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Cost-effective banana (*Musa paradisiaca*) waste management and the welfare of banana farmers in Kakamega county Kenya

1*MUSONYE A B

[1]Department of Environmental Science, School of Environment and Earth Science Maseno University, Kisumu Kenya

Corresponding author: bamusonye@yahoo.com

Abstract

Horticultural waste management is global war that must be won particularly in Kenya. Utilisation of banana waste can mitigate the dwindling welfare of banana farmers in Kakamega County. Unlike India's preferred processing approach, on-farm management of banana waste was a cost-effective strategy compatible to Kenya given the Climate change and Covid-19 pandemics. Unfortunately, knowledge on fitting 7Rs denoted by reducing, rethinking, refusing, recycling, reusing, repairing and refilling strategy onto the banana waste generated; banana waste utilisation technologies; and challenges of on-farm banana waste management was scanty in Kakamega County. Therefore, this paper examined the influence of cost-effective banana waste management on the welfare of banana farmers in Kakamega County, Kenya. It particularly established the: on-farm and off-farm weight of banana waste; appropriate innovative on-farm banana waste utilisation; and on-farm banana waste management challenges experienced in Kakamega County, Kenya. Across sectional design was adopted. A purposive sample of 150 from 600 banana farmers with at least 100 banana plants was studied. Frequency tables and plates were used to analyse data Kakamega County. Primary data was complemented by Key informants and secondary sources. The results revealed that out of the 7Rs, reuse, reduce and refill (3Rs) facilitated banana waste management. The weights of peeled banana fruit and waste were 10.1% and 89.9% of the entire banana plant respectively. Banana waste was the driver of integrated organic innovative crop farming, animal husbandry and agro-forestry. Dogmatic beliefs and low agricultural innovation adoption rate hindered banana waste utilization. It is concluded that 7Rs minimized the quantity; enhanced utilization; and mitigated challenges of banana waste, culminating to the improved welfare of banana farmers. Adoption of optimal innovative cleaner banana production technologies to streamline the 7Rs was recommended to achieve sustainable banana waste management and improve livelihoods in Kenya.

Keywords: *Banana; farmers; waste management; welfare; Kenya*

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Introduction

Banana (Musa paradisiaca) is a resilient gargantuan and common cultivated fruit that thrives in most ecological conditions in the world. As a diet, banana is source of carbohydrate with calorific value of 67 calories per 100g fruit and is one of the most widely traded fruits across the world (Emaga *et al.,* 2008 and Kumar *et al.,* 2012). In different countries, about 300 varieties of bananas are grown especially in tropical Asia (Simmonds, 1962). India, China and Nigeria are the leading bananas producers. They produce

bio-products such as fibre to make yarn, fabric, bio-ethanol, single cell protein, cellulose, citric acid, lactic acid, amylase, cosmetics, fibre, bio-film, pulp and paper, bio-plastic bio-electricity in the agro-industry, pharmaceuticals, bio-medicals and bio-engineering aspect, as well as livestock and fish feed, bio-sorbents, cosmetics, organic fertilizer (Mohapatra *et al.,* 2010) as a banana waste management strategy.

Improper handling of banana fruit and utilisation of the banana waste gravitated to adverse direct and indirect environmental impacts. Collectively, waste of banana production was approximately 200 tons of by product per hectare annually (Padam *et al.,* 2012). Neglect of the banana waste and the associated non-degradable agrochemical containers, sacks and polythene bags engendered environmental degradation. However, such wastes were yet to be incorporate in the gamut of banana waste. This paper argues that such a practice is unsustainable, militates against the value addition and poverty eradication principles; and contrary to the Sustainable Development Goals and Vision 2030's economic and social pillars, contrary to Russo's and Hernández's (1993) suggestion that environmental impact of banana production can be diminished by proper treatment of waste. Thus, fabrication of banana waste into useful items and livestock feeds that substitute and complements industrial products is a sustainable path to the resilience for the Kenyan banana famer. Unfortunately, the link between adverse environmental impacts and banana production was blurred,

Banana is a major food crop as well as a cash crop in East Africa. It is the staple food in Uganda and a critical component in the Tanzanian and Kenyan diets. East African countries have a huge but underexploited potential for banana production. This could be attributed to social economic constraints including pests, diseases and declining soil fertility, marketing (Kiiza *et al.,* 2004). However, this paper argues that poor banana waste management practices could be the most stubborn constrain to achieving full banana production potential in Kenya. According to Agwara (2017), Meru (19%), Kirinyaga (14%), Embu (12%), Taita Taveta (9%), Muranga (7%), Kisii (6%), Tharaka Nithi (6%) and Bungoma (5%) are the main producers of banana in Kenya. However, the choice of Kakamega County was informed by the crisis facing maize and sugarcane farming reported by the Kenya National Assembly 11th Parliament (Third Session - 2015) (Clerk's Chambers, 2015) together with the looming food crisis in the county. This has witnessed massive conversion of maize and sugar cane farms to livestock and banana farming. About 90% of bananas produced in Kenya is domestically consumed either as cooked or fresh fruit. Apart from enriching human diet and supplementing livestock feed, utilisation of banana waste is an inbuilt incentive for management of banana waste. Never the less little effort has been invested in the management of the ever-increasing banana waste generated.

