IMPROVED URBAN LIVESTOCK PRODUCTION FOR EFFECTIVE AND SAFE MANAGEMENT OF ORGANIC AND OTHER URBAN WASTES IN KISUMU CITY, KENYA:

DEVELOPMENT OF TECHNOLOGIES THAT USE ORGANIC AND INORGANIC WASTES.

(PART 1; USE OF ORGANIC WASTES)

Dump heap near Kisumu City Stadium, with a man scavenging for valuables. This dump measures 1,000 metres long by 1,000 metres wide and 3 meters deep.

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Major Highlights and Conclusions from this study.

This study has brought out a number of very interesting findings:

i. It was observed in this study, that waste dump heaps in Kisumu City are valuable resource for the poor and animals that scavenge through them for valuables and food. The people and animals scavenge for wastes like broken plastic, broken glass, discarded metals, food and feeds from markets (open air and super markets) and households.

Figure 1. A cow enjoying a bite at Kibuye Market waste dump, Kisumu City; note another cow in the background.

ii. In this study, it was observed that adult cattle can produce very large quantities of fresh dung, between 6.0 kg to 11.3 kg per day. Therefore in a case like the City of Kisumu where there are approximately 4,162 cattle, these animals produce approximately 12 million tones per year.

iii. The poor slum dwellers who keep livestock in the City of Kisumu, reported that 76% of the fresh dung produced by their cattle was not gainfully utilized, and it was therefore a major constraint to them.

iv. The study revealed that of all the uses of animal manure, 84% of the uses is as animal manure for improving soil fertility. However, the poor slum dwellers in the City of Kisumu do not have adequate farmland to absorb these quantities of manure, unless the manure is sold.

v. The study also revealed that dung is not used as fuel, either as dung cake (0.0%) or biogas (0.8%). Therefore, developing fuel products from cattle dung with high potential to be used by the poor slum and other urban dwellers was of very high priority. The fuel products developed from dung and other city wastes also have an excellent potential for selling. This will make the improved waste management in the City of Kisumu be readily adopted, and with a potential of cheap fuel processing units being set up in various parts of the slums and the city.

vi. The other accompanying wastes in the processing of these fuels, like saw dust and charcoal dust will most likely be limiting once these fuels become popular, but that will make the city cleaner.

vii. If the above happens, then 12 million tons of fresh dung per year will be readily available as raw material. When sun dried, fresh dung weight drops by 79% to 21%. This means that 12 million tons of fresh dung will produce 2.52 million tons of dry dung that we will turn to 2.52 million tons of dung cake. Since dung cake performed nearly as well as commercial charcoal in this study, we will be modest and start selling dung cake used in this study at Kshs 10.00 for 2 kg packs, while 2 kg of commercial wood charcoal in the city of Kisumu costs Kshs 20.00. Therefore the potential cost of our dung cake from the city of Kisumu would be 2.52 million tons, divided by 2 kg then multiplied by Kshs 10.00. If this proposal works, then the dung cake would fetch Kshs 12.6 million (Sterling Pounds 86,897) per year.

viii. It is therefore possible to set up dung cake processing units in several areas in the City of Kisumu, among the poor slum dwellers, especially women. This is the message we will extend to the stakeholders and slum communities in the next few months.

1. Introduction.

In the City of Kisumu, there are two major types of wastes found in the slums, namely organic and inorganic. The most important organic wastes are presented in Table 1.

Table 1. Types of Wastes in the slum Areas Studied

Name of Slum	# of families	Organic Wastes	Inorganic Wastes				
			Polythene	Pieces of metal	Plastics	Pieces of Glass	Total positive cases
Obunga	25	10	15	6	15	5	41
Nyawita	18	7	12	3	10	5	30
Manyatta A	29	0	29	0	11	0	40
Manyatta B	26	0	26	0	14	0	40
Nyalenda A	48	6	42	1	38	13	94
Nyalenda B	54	0	54	1	43	4	102
Total	**200**	**23**	**178**	**11**	**131**	**27**	**347**
%	**100**	**11.5**	**51.3**	**3.2**	**37.8**	**7.8**	**100**

- 23 families of the 200 households studied (11.5%) had only organic types of wastes in their environment, while out of 347 positive responses regarding inorganic wastes, 51.3% had polythene, 37.8% had plastics, 7.8% had pieces of glass and 3.2% had pieces of metal. Organic wastes include also paper.

