findings, more trials need to be conducted under controlled greenhouse and field conditions. Monitoring nutrient availability and plant uptake from compost based treatments with adapted mineral additives are crucial parameters to develop a cost-effective compost-based fertilization method. In addition, a full cost cycle analysis needs to be conducted to evaluate the overall cost and benefits of pelletizing co-compost with and without amendments.

Furthermore, clarification on the safety, concerning harmful trace elements and human pathogens, is needed. Apart from product analysis, the possibility of a contamination pathway has to be explored from the feedstock of the co-compost to the harvested commodity.

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References

1. Eheliyagoda, D.; Prematilake, N. Assessment of a planned Municipal Waste Management System in Sri Lanka. *J. Appl. Sci. Envrion. Manag.* **2016**, *20*, 58061. [CrossRef]
2. Meinzinger, F. Resource Efficiency of Urban Sanitation Systems: A Comparative Assessment Using Material and Energy Flow Analysis. Ph.D. Thesis, University of Hamburg, Hamburg, Germany, 2010.
3. Lal, R. Soils and world food security. *Soil Tillage Res.* **2009**, *102*, 1–4. [CrossRef]
4. Horn, R.; Blume, H.-P.; Brümmer, G.W.; Fleige, H.; Horn, R.; Kandeler, E.; Kögel-Knabner, I.; Kretzschmar, R.; Stahr, K.; Wilke, B.-M. *Scheffer/Schachtschabel Soil Science*; Springer: Berlin Heidelberg, Germany, 2015.
5. Wimalawansa, S.A.; Wimalawansa, S.J. Impact of changing agricultural practices on human health: Chronic kidney disease of multi-factorial origin in Sri Lanka. *Wudpecker J. Agric. Res.* **2014**, *3*, 110–124.
6. Cofie, O.; Nikiema, J.; Impraim, R.; Adamtey, N.; Paul, J.; Koné, D. *Co-composting of Solid Waste and Fecal Sludge for Nutrient and Organic Matter Recovery*; Resource Recovery and Reuse Series 3; IWMI: Colombo, Sri Lanka, 2016.
7. Grau, F.; Drechsel, N.; Trautz, D.; Weerakody, J.; Ranaweera, B. Fertiliser Derived from Fecal Sludge in Sri Lanka: Analysis of Plant Nutritional Value and Heavy Metal Contamination. In Proceedings of the Tropentag, Vienna, Austria, 19–21 September 2016.
8. Strauss, M. *Human Waste (Excreta and Wastewater) Reuse*; EAWAG/SANDEC: Duebendorf, Switzerland, 2000.
9. Nikiema, J.; Cofie, O.; Impraim, R. *Technological Options for Safe Resource Recovery from Fecal Sludge*; Resource Recovery and Reuse Series 2; IWMI: Colombo, Sri Lanka, 2014.
10. Hargreaves, J.C.; Adl, M.S.; Warman, P.R. A review of the use of composted municipal solid waste in agriculture. *Agric. Ecosyst. Environ.* **2008**, *123*, 1–14. [CrossRef]
11. Soumare, M.; Tack, F.M.G.; Verloo, M.G. Characteristics of Malian and Belgian solid waste composts with respect to fertility and suitability for lan application. *Waste Manag.* **2003**, *23*, 517–522. [CrossRef]

12. García-Gil, J.C.; Plaza, C.; Soler-Rovira, P.; Polo, A. Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. *Soil Biol. Biochem.* **2000**, *32*, 1907–1913.
13. Montemurro, F.; Maiorana, M.; Convertini, G.; Ferri, D. Compost organic amendments in fodder crops: Effects on yield, nitrogen utilization and soil characteristics. *Compost Sci. Utili.* **2006**, *14*, 114–123. [CrossRef]
14. Agassi, M.; Levy, G.J.; Hadas, A.; Benyamini, Y.; Zhevelev, H.; Fizik, E.; Gotessman, M.; Sasson, N. Mulching with composted municipal solid wastes in Central Negev, Israel: I. Effects on minimizing rainwater losses and on hazards to the environment. *Soil Tillage Res.* **2004**, *78*, 103–113. [CrossRef]
15. Celik, I.; Ortas, I.; Kilic, S. Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. *Soil Tillage Res.* **2004**, *78*, 59–67. [CrossRef]
16. Department of Agriculture. Available online: http://www.doa.gov.lk/index.php/en/croptechnology (accessed on 29 April 2017).
17. Mapa, R. *Soils of the Intermediate Zone of Sri Lanka: Morphology, Characterization and Classification, Special Publication Soil Science Society*; Soil Science Society of Sri Lanka: Colombo, Sri Lanka, 2005.
18. Eriyagama, N.; Smakhtin, V.; Chandrapala, L.; Fernando, K. *Impacts of Climate Change on Water Resources and Agriculture in Sri Lanka: A Review and Preliminary Vulnerability Mapping*; IWMI: Colombo, Sri Lanka, 2010.
19. Adamtey, N.; Cofie, O.; Ofosu-Budu, K.G.; Ofosu-Anim, J.; Laryea, K.B.; Forster, D. Effect of N-enriched co-compost on transpiration efficiency and water-use efficiency of maize (*Zea mays* L.) under controlled irrigation. *Agric. Water Manag.* **2010**, *7*, 995–1005. [CrossRef]
20. Smith, S.R. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. *Environ. Int.* **2009**, *35*, 142–156. [CrossRef] [PubMed]
21. Amoah, P.; Keraita, B.; Akple, M.; Drechsel, P.; Abaidoo, R.C.; Konradsen, F. *Low-Cost Options for Reducing Consumer Health Risks from Farm to Fork Where Crops Are Irrigated with Polluted Water in West Africa*; Research report 141; IWMI: Colombo, Sri Lanka, 2011.
22. Vögeli, Y.; Lohri, C.R.; Gallardo, A.; Diener, S.; Zurbrügg, C. *Anaerobic Digestion of Biowaste in Developing Countries: Practical Information and Case Studies*; Swiss Federal Institute of Aquatic Science and Technology: Dübendorf, Switzerland, 2014.

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