The introduction of Tissue Culture (TC) banana farming technology introduced in Kenya and East African at large in 1990s (Qaim, 1999 and Dubois *et al.,* 2006) sought to mitigate pests and diseases that plagued traditional sucker propagated bananas (Eckstein and Robinson, 1995). Generally, TC banana technology accelerated vigorous growth and higher banana yields globally in large plantations. Unfortunately, this could not be actualised in East Africa, where banana farming is dominated by conservative smallholder peasant farmers who hardly afford proper management practices and adequate inputs (Qaim, 1999). This could explain Muyanga's (2009) view that no significant difference was reported in yield between adopters and non-adopters of TC bananas. Consequently, this paper reaffirms that TC is an affordable cleaner banana production and waste management strategy to be adopted. TC banana epitomize increased banana quality and quantity through reduced pests and diseases infestation hence minimize quantities of rejected bananas.

Kenya's draft National Horticulture Policy underscores the immense contribution of agriculture to the Kenyan economy and the significance of horticultural industry her Gross Domestic Product (GDP). Horticulture amplifies foreign exchange earnings, food security, employment creation, and poverty alleviation as outlined in Kenya Vision 2030 (Republic of Kenya, 2012). Regrettably, the horticultural industry faces a myriad of challenges including

unhealthy foreign competition, high cost of local production and low adoption rate of modern farming technologies. This disturbs, disrupts and strains Kenyan banana farmers whose livelihood is anchored on the horticulture industry. It also hampers environmental, economic and social sustainability manifested in on-farm and off-farm skyrocketing horticultural and banana waste generation that pose a serious threat to Kenya's environmental management policy.

Banana production, transportation, processing, marketing and consumption generate huge quantities of solid waste (FAO, 2014) as witnessed in Kenya. On-farm banana waste contributes a significant quantity of waste in the horticultural industry. After harvesting the fruit, the banana pseudo stem often degenerates into waste in Kakamega County yet according to Yadav *et al.,* (2016), Mohiuddin *et al.,* (2014) and Kumar *et al.,* (2012), many countries including India, China and Nigeria process it into vital commodities like cloths, detergents yarn and paper. Thus, banana waste was prevalent in homes, markets and urban centre of Kakamega County. However, all the banana waste can be transformed into economic resources as dictated by the reduce, rethink, refuse; recycle, reuse; repair and refill (7Rs) waste management strategy and the zero-waste principle. However, little is known as to why the application of 7Rs to banana waste remains minimal. Thus, invoking disposal as a banana waste management strategy is retrogressive and perpetuates environmental degradation and retard the welfare of Kenyan banana farmers.

This paper is premised on the fact that the whole banana plant can be used as bio-fuel, human food, livestock feed, pharmaceuticals, packaging material, mulch and raw material for industries. Utilization of banana waste prevents pollutions and taps the post-harvest bananas plant utility. Rising fossil fuel, electricity, wood fuel, vegetables, chemical fertilizer and irrigation bills catalyse the utilisation of banana waste. In Kenya, banana is a major food and cash crop that contributes significantly to the diet and the Gross Domestic Product (GDP) (Kahangi, 2002 and Nguthi, 2007). Consumption of banana as fruit is driven by its high nutritional and medicinal value (Kirogo, 2006) and widespread subsistence production. Banana farming has also been boosted by crumbling coffee, maize, tea and dairy industries, a trend that has increase the quantity of banana waste generated. This not only enhances environmental decay but also perpetuates the vicious cycle of poverty in Kenya and Kakamega County in particular.

Many studies have examined the industrial management of banana waste and converted it into numerous valuable products. Regrettably, Chamber's (1990) rural development concern of putting the last first ails the banana farming industry. The preference of complex practice of industrial banana waste treatment to the simple and cost relatively cheaper on-farm and market-based utilisation of banana waste remain a paradox. Thus, many peasant banana farmers ignorantly discard banana valuable waste that could earn them revenue through value addition. Banana peelings together with the associated odour and flies dominate homes and open are market deny people the right to a clean and safe environment (Republic of Kenya, 2013). Accordingly, this paper posits that integration of appropriate banana waste management strategies together with effective dissemination bio-technologies can not only mitigate banana waste but also better the farmers' welfare and augment environmental quality.

Various challenges face management of horticultural waste in the twenty-first century (Warrington, 2011). In Kenya, such challenges upset banana waste utilisation practices derailing sustainable waste management strategy. Innovation oriented utilization of banana waste require that banana farmers acquire knowledge of an innovation to facilitate either adoption or rejection, and its implementation. Therefore, this paper adopts the diffusion of innovations theory that traces the knowledge, persuasion, decision, implementation and confirmation path to innovation adoption (Rogers, 1983). In this regard, acquired knowledge can persuade banana farmers in Kakamega County to make rational decision for the implementation and confirmation of the cost-effective banana waste management process. Knowledge received could notify banana framers the relevance of banana waste utilisation which can persuade them to acquire either favourable or unfavourable

attitude toward banana waste management. Decision to either adopt or reject banana waste utilization strategies is made, which if adopted gravitates to implementation and confirmation through reinforcement of sustainable banana waste utilization. Otherwise, the farmer might revert to the previous irresponsible banana waste disposal habits if exposed to conflicting innovation signals. The success of banana waste utilisation innovation process encountered many challenges that inspired this paper.