Types of Livestock wastes are presented in Table 2.

Table 2. Types of livestock wastes in the compounds of livestock keepers in the slums.

Slum	# of families	Cattle Dung	Pigs Dung	Donkey Dung	Goat Drops*	Sheep Drops*	Poultry Drops*	Dog Drops*	Cat Drops*	Total
Obunga	25	18	3	0	15	9	17	4	2	68
Nyawita	18	15	0	0	10	6	14	2	2	49
ManyattaA	29	21	7	1	20	4	18	2	2	75
ManyattaB	26	23	5	0	17	8	10	1	1	65
NyalendaA	48	45	7	0	25	12	23	2	2	116
NyalendaB	54	31	4	0	20	9	15	2	3	84
Total	**200**	**153**	**26**	**1**	**107**	**48**	**97**	**13**	**12**	**457**
%	**-**	**33.5**	**5.7**	**0.2**	**23.4**	**10.5**	**21.2**	**2.8**	**2.6**	**99.9**

Drops*- Droppings

The results presented in Table 12 indicate that cattle contributed the highest amount of livestock wastes (33.5%), followed by goats (23.4%), poultry (21.2%) and sheep (10.5%). The other types of livestock (pigs, donkeys, dogs and cats) produced small amounts of wastes. It is important to remember that these wastes are not presented in terms of their biomass, but rather by their presence only.

The respondents were asked how much these livestock wastes were a constraint to them in their homes. Their responses are presented in Table 3.

Table 3. Types of livestock wastes as constraints to the livestock keepers in the slums.

Slum	No of families	Cattle Dung	Pigs Dung	Goat Droppings	Sheep Droppings	Poultry Droppings
Obunga	25	17	3	4	1	0
Nyawita	18	15	0	1	1	1
ManyattaA	29	18	4	6	0	1
ManyattaB	26	20	2	4	0	0
NyalendaA	48	43	1	4	0	0
NyalendaB	54	39	1	4	3	7
TOTAL	**200**	**152**	**11**	**23**	**5**	**9**
%	**100.0**	**76.0**	**5.5**	**11.5**	**2.5**	**4.5**

As Table 3 shows, the 200 farmers interviewed reported that the type of livestock waste most constraining to them was cattle dung (76%), followed by goat droppings (11.5%) and pigs and poultry droppings being 5.5% and 4.5% respectively. Sheep dropping was lowest (2.5%). It therefore implies that cattle dung presents the most serious constraint to the livestock farmers in the slums, and this needs to be addressed urgently.

The respondent farmers were asked if they use these livestock wastes, and their responses were that of the 200 farmers interviewed, 58.0% reported that they use livestock wastes in various ways, while 42.0% reported that they do not use them.

2. Development of technologies that use organic and inorganic wastes.

In Table 3 above, cattle wastes in slums constituted 76% of the total constraints that livestock wastes generated in the compounds of slum livestock keepers. It was therefore clear to the study team and slum dwellers that this project should develop technologies that make the slum dwellers find alternative uses for cattle wastes. There are several ways to which slum dwellers put to livestock wastes, and there are potential other ways of utilizing animal wastes in Kisumu City slums. These are presented in Table 4.

Since the slum dwellers were fully aware of the use of livestock manure for improving soil fertility, and at the same time they do not have large parcels of farmland in the slums that could absorb the large quantities of manure available, it was considered that ways of selling their livestock manure should be sought. Therefore the need for accessibility to their homes by road or cart paths to facilitate this was necessary.

Table 4. Uses of livestock wastes in the slums of Kisumu City, Kenya..

Slum	No. of families studied	Using Composted Manure for soil fertility	Dung cake	Biogas	Smearing mud walls floors	Smoke used as mosquito repellant	Feed mix	Total no. of uses
Obunga	25	17	0	0	0	0	0	17
Nyawita	18	10	0	0	0	0	0	10
Manyatta A	29	8	0	1	0	0	0	9
Manyatta B	26	15	0	0	0	0	0	15
Nyalenda A	48	19	0	0	8	8	1	36
Nyalenda B	54	31	0	0	1	0	0	32
Total	**200**	**100**	**0**	**1**	**9**	**8**	**1**	**119**
%	**-**	**84.0**	**0.0**	**0.8**	**7.6**	**6.7**	**0.8**	**100.0**

Since in Table 4, the use of animal manure as fertilizer for improving soil fertility by slum dwellers in Kisumu was 84%, and the use of animal manure as dung cakes for fuel (0%) and as biogas for fuel and lighting (0.8%), it was decided that the best technologies to develop would be using animal manure in various forms for fuel and lighting. Fuel energy is acutely short and expensive among slum dwellers.

2.1. Fresh dung output of cattle in the slums of the City of Kisumu.

2.1.1. Methodology.

Test animals selected were cows because the greatest livestock waste recorded as constraint is cattle dung manure, and cows constitute about 98% of the cattle population in Kisumu city. Four cows were selected: two local cows and two exotic cows. The selected animals were fed normally for example those that go out continued to be grazed but under supervision. Two field staff were assigned two animals each per breed. Three days were used to collect dung for a 12 hours day, and a 12 hours night. Day started at 6.00 am – 6.00 pm. while night started at 6.00 pm.- 6 am.

Using hand gloves, plastic scoops, wire brush, polythene bags, and spring balances, each field staff collected cow dung droppings produced per animal. Herding test animals were monitored during the 12 hours day, dung produced was put into polythene bags, labeled appropriately and weighed using the spring balances immediately without losing moisture. During 12 hours night, the test animals were separated from the rest and tied inside the cattle shed. Zero-grazed animals were put in their respective feeding stalls throughout the study period. Field officers also registered the frequency of dung droppings per animal per day and their findings were recorded as is presented in Tables 5 and 6.

Table 5. Day and night dung collection per monitored animals.

Day	Time period	Mass of fresh dung produced per animal (kg)			
		Local		Exotic	
		Cow 1	Cow 2	Cow 1	Cow 2
1	**12hr day**	3.50	5.00	8.00	8.50
	12hr night	0.70	3.40	3.00	4.00
	Total (kg)	**4.20**	**8.40**	**11.00**	**12.50**
	Mean	**2.10**	**4.20**	**5.50**	**6.30**
2	**12hr day**	2.20	3.00	7.00	6.30
	12hr night	1.50	3.00	4.00	5.30
	Total (kg)	**3.70**	**6.00**	**11.00**	**11.60**
	Mean	**1.85**	**3.00**	**5.50**	**5.80**
3	**12hr day**	2.20	4.60	4.80	5.00
	12hr night	2.50	4.20	4.00	8.00
	Total (kg)	**4.70**	**8.80**	**8.80**	**13.00**
	Mean	**2.30**	**4.40**	**4.40**	**6.50**

Table 6. Total daily fresh dung production per monitored animal.

Day	Local		Exotic	
	Cow 1	Cow 2	Cow 1	Cow 2
Day 1	4.20	8.40	11.00	12.50
Day 2	3.70	6.00	11.00	11.60
Day 3	4.70	8.80	8.80	13.00
Total	**12.60**	**23.20**	**30.80**	**37.10**
Mean	**4.20**	**7.73**	**10.27**	**12.37**

2.1.2. Fresh dung output from cattle in the city of Kisumu.

According to the scoping study of urban livestock in the City of Kisumu of 2002, there were 4,162 cattle (Final Report of Scoping Study for Urban and Peri-Urban Livestock keepers in Kisumu City; pp 16). From Tables 5 and 6, mean daily output of fresh dung of local cows was 6.0 kg, while that of exotic cattle and their crosses 11.3 kg. If we assume that all the cattle in the City of Kisumu were adults, therefore the following calculations of fresh dung output can be estimated (Table 7).