Integrated solid waste management hierarchy protects and conserves the environment sustainably through waste reduction, reuse, recycling, resource recovery, incineration, and land-filling (National Environment Management Authority, 2014). Contrary to the 7Rs, the long waste management chain comprising generation, collection, transportation, treatment and disposal negates utilization of banana waste. In this regard, this paper employed the 7Rs typology to guide and reorient Kakamega County banana farmers to reduce, rethink, refuse; recycle reuse; repair and refill banana waste. Outright incineration and disposal undermine value addition strategies embedded in the banana supply chain leading to dumpsite that are injurious to settlements and the pristine environmental (UNEP and UN-Habitat - Kenya, 2007).

The rationale for linking banana waste management to the welfare of banana famers was guides extreme poverty, hunger and malnutrition in Kakamega County. This was in concurrence with FAO's (2016) reported heavy reliance on agriculture among rural households to meet their livelihoods and food security in Sub-Saharan Africa. Exploiting the tripartite synergies between banana waste management, agriculture and agroforestry could lower production cost and increase returns for banana famers based on the min-max principle in the game theory. Consequently, banana farming could become a lucrative enterprise and a key pillar in combating poverty and hunger in the County as reflected in the World Bank (2007) report. This paper therefore argued that neither banana waste management practices nor welfare of banana farmers operate in isolation since their coherence not only earns economies of scale for farmers but also avoids potential environmental harm.

Materials and Methods

The theoretical and conceptual underpinnings of this paper were domesticated in the 7Rs waste management strategy propelled by innovative value addition-oriented banana waste management framework. This methodology was grounded on four ('S') elements namely banana waste identification (Screening), weighing (Survey), tracking and sampling (Sampling) and sustainable utilization (Synthesis), tailored along the FAO (2014) approach to assessing the causes and solutions to food loss in Kenya.

The paper adopted a cross-sectional research design. A purposive of 150 from 600 banana farmers who owned least 100 bananas in all the Sub-Counties of Kakamega County was studied. The sample included banana farmers drawn from Shinyalu, Navakholo, Mumias East, Mumias West, Matungu , Malava, Lurambi, Lugari, Likuyani, Ikolomani, Butere and Khwisero Sub-Counties owning at least 100 banana plants. This paper was anchored on the assumption that 100 bananas plants marked the ceiling of Earth's assimilative capacity for banana waste beyond which the waste adversely effected the environment. With the help of one research assistant, each farmer identifies a dual purpose (consumed both as cooked and ripe) mature banana and harvested the fruit, then uproot the stem for analysis of banana waste. The choice of dual-purpose banana was appropriate because it concurrently addressed both ordinary and sweet banana waste. All the parts of each of the remaining uprooted banana plants waste were cut, separated and weighed separately. Each fruit was then longitudinally de-handled from the bunch into halves using sharp knife. The first half prior to cooking was peeled and the other half was ripened. Both the raw and ripe fruits and their respective fresh peelings weighed separately. The total weights of both the raw and ripe peeled banana fruits on one hand and their respective peelings on the other hand were computed for each banana. The net average direct banana waste generated was computed by

adding all the types of waste generated from the banana plant.

Banana waste tracing was used to consolidate banana waste emanating from poor harvesting, storage, packaging, de-handling, transportation, ripening, processing, marketing and consumption processes reported in urban centres, hotels, schools and hospitals. Information on indirect waste in terms of agrochemical containers, sacks and polythene tubes/bags/sheets was procured from banana farmers and traders. On-farm and off-farm waste were aggregated to compute the total banana waste. Banana waste parts were then used in the integrated organic innovative agriculture encompassing nursery management, vegetable planting and livestock feeding. Finally, banana waste management challenges were interrogated. Secondary data source complemented primary data. Sub County agricultural offices and market managers were also consulted. Tools used in the data collection process conducted in September, 2020 included an interview schedule for both banana farmers and key informants, weighing scale, panga, *jembe*, knife, and basket, bucket, polythene bag, internet search and digital camera.

Descriptive statistics and plates constituted data analysis. Percentages and frequency tables helped to fit the 7Rs to banana waste management practices, estimation of the quantity of banana waste generated and the challenges encountered by farmers. On the other hand, plates were used to show banana waste as a driver in of sustainable organic farming and agroforestry. Particularly, it demonstrated the use of banana fibre in tree nursery management as well as banana stem, leaves and waste containers for planting and mulching vegetables.

A conceptual framework in Figure 1 demonstrates that 7Rs waste management strategy, weight of banana waste generated (Kilograms), Banana wastes utilisation technologies and challenges of on-farm banana waste management influenced the welfare of banana farmers in Kakamega County. In particular higher yields and income together with wider choice notwithstanding a cleaner environment were the key benefits accrued. This was however subject to intervening variables including and not limited to peasant farmers, banana hawkers and banana cultivars.