Table 7. Fresh dung output in the City of Kisumu (kg).

Time period	Type of breed and mean daily dung production		Type of breed, their populations and dung outputs over period of time		Total dung output in Kisumu City
	Local	Exotic and their Crosses	Local	Exotic and their Crosses	
	6.0	11.3	2,739	1,423	
Daily dung output per cow per day			16,434	16,080	32,514
Monthly dung output			493,020	482,400	975,420
Annual fresh dung output			**5,916,240**	**5,788,800**	**11,705,040**

Annual cattle fresh dung production in the city of Kisumu is approximately 12 million tones.

2.1.3. Research and Development of making dung cake and its various combinations for fuel.

2.1.3.1 Materials and Methods.

a). Materials.

The raw materials used included fresh dung, saw dust, charcoal dust, clay, and water. Mixtures of clay with charcoal dust in various proportions are called "Makwangla" in local expression in the City of Kisumu. For example, local Makwangla is already in the slum market competing with charcoal, and local poor slum women make it. Two kilograms of Makwangla cost Kshs 10.00 (Sterling Pounds 0.07) while 2.0 kg of charcoal cost Kshs 20.00 (SP 0.14).

b). Equipments used.

Weighing scale, pieces of pvc pipe to be used as moulds, plastic basins and buckets, clay lined charcoal stoves, aluminum pans, aluminum pan covering lids, thermometers, empty shoe polish containers, safety matches, syringe and needle for measuring kerosene for starting fires, and a watch.

c). Methods.

Moulds were fabricated out of pvc pipes of dimension 4 cm diameter by 2 cm depth. Various raw materials were accurately weighed and put into plastic basin, water was added and mixing done thoroughly to improve homogeneity and workability. Where materials were required to be combined in various ratios, proportions were determined on dry weight basis. A polythene sheet was spread on a flat-cemented floor, and then pvc moulds were placed on the sheet. Workable dough was placed into the plastic moulds and hand pressed. The pressed dough was then extracted as round pieces and left to dry in the sun. The sun dried finished products are presented in Figure 1. The dried products were then used for the various experiments as fuel.

Figure 2. A picture showing eight types of fuel cakes made using pvc pipe as a mould (front of the picture) ready for burning test.

2.1.4. Burning test experiment to establish fuel energy contents of various sources of fuels

Materials.

Eight sources of prepared fuel materials, eight thermometers, eight similar heating pans, eight similar aluminum covering lids, eight rubber stoppers, a stop clock for accurate timing, eight energy clay lined saving charcoal stoves, a graduated measuring jar (ml) for measuring equal volumes of water and eight empty shoe polish containers to contain kerosene loaded ash for starting up fire. Other materials used also included a 5-ml. syringe for drawing known amount of paraffin to be applied to the ash in the empty shoe containers, a box of matches for starting the fires. Clean water for boiling in the trial.

Methodology for the experiment

Each heating experiment was replicated three times. In the setting up of the experiment the following procedures were used in all the three replications.

Eight clay lined charcoal stoves were arranged in line for this experiment (see sample in Fig. 2). For each of the eight fuel sources selected, 200 g were weighed. Each of the eight clay lined charcoal stoves was filled with the 200 g of selected fuel. Figure 2 presents a sample of the layout.

Figure 3. A picture showing four clay lined charcoal stoves filled with four different test fuels, with four other test fuels in the background, and empty shoe polish tins and syringe in the foreground.

Each pan was labeled to indicate the fuel type used in the stove. Each pan was then filled with 1.5 litres of water. Eight lids were used to cover the pans during heating to reduce evaporation and conserve heat. In the center of each lid, a hole was punctured through which a thermometer was inserted and suspended in water by using a rubber stopper. The water and air temperatures (°C) were recorded at the start of the experiment. Eight similar small shoe polish tins were filled with ash to the brim. Using a syringe, 15 ml of kerosene was added to the ash in the shoe polish tins. The shoe polish tins were then placed into the charcoal stoves, but below the experimental fuel materials, ready for lighting. This was done to give uniform fire for lighting up the various experimental fuel materials in the test. The paraffin in the shoe polish tins was then lit with a burning stick at the same time for all the eight stoves. This time of lighting was recorded.

The charcoal stoves were then monitored closely to ensure that the moment the experimental fuel materials in the stoves started burning, the time was recorded. Additional paraffin was added and recorded in cases where it took longer for the fuel to catch fire. The difference in minutes between the time to start fire, and the time the test fuel caught fire recorded. Immediately the fuel caught fire the pans filled with water were placed on the clay lined charcoal stoves and heating began (Figure 3).

Figure 4. Four burning and heating experiments just started when the four test fuels started burning (1.5 litres graduated jar is shown in the foreground).

The water was then heated and the rise in temperature monitored, immediately the water in the pans begun to boil, the temperature at boiling (°C) and the time (minutes) taken to boil the water were recorded. This was the difference between the time the pan was placed on the stoves and when water started boiling. The water was left boiling, and the temperature monitored until the temperature started dropping below the boiling point. At this moment, the time was recorded, and the difference between the time water started boiling and the time the boiling temperature started dropping, this time was recorded as the time taken boiling. The pans were then removed from the clay lined charcoal stoves and the water was poured out. The pans were then placed upside down and observed for soot deposit (smokiness). The pans were then arranged in order of the extent of soot deposited on them by the fuel. Using a scale of 1 to 8 (1 – least soot deposit and 8 – most soot deposit) the levels of soot deposit were scored (Figure 4).

The pans and clay lined charcoal stoves were then cleaned up and another replicate of the same experiment was carried out, using the same procedure.

Figure 5. **Ranking of water heating pans for the extent of soot deposit as influenced by the fuel types.**

2.1.5. Results of testing the various characteristics of the fuels.

2.1.5.1 Time to start fire (Minutes).

Time taken to start fires for each fuel type significantly differed (P<0.001) from each other as is shown in the table of Analysis of Variance (Table 9). This is due to the material the fuel was made of. For example, 1:1 dung:saw dust, 100% dung cake, 1:1 dung: rough charcoal dust, and 1:1 dung:ground charcoal dust took between 3 to 3.67 minutes to start burning, and they were not significantly different (P<0.05). Other than 1:1 dung:saw dust, the others were also not significantly differently different (P<0.05) from 100% charcoal (check) with a mean of 5.33 minutes for the fire to be started. The clay:charcoal dust mixtures (Makwangla) were the most difficult to catch fire, taking between 8.00 to 15.67 minutes, depending on the amount of clay in the mixture.

The taken to start burning for any fuel used for cooking is important because meals should take the shortest time possible to prepare, for example for children from school rushing home to get lunch ready, who only have one hour.

Table 8. Time to start fire (Minutes).

Materials	Rep 1	Rep 2	Rep 3	Material Totals	Material Means
1. 100% Dung Cake	2.0	5.0	4.0	**11.0**	**3.67**
2. 100% Charcoal	4.0	5.0	7.0	**16.0**	**5.33**
3. 50% Saw Dust: 50% Cow dung	2.0	3.0	4.0	**9.0**	**3.00**
4. 50% Rough Charcoal Dust: 50% cow dung	2.0	5.0	4.0	**11.0**	**3.67**
5. 50% Ground Charcoal Dust: 50% cow dung	2.0	4.0	5.0	**11.0**	**3.67**
6. Makwangla (Local) charcoal dust: clay	6.0	10.0	8.0	**24.0**	**8.00**
7. Makwangla (charcoal dust: clay ratio 1:1)	15.0	17.0	15.0	**47.0**	**15.67**
8. Makwangla (charcoal dust: clay ratio 2:1)	8.0	15.0	14.0	**37.0**	**12.33**
Rep Totals	**41.0**	**64.0**	**61.0**	**166.00**	
Rep Means	**5.13**	**8.00**	**7.63**		

Table 9. Analysis of variance (Anova) for time to start fire (Minutes).