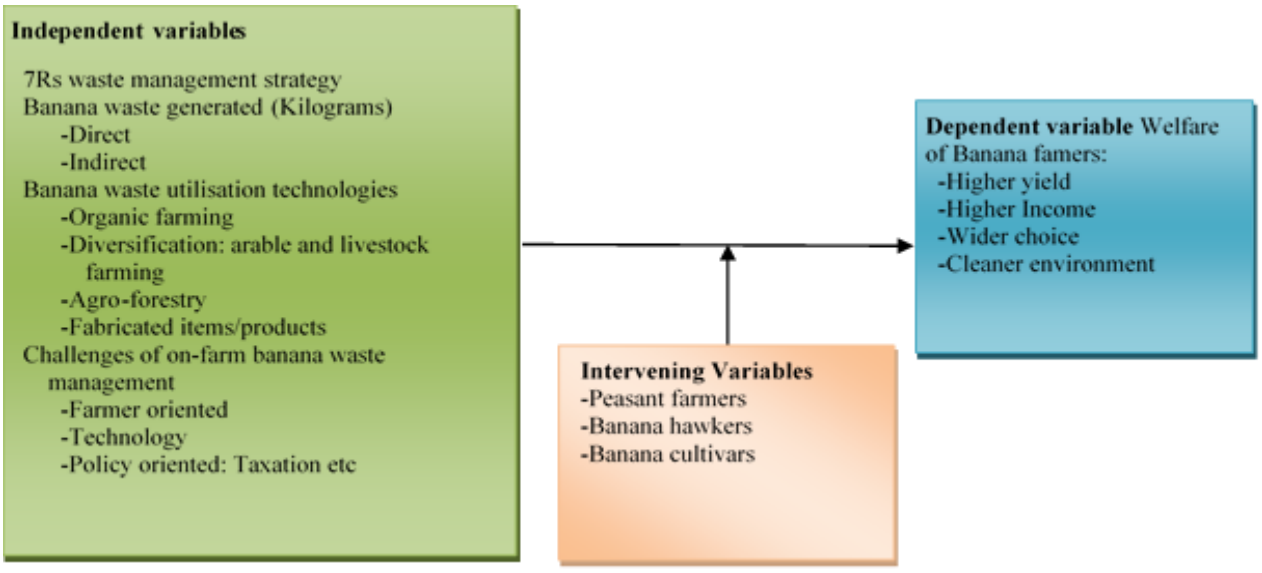


Figure 1: Conceptual framework for banana waste and farmer's welfare

Results

Fitting the 7Rs waste management strategy onto banana waste management

Banana farmers decried the voluminous waste generated from banana production. It was revealed that they had invoked the 7Rs waste management strategy to either mitigate or cope with ever-growing banana waste in conformity with NEMA (2014) guidelines. From the 7Rs, 3Rs including reuse (86.7%) Reduce (63.3%) and rethink (50%) emerged to be the most appropriate cost-effective banana waste management strategies. Nevertheless, all the 7Rs were instrumental to banana waste utilisation scheme that not only enhance waste management campaign and environmental quality but also alleviate poverty among banana farmers in Kakamega County as outlined in Table 1.

Table 1: Application of 7Rs waste management strategy in banana waste management by farmers in Kakamega County

Strategy	Applied	Not applied
Reduce waste	95 (63.3)	55 (33.7)
Rethink waste	75 (50.0)	75 (50.0)
Refuse waste	30 (15.0)	120 (85.0)
Recycle waste	45 (30.0)	105 (70.0)
Reuse waste	130 (86.7)	20 (13.3)
Repair waste	10 (6.7)	140 (93.3)
Refill waste	8 (5.3)	142 (94.7)

Notes: n=150 and (.) represents percentages.

Reduction of banana waste entailed the adoption of cleaner production technologies as reported by 65% of the farmers. It involved appropriate farm-care, fruit handling, preservation and refrigeration to minimise on the pest and disease infestation, breakages, smashing and perishability that engender rejected banana fruit waste. Removal of the bell at the tail-end of the pollination process was also a common practice geared towards achieving this goal. Unfortunately, this was subject to the House of Lords' (2008) view that waste reduction through better design often succumbed to inadequate knowledge on designing for sustainability. Thus, the farmers had significantly reduced banana farming waste, 35% of them were yet to effect the waste reduction strategy.

Rethinking in terms of banana waste business incubation, innovations and diffusion of banana waste utilisation and management strategies had been embraced and neglected by farmer in equal measures (75%). The value addition culture among banana farmers particularly through cooperative movement to excommunicate the middlemen (intermediaries) who lengthen and overload the supply chain, delay consumption and exaggerate rejected fruit waste. Diffusion of banana innovation through public rallies, mobile phones, agricultural extension officers, community-based organisation and media like the Shamba Shape Up Citizen Television program aired weekly on Sunday. Consequently, this concurs with the rethinking the definition of banana waste by Arroyo & Gonzalez, (2016) to incorporate environmental and social impacts as a road map to sustainability and better compliance to EU Waste Law for Europe's environment (IEEP, 2012)

Refusing waste by 15% of banana farmers entailed discarding poor yielding conventional cultivars in favour of high yielding seeds from KARI and Jomo Kenyatta University of

Agriculture and Technology. According to Kabunga, Dubois and Qaim (2011) and Kahangi (2002), this was enhanced by adoption of TC suckers and setting quality standards for banana farming and marketing through demonstration plots and extension services. Alternatively, the 85% farmers reported not to reject waste succumbed to the second law of thermodynamics that revolved around entropy.