Sources of variation	Df	SS	MS	Observed F
Total	23	529.83	23.04	15.46***
Replications	2	39.08	19.54	13.11ns
Treatments	7	469.83	67.12	45.05***
Error	14	20.92	1.49	-

Table 10. Least Significant Differences ($LSD_{(0.05)}$ = 2.09) between different fuel sources in the trial.

50% dung:50% Saw Dust	100% Dung Cake	50% dung:50% Rough Charcoal Dust	50% dung:50% Ground Charcoal Dust	100% Charcoal	Makwangla (Local); unknown ratios of clay and rough charcoal dust	Makwangla; clay:rough charcoal dust (ratio 2:1)	Makwangla; clay to rough charcoal dust (ratio 1:1)
3.00a	3.67ab	3.67ab	3.67ab	5.33b	8.00c	12.33d	15.67e

Figures followed by the same letters are not significantly different (P< 0.05)

2.1.5.2 Time to boiling temperature (Minutes)

Time taken for 1.5 litres of water to start boiling differed for each fuel type significantly (P<0.001) from each other as is shown in the table of Analysis of Variance (Table 12). This is due to varying abilities of the different fuels in burning and generating heat. Just like in the time it takes to start a fire, this also depends on the material the fuel was made of. For example, 1:1 dung:saw dust, 100% dung cake, 1:1 dung: rough charcoal dust, and 1:1 dung:ground charcoal dust took between 13.67 to 19.00 minutes to attain boiling temperature, and they were not significantly different (P<0.05) from each other. Similarly, 1:1 dung:ground charcoal dust and 100% commercial charcoal, there was no significant difference (P<0.05) between the two. This is important to note since commercial charcoal is not only expensive, it also significantly and negatively impacts on the environment through destruction of trees. The clay:charcoal dust mixtures (Makwangla) took the longest time to bring water to boiling, taking between 30.33 to 39.00 minutes, depending on the amount of clay in the mixture. One:one charcoal dust:clay significantly (P<0.05) took longest (39 minutes) to bring water to boiling than any other fuel in the trial.

Table 11. Replications of time taken to bring 1.5 litres of water to boiling Temperature (Minutes).

Materials	Rep 1	Rep 2	Rep 3	Material	
				Totals	Means
1. 100% Dung Cake	16.0	15.0	21.0	**52.0**	**17.33**
2. 100% Charcoal	22.0	30.0	24.0	**76.0**	**25.33**
3. 50% Saw Dust: 50% Cow dung	15.0	11.0	15.0	**41.0**	**13.67**
4. 50% Rough Charcoal Dust: 50% cow dung	22.0	16.0	17.0	**55.0**	**18.33**
5. 50% Ground Charcoal Dust: 50% cow dung	20.0	20.0	17.0	**57.0**	**19.00**
6. Makwangla (Local) charcoal dust: clay	30.0	30.0	31.0	**91.0**	**30.33**
7. Makwangla (charcoal dust: clay ratio 1:1)	45.0	32.0	40.0	**117.0**	**39.00**
8. Makwangla (charcoal dust: clay ratio 2:1)	41.0	30.0	32.0	**103.0**	**34.33**
Rep Totals	**211.0**	**184.0**	**197.0**		
Rep Means	**26.38**	**23.00**	**24.63**		

Table 12. Analysis of variance (Anova) for time to boiling 1.5 litres of water.

Sources of variation	Df	SS	MS	Observed F
Total	23	1983.33	86.23	5.96***
Replications	2	45.58	22.79	1.58ns
Treatments	7	1735.33	247.90	17.14***
Error	14	202.42	14.46	-

Table 13. Least Significant Differences ($LSD_{(0.05)}$ = 6.51) between different fuel sources in the trial.