Recycling banana waste by farmers (30%) witnessed reprocessing cooked banana into flour for preparation of snacks and overripe bananas into pudding and banana juice. Also making organic fertilizer from the outdated banana waste-oriented product or drying them to serve as bio-fuel. Recycling waste was motivated by many factors including opportunities for profiteering, the concept of "zero waste" and meeting meet government targets according to UN-Habitat (2012). However, the assumption that not all types of wastes were recyclable at affordable cost accounted for the actions of banana famers (70%) who hardly recycled banana waste.

Reusing banana wastes was a common practice among most banana farmers (86.7%) engineered the principle of diversification in agriculture. Banana waste from dairy farms were used either as direct bio-fuel or indirectly to feed bio-digesters. Culled suckers were also used as seed to establish new banana fields. The process of reusing started with the assumption that the used materials that flow through our lives can be a re-source rather than refuse was in line with the first law of thermodynamic that matter can neither be created nor destroyed, but change from one state to another.

Repairing (6.7%) and refilling (5.3%) of banana waste were the most unpopular of the 7Rs strategies among banana farmers in Kakamega county. *Kiondos*, hatcheries, brooders and mats made of banana fibre were among the few repaired. This was however hampered by the cheap second-hand imports compared to repairing and use an existing product like mobile phones and domestic appliances. On the other hand, refilling indirect waste including fertilizer bags and herbicide jerricans with organic manure to be used in the next season had also emerged in many homes.

Implementation of the 7Rs in banana waste management sanitised the environment, diversifies agriculture and improved food security for banana farmers. These answered to their subsistence and self-ego needs as well as widened the freedom culminating to improves welfare of banana farmers (Republic of Kenya 2010; Todaro and Smith, 2014)

Common on-farm and off-farm banana waste

The common direct and indirect on-farm and off-farm banana waste were generated at different stages of banana production. In this context, production entailed banana cultivation, pruning, harvesting, storage, de-handling, transportation, marketing, preparation (cooking, ripening and processing) and consumption. Direct waste emanates from banana plants including the corm, roots, Pseudo-stem, Leaves, fibre, bunch, culled suckers and bell (https://hardytropicals.org/blog/splitting-banana-pups) together with peelings, and rejected fruit. Alternatively, indirect waste implied auxiliary waste like agrochemical containers and polythene tubes/bags/sheets that enabled the propagation of TC banana seedlings as well as packaging and ripening of banana fruits.

Pre-harvesting waste that was often neglected included the corm, roots, pseudo stem, fibre, culled suckers and the bell. However, these would have been utilised extensively for weave baskets, and Mats; wrapper food for marketing and cooking as well as cover food and act as plates for eating as revealed by Yadav (2016) After harvesting banana fruits were marketed either in whole or parts banana fruit. Banana fruits were de-handled to facilitate packaging, storage, transportation, ripening as well as peeling for cooking the bunch is considered to be an on-farm waste. However, in the process of harvesting, de-handling, storage, transportation, processing, marketing and consumption, the quality of banana fruit could deteriorate resulting in rejected banana waste. Some banana infested by pests/diseases, hit by hailstones, smashed, broken, rotten, poorly prepared and even contaminated prompting further rejection. This waste not only lowered banana revenue but also attracted a wide range of scavengers and flies and, emitted odour that epitomise the peak of

environmental decay and lowered human welfare. Contrary to that, Kumar *et al.,* (2012) noted the medicinal use of banana leaves and as a cool application for headaches, dressings for skin wounds to treat inflammation while leaf ash ingested treated diarrhea.

Consequently, this paper adopted the on-farm and off-farm categorization as the most appropriate strategy towards cost-effective tracking and utilisation of banana waste. This classification was instrumental estimating the total weight of banana waste by tracking and aggregating all the on-farm and off-farm waste as outlined in Table 2.

Table 2: Average weights of on-farm and off-farm banana waste per banana plant in Kilograms

Banana parts	On-farm	Off-farm	Total (%)
Corm: At the end of the bananas' life cycle	7.4	-	7.4(4.1)
Roots	2.9	-	2.9(1.6)
Pseudo-stem	61.3	-	61.3(33.3)
Leaves: Current and pruned during the lifespan of the banana	52.5	5.0	57.5(31.2)
Fibre: Peelings in the lifespan of the banana	5.6	0.5	6.1(3.3)
Bunch: From the stem to the bell	3.3	1.5	4.7(2.6)
Bell: End bell and consolidated bell droppings since fruiting	6.7	1.2	7.9(4.1)
Peelings (Peelings from unpeeled banana in built): Raw	7.6	3.4	11.0(6.0)
Ripe	1.4	4.7	6.1(3.3)
Rejected fruit: Broken/smashed/hailstone hit/rotten: Raw	21.3	2.0	3.2(1.7)
Ripe	2.1	8.3	10.4(5.6)
Suckers: Culled	4.2	-	4.2(2.3)
Agrochemical containers: jerricans, sacks and paper bags*	0.7	0.2	0.9(0.5)
Polythene bags*	0.1	0.3	0.4(0.2)
Total	156.8	27.3	184.1(100.0)
	(85.2)	(14.8)	(100.0)