50% Saw Dust: 50% cow dung	100% Dung Cake	50% Rough Charcoal Dust:50 % cow dung	50% Ground Charcoal Dust:50% cow dung	100% Charcoal	Makwangla (Local) unknown ratio	Makwangla charcoal dust:clay ratio 2:1)	Makwangla charcoal dust: clay ratio 1:1)
13.67a	17.33a	18.33a	19.00ab	25.33bc	30.33cd	34.33de	39.00e

Figures followed by the same letters are not significantly different (P<0.05)

2.1.5.3 Time taken boiling (Minutes).

Time taken boiling 1.5 litres of water differed for each fuel type significantly (P<0.001) from each other as is shown in the previous tables of Analyses. Again this is due to varying abilities of the different fuels in burning and generating heat and sustaining the process. Just like in the time it takes to start a fire, this also depends on the material the fuel was made of. As is presented in Table 16, 1:1 dung:saw dust, 100% commercial charcoal, 100% dung cake, Makwangla 1:1 charcoal dust:clay, Makwangla 2:1 charcoal dust:clay took between 39.33 to 56.83 minutes to maintain boiling temperature, and they were not significantly different (P<0.05) from each other. It is important to note that commercial charcoal was the second poorest (42.83 minutes) in maintaining boiling temperature of water. It was only slightly better than, but not significantly (P<0.05) different from 1:1 dung:saw dust (39.33 minutes). Similarly, Makwangla 2:1 charcoal dust:clay and 1:1 dung: rough charcoal dust, there was no significant difference (P<0.05) between the two, taking between 56.83 to 67.33 minutes, respectively, maintaining boiling water. It is important to note that the slum women's product (Makwangla local) maintained boiling water longest (75.35 minutes) followed by the projects product (1:1 dung: ground charcoal dust) maintaining boiling water for 71 minutes. These two were not significantly different (P<0.05).

This last observation, and the previous presentations in the above tables are showing that charcoal dust, even when only half of it is used in the test fuels, is still better than or equal to 100% commercial charcoal.

Table 14. Replications for time taken boiling 1.5 litres of water (Minutes).

Materials	Rep 1	Rep 2	Rep 3	Material	
				Totals	Means
1. 100% Dung Cake	53.0	31.0	45.0	**129.0**	**43.0**
2. 100% Charcoal	43.0	42.5	43.0	**128.5**	**42.8**
3. 50% Saw Dust: 50% Cow dung	36.0	35.0	47.0	**118.0**	**39.3**
4. 50% Rough Charcoal Dust: 50% cow dung	52.0	74.0	76.0	**202.0**	**67.3**
5. 50% Ground Charcoal Dust: 50% cow dung	70.0	71.0	72.0	**213.0**	**71.0**
6. Makwangla (Local) charcoal dust: clay	82.5	60.5	83.1	**226.1**	**75.4**
7. Makwangla (charcoal dust: clay ratio 1:1)	45.5	47.0	58.0	**150.5**	**50.2**
8. Makwangla (charcoal dust: clay ratio 2:1)	59.5	49.0	62.0	**170.5**	**56.8**
Rep Totals	**441.5**	**410.0**	**486.1**	**1337.6**	
Rep Means	**55.19**	**51.25**	**60.8**		

Table 15. Analysis of variance (Anova) for time taken boiling 1.5 litres of water.

Sources of variation	Df	SS	MS	Observed F
Total	23	5359.22	233.00	3.85**
Replications	2	365.03	182.52	3.01ns
Treatments	7	4146.45	592.35	9.78***
Error	14	847.74	60.55	-

Table 16. Least Significant Differences ($LSD_{(0.05)}$ = 13.34) between different Fuel sources in the trial.