Notes: The weight of peeled banana fruit (ripe plus raw) de-handled from the bunch was 21.3Kgs being only 10.1% of the entire banana plant weight (184.1 +21.3 = 205.4) kilograms hence 89.9% of the plant constitutes banana waste.
*Most critical and non-biodegradable banana waste that is often neglected,

The myopic and misleading waste management endeavour converging at the negligible off-farm waste witnessed in markets, factories and hotels at the expense of the massive on-farm waste informed the classification. The paper further argues that managing banana waste at farm level could not only enhance value addition and environmental quality but also break the vicious cycle of poverty bedevilling banana farmers.

The weights of each type of on-farm and off-farm banana waste were computed then aggregated to determine the total banana waste. The scope of this paper to incorporate bulkiness was limited by the difficultly involved measuring the volume limited banana waste. Thus, weight was used as a proxy for all the parameters of banana waste that hampered horticultural value addition and waste management campaigns. In a nutshell, the

analysis revealed that 156.8 kilograms (85.2%) on-farm banana waste exceeded 27.3 kilograms (14.8%) off-farm banana waste. Thus, emphasising on-farm banana waste management was an appropriate and rational decision. This is a pointer towards Africa's agricultural postharvest losses offer opportunity for the private sector as postulated by IITA (2010).

Agrochemical containers and polythene waste were the invisible component of banana waste reveal in this paper. Containers, bags and wrappings of pesticides, herbicides, fertilize and preservatives were common on farm. Occasionally, the containers and bags were reused for grain and water storage but without adequate sanitation exposing crops, livestock and human health and life to dire risks. Alternatively, polythene bags used in TC bananas breeding as well as packaging banana fruits to facilitate banana production and packaging. The early maturing TC banana suckers bred in few isolated research institutes were free from pests and diseases. Consequently, polythene tube and bags enhanced their distribution to banana farmers all over the country. Polythene bags also simultaneously accelerated maturation and, boosted disease and pest control in bananas. They also facilitated safe transportation and/or ripening of banana fruit to minimise on rejected fruit waste. The small quantities of agrochemicals container (0.5%) and polythene bags (0.2%) per banana plant reported in Table 1 was often misinterpreted as negligible yet the two were stubborn but often neglected non-biodegradable waste. Agrochemical containers and polythene bags catalysed the banana waste dilemma and harmed the environment as banana farming remains popular in Kenya. This was concurrence with the observation of Russo and Hernández (1993) that proper treatment of wastes could be diminished its diverse environmental impact.

Utilisation of on-farm and off-farm banana waste

Banana waste: Driver of integrated organic innovative crop and livestock farming

Utilisation of banana waste enhances agricultural diversification through strengthening forward and backward feedbacks between crop and livestock farming. Harmonised crop farming and animal husbandry absorbed large quantities of banana waste as inputs in the agribusiness. Reuse of banana waste was instrumental in establishment and maintenance of vegetable, fruits and tree nursery bed nursery bed could be a boost in the horticultural industry. It is also friendly agroforestry lased with tree-fruit crops as an emerging eco-friendly farming practice. This was in line with UNDP (2012). Equator initiative in conjunction with Muliru Farmers Conservation Group (MFCG) to support vulnerable communities to stimulate their participation in conservation of Kakamega Forest

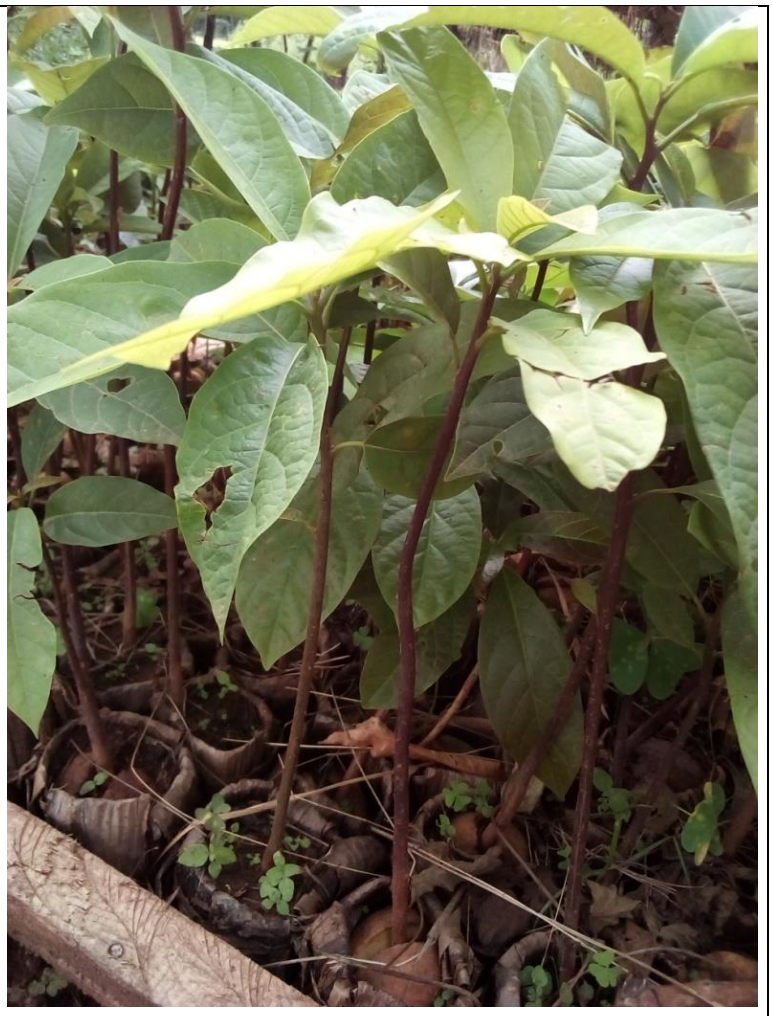
Surface run off threatened to erode crop and tree nursery beds especially during the rainy season. To mitigate this, banana pseudo stem be used to establish embankments on the sides of the nursery beds to protect the nursery bed from flash floods. Covering nursery bed with banana leaves and fibre improved soil moisture content that guaranteed maximum seed germination. After germination, the delicate tree seedlings are also protected from the heavy rains, hail stones and host sun by a shade made of banana leaves and fibre. Banana fibre with the help of simple technology can boost tree and tree fruit nursery bed establishment as shown in Figure 2.

The MFCG had fabricated banana fibre tubes that substituted conventional non-biodegradable polythene tube and sheets used in establishment of tree and tree-fruit nurseries. Contrary to the polythene tube that impair soil air, water, moisture and organic matter, banana fibre tubes enrich soil, reduce fertilizer expenses and catalyse growth and maturity of the trees/crops. Banana fibre tubes complemented by banana leaves that had replaced polythene sheets to cover the nursery bed in order to boost soil moisture content necessary for seed germination and growth of seedlings. Such efforts by MFCG enhanced compliance to the ban on plastic bags in Kenya (NEMA, 2017) by providing appropriate environmentally friendly substitutes for polythene tubes and sheets used in crop and tree nursery establishment. The cover/shed also protected seedlings from the disastrous effects of hot sun, heavy rain and hailstones. This concurred with Buyinza and Opolot (2016) view that effective tree nursery establishment and management in eastern Africa. Utilisation of banana stem, fibre and leaves to establish manage

horticultural and tree nurseries gravitate towards Kenya's green horticulture agenda. Particularly, propagation of tree-fruits like avocados, mangoes, apples, Bananas, oranges, lemons and medicinal trees using banana waste could thrive despite polythene ban policy.

The author displays banana fiber tubes.

a) Indigenous tree seedlings raised in banana fibre tubes for marketing and transplanting.



b) Avocado tree-fruit seedlings raised in banana fibre tubes ready for marketing and transplanting.

***Figure 2**: Banana fibre tubes tree nursery establishment by Muliru Farmers Conservation Group (MFCG) at the Muliru conservancy in Shinyalu Sub County*

Organic farming is a resilient agricultural strategy to resuscitate soil fertility after prolonged use of chemical fertilizers. Banana farmers have invented innovative idea that converts banana pseudo stem to and arable soils with a high-water retention capacity that yield organic food as well as simplify irrigation for farmers. Banana tree trunk is used for growing vegetables (Kales) with minimal irrigation during dry seasons as illustrated in Figure 3 conforming to Ahmar (2019), Saputro *et al.,* (2017) and Mwende (Undated).

The pseudo stem exhibits a high retention capacity that can withstand planting short fibrous root crops to maturity. This was achieved through scooping small holes in the banana stem with the help of a sharp object like a knife. A little soil is added primarily to allow plants to growth

even when dry periods are on without the use of proper irrigation facilities. After decomposing, the banana stems supplement soil as fertilizers and manures. However, it was an improvement to Buyinza and Opolot (2016) view that banana stems were effective embankments in nursery establishment and management improved sustainability in farming systems and enhance livelihoods.

Panel 1: Onions, pigweed, kales, spinach, black night shed, and carrots planted in a pseudostem outdoor since the balcony is prone to shed

Panel 2: The vegetables in Panel 1 are mulched by dry banana leaves to upscale the moisture content of the pseudostem and control weeds

Panel 3. A wild fruit panted in a 20Litre jerican previously used to store bananas. A tomato and Kales/pigweed planted in Urea and CAN fertilizer 50Kg sacks

***Figure 3**: A demonstration of Banana pseudostem, dry banana leaves, a cut jerican and fertilizer sacks used in diversified outdoor vegetable farming by Mr. William Sunguti at Musoli Village in Ikolomani Sub-County*

The immense value of banana waste as a catalyst of value-addition in agriculture was underscore by 62% of banana farmers. It was a common livestock feed rich in water hence reduces dehydration in livestock during the dry season when fodder and water were scarce. Unfortunately, 38% of the farmers faulted the trend of feeding livestock on banana waste. They argued that feeding livestock on banana stems not only compromised livestock health but also lowered the quality and quantity of milk and meat products in cattle, pig, goat, sheep and poultry farming. This could be attributed to the prevailing dogmatic beliefs resulting in extreme losses of milk, meat and wool yields; higher cost of livestock feeds, heaps of banana waste that tighten the vicious cycle of poverty. Conversely, Dayana and Marbun (2018) report that the banana stem has many benefits because it contains vegetable protein that used for making fat and animal feed. Similarly, in Tanzania feeding dairy cows on banana waste increased milk production according to Wire (2019). It is argued here that gradually integrating banana stem, leaves and rejected fruit in conventional livestock feeds was the most feasible cost-effective value-addition approach to effective banana waste management in Kakamega County.