50% dung:50% Saw Dust	100% Charcoal	100% Dung Cake	Makwangla; clay:rough charcoal dust (ratio 1:1)	Makwangla; clay:rough charcoal dust (ratio 2:1)	50% dung:50% Rough Charcoal Dust	50% dung:50% Ground Charcoal Dust	Makwangla (Local); Unknown ratios of clay and rough charcoal dust
39.33a	42.83a	43.00a	50.17a	56.83ab	67.33bc	71.00cd	75.35cd

Figures followed by the same letters are not significantly different (P< 0.05)

2.1.5.4. Soot Deposit (Ranking from 1-8, where 1 has least soot deposit and 8 has most).

It is important that fuels should produce as little smoke and soot as possible since both of these pose health hazard to the fuel users. Therefore the eight fuels were also tested for their ability to produce both smoke and soot. However, it is soot deposit at the bottom of the water boiling pans that was estimated in these trials.

Figure 4 shows how the various fuels deposited soot at the bottom of the pans, and Table 19 shows that there were very large and significant ($P<0.001$) differences among the fuels in their ability to deposit soot. The least soot producing fuels were the charcoal dust with clay mixtures, followed by commercial charcoal, and they were not significantly ($P<0.05$) different. Their soot deposit ranking was from 1.67 to 3.67. The rough and ground charcoal dusts mixed with dung at 1:1 in each case, were the next sooty group, but were not significantly different from each other ($P<0.05$), with means of 5.33 and 5.67 for ground and rough charcoal dust respectively. However, they were significantly ($P<0.05$) different from the first four fuels. The highest soot producers, which were not significantly different from each other were 1:1 dung: saw dust and 100% dung cake, with means of 7.33 and 7.67 respectively. These last two fuels were significantly ($P<0.05$) different from all the six tested fuels.

Table 17. Soot Deposit (Ranking from 1-8, where 1 has least soot deposit and 8 has most).

Materials	Rep 1	Rep 2	Rep 3	Material	
				Totals	Means
1. 100% Dung Cake	8	7	8	**23**	**7.67**
2. 100% Charcoal	4	3	4	**11**	**3.67**
3. 50% Saw Dust: 50% Cow dung	7	8	7	**22**	**7.33**
4. 50% Rough Charcoal Dust: 50% cow dung	5	6	6	**17**	**5.67**
5. 50% Ground Charcoal Dust: 50% cow dung	6	5	5	**16**	**5.33**
6. Makwangla (Local) charcoal dust: clay	3	2	2	**7**	**2.33**
7. Makwangla (charcoal dust: clay ratio 1:1)	1	1	3	**5**	**1.67**
8. Makwangla (charcoal dust: clay ratio 2:1)	2	4	1	**7**	**2.33**
Rep Totals	**36**	**36**	**36**		
Rep Means	**4.5**	**4.5**	**4.5**		

Table 18. Analysis of variance (Anova) for ranking soot deposit by various fuels.

Sources of variation	Df	SS	MS	Observed F
Total	23	612.00	26.61	32.85***
Replications	2	0.00	0.00	0.00ns
Treatments	7	600.67	85.81	105.94***
Error	14	11.33	0.81	-

Table 19. Least Significant Differences ($LSD_{(0.05)} = 1.54$) between different Fuel sources in the trial.

Makwangla; clay:rough charcoal dust (ratio 1:1)	Makwangla; clay:rough charcoal dust (ratio 2:1)	Makwangla (Local); unknown clay:rough charcoal ratio	100% Charcoal	50% dung:50% Ground Charcoal Dust	50% dung:50% Rough Charcoal Dust	50% dung:50% Saw Dust	100% Dung Cake
1.67a	2.33a	2.33a	3.67ab	5.33c	5.67c	7.33d	7.67d

Figures followed by the same letter are not significantly different ($P<0.05$).

Because the test fuels developed in this study to use waste products as raw materials basically cost nothing except for collection and processing labour; and because the use of these wastes will have several benefits to the poor urban dwellers and the environment, even the high soot producers have a very high value. It is therefore important to recommend that the cooking stoves be placed outdoors or under a chimney when the fuels that produce smoke are used.