Challenges of on-farm banana waste utilisation

According to the farmers the following four challenges were the most critical impediments to utilization and management of banana waste

Table 3: Average weights of on-farm and off-farm banana waste per banana plant in Kilograms

Challenge	Counts (%)
Weak understanding of the 7Rs solid waste management	110 (73.4)
Low adoption rates of banana waste management strategies.	93 (62.0)
Utilization of banana waste into to useful products was cumbersome	80 (53.3)
Conservative banana farmers buried in dogmatic beliefs	58 (38.7)

Weak understanding of the 7Rs solid waste management techniques (73.4) outlined in the National Environment Management Authority (2014) rendered banana waste management process an uphill task. These strategies could be applied to different types of banana waste but farmers are not well versed with the appropriate innovations to achieve this. Plastic paper tubes were used to plant seedlings while sheets of plastic papers protect the seedling from hot sun, heavy rains and hailstone. This was in conformity with Warrington's (2011) reported Challenges and Opportunities for Horticulture and Priorities for Horticultural Research at the start of the Twenty-First Century

Low adoption rate of banana waste management strategies (62%) was also reported. This was attributed to high cost of collecting, transporting and storing the heavy and bulky banana waste that requires huge labour input, patience and monitoring to achieve the process. This conforms with, the adoption the acceptance of tissue culture banana has been dragging as reported by Mbaka *et al.,* (2008), Acharya and Mackey (2009), Indimuli (2013) and Wasala (2014) yet it would directly better their welfare.

Utilization of banana waste into to useful products was cumbersome (53.3%). Stubborn sticky stain discharged by all the banana waste including the fruit scares off potential handlers and users of banana waste explains this observation. Additionally, banana waste was not only slippery but also harbored snails, bees and snakes hence exposed both people and livestock to potential risk of injuries, fractures and bites. This concurs with the revelation Mohiuddin *et al.,* (2014) that manual banana fibre extraction is a cumbersome process involving cutting the stem into pieces followed by scrapping and separating fibre using scraper or a flat blunt blade. This accounts for the preference of mechanization of banana waste as echoed by Patil and Kolambe (2011) and Mukhopadhay *et al.,* (2008)

Conservative banana farmers buried in dogmatic beliefs (38.7%) were gradually fading off. Initially banana farmers preferred industrial product and processes products to the banana waste-oriented products. According to such farmers, hay and chemical fertilizer superseded banana feeds and organic farm yard manure. However, the advent of education and public awareness converging at reincarnation of indigenous knowledge accounts for the dwindling influence of beliefs among banana farmers.

Conclusion

Common banana waste is both direct and indirect as well as on-farm and off-farm. Peeled banana fruit (ripe plus raw) weighed 21.3 kilograms being only 10.1% of the entire banana plant weight (184.1 +21.3 = 205.4) kilograms. Thus 89.9% of the plant that constituted banana waste if appropriately utilised would turn into a fortune for the vulnerable banana farmers. Banana waste was the driver of integrated organic innovative crop and livestock farming in the region. It was used to prepare tree and crop nursery preparation and establishment; grow vegetables in stare to save on space and feed livestock. Weak understanding of the 7Rs, limited funds, dogmatic beliefs and low adoption rate of organic innovative banana faming were the crucial challenges of banana waste utilisation. Synchronising the various types of banana waste

with its uses notwithstanding the challenges had simultaneously improved environmental quality and human welfare in Kakamega County through the multiplier and accelerator effects.

Recommendations

Banana famers, traders and consumers should adopt the on-site 7Rs integrated waste management approach to mop out banana waste in the banana supply chain. This could be achieved through agricultural extension services and, community based and non-governmental organizations through income generating ventures.

Tracking of both on-farm and off-farm as well as direct and indirect banana waste throughout the lifecycle of the banana was necessary. This would inform appropriate on-farm and off-farm waste management innovations since it was uneconomical to transport heavy and bulky waste.

The government should formulate incentive oriented policies, legislations, economic instruments and innovations entrenched in the banana waste business incubation centre to impel banana waste utilization and management. A tripartite approach to Organic crop and livestock farming, and agribusiness would cost-effectively boost food security and welfare among banana farmers.

Capacity building in terms of training, awareness creation and innovation dissemination with respect to banana waste utilization approaches among farmers. This can enhance the understanding of the 7Rs, augment adoption rates of banana waste utilization of banana technologies and transform dogmatic beliefs into opportunities among banana farmers thus mitigating the challenges of waste management

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