Potassium Recovery Potential of Selected Agroforestry and Organic Wastes in Ibadan, Nigeria

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Abstract

This study explored potassium recovery from agroforestry wastes that may be a cheap alternative to imported ones. The wastes: Plantain Peel (PP), Coconut Fibre (CF), Coconut Shell (CS), Cocoa Pod (CP), Sugarcane Bagasse (SB), Sawdust (SD) and four common wood-fuel species - *Antiaris toxicaria* (Wd1), *Cordia millenii* (Wd2), *Khayas senegalensis* (Wd3) and *Milicia excelsa* (Wd4) were assessed for their ash content (AC) and moisture content (MC), using standard procedures of AOAC. Atomic Absorption spectrophotometer was used to determine mineral concentrations: potassium, sodium, magnesium, calcium, zinc, lead and iron of the wastes. In addition, efficacy of three methods of extracting potassium from ashes: cold water extraction at 35 ^{O}C, hot water extraction at 90 ^{O}C and steam extraction was assessed. Data were analysed using descriptive statistics and correlation test at $p<0.05$. Wastes with highest values in terms of AC and MC were: CP (AC- 11.62 ± 0.3 %) and SB (MC- 82 ± 2.64 %). The highest concentration of K ($mg \cdot kg^{-1}$) was found in CP (8,387.50 ± 2.00 $mg \cdot kg^{-1}$). Cold water extraction gave the most potassium yield (88.44 %) and the highest solid potash content was found in PP (68 500 $mg \cdot kg^{-1}$) while CP had the highest K concentration (12.51±0.20 $g \cdot dm^{-3}$). Cocoa pod, plantain peel and *Cordia millenii* are very good sources of agroforestry/organic wastes for local production of potassium both in terms of solid potash yield and potassium recovery potential. Development of a suitable technology which can be used to extract potassium locally is recommended.

Keywords: Agroforestry waste, Cold water extraction, Organic waste, Potassium recovery, Solid potash content

Introduction

The recovery of resources from agricultural waste is one of the ways by which agricultural wastes can be managed, such management practices tend to reduce waste disposal costs and generate the revenue from the sale of the recovered materials (UNEP, 2009). Potash is the trade term commonly applied to crude potassium carbonate obtained by leaching the ashes of burnt plant and animal bones with water and evaporating the resulting solution to dryness. Local potash is a brownish or blackish substance (due to impurities) but when pure, it is white in appearance. Potash chemical configuration is K_2CO_3 with molecular weight of 138.7 $kg \cdot Mol^{-1}$. It is a translucent (granular) or white odourless deliquescent solid known in the anhydrous and hydrated forms (Shagal, 2011). That is, it is a white crystalline residue that remains after aqueous extract from ashes has been evaporated (Kevin, 2003). The highest soluble metal is potassium, though this depends on the species of the plant material and the type of soil where the plant grows (Babayemi et al., 2010). Potassium is the seventh most abundant element in the earth and in high demand in several countries of the world. Also, potassium is employed in fertilizer production (as an essential nutrient for plant growth), cement industry, soap making, production of glass, ink, dye and matches, electroplating processes, production of anti-freezing and cleansing agents, production of pesticides for farm crops and leather tanning.

In a study, it was revealed that wood waste and ashes took a considerable percentage of solid wastes being generated in Nigeria every day (Babayemi and Dauda, 2009) and on the average, the burning of wood results in 6 to 10 percent ashes (Risse, 2013). Potash content of some plant materials have also been studied in several investigations (Afrane, 1992; Taiwo and Osinowo, 2001; Onyegbado et al., 2002; Adewuyi et al., 2008) and there have been previous studies on the analyses of extracts from ashes (Nwoko, 1980; Kuye and Okorie, 1990; Onyekwere, 1996; Onyegbado et al., 2002). Many of these researchers showed that the extract was chiefly potassium hydroxide with some quantities of sodium hydroxide. However, very few studies have focused on recovery of potassium from agroforestry wastes, including wood waste. Nigeria at present lacks the resources to build a modern alkali plant, following the Federal Government's call out to industries to source their raw materials as much as possible locally. The conventional technology for potassium production is expensive and not sufficiently available in developing countries, whereas the local potash production from agroforestry and organic waste ashes is seen to be cheap and requires no complex technology.

Nigeria's local and Industrial agriculture relies on continual use of imported and Non-renewable potassium supply, relatively potassium hydroxide and potassium carbonate used for soap production (Taiwo and Osinowo, 2001). The consequences of relying on imported potassium includes drain on foreign reserve and insufficient supply due to high capital requirements for the farmers, which renders its inputs into farms unaffordable. In addition, agroforestry wastes are continuously been generated from agricultural activities that are still largely under-utilized and left to rot the field, which causes chronic environmental and health problems. Through the experimental determination, potassium recovery potential from various agroforestry waste ash, Nigeria could drastically reduce her importation of potassium and also generate wealth. The broad objective of this study was therefore to evaluate the recoverable potassium potential of selected agroforestry and other very common organic wastes generated in Nigeria.

Materials and Methods:

Study location

The experiments were conducted in the multidisciplinary laboratory of Environmental Health Science Department that is located in the Faculty of Public Health, University of Ibadan, Nigeria. Ibadan is the capital city of Oyo State, the largest indigenous city in West Africa with a total land area of 3,123 km and population of 1,338,659, according to the 2006 census. Ibadan municipality is divided into 11 Local Government Areas (LGAs) consisting of five urban local governments and six semi-urban local governments (Figure 1). The principal inhabitants of the city are of Yoruba ethnic group and majority of them are farmers, traders and civil servants. The farmers produce varieties of agricultural items to meet the food needs and other requirements of the urban population. Ibadan has mean maximum temperature of 26.46 °C with minimum of 21.42 °C, relative humidity of 74.55 % and the mean total rainfall of 1420.06 mm, falling in just about 109 days. There are two peaks for rainfall: June and September. Ibadan was selected as study area because of its high rate of agricultural activities and in turn generation of enormous agro based wastes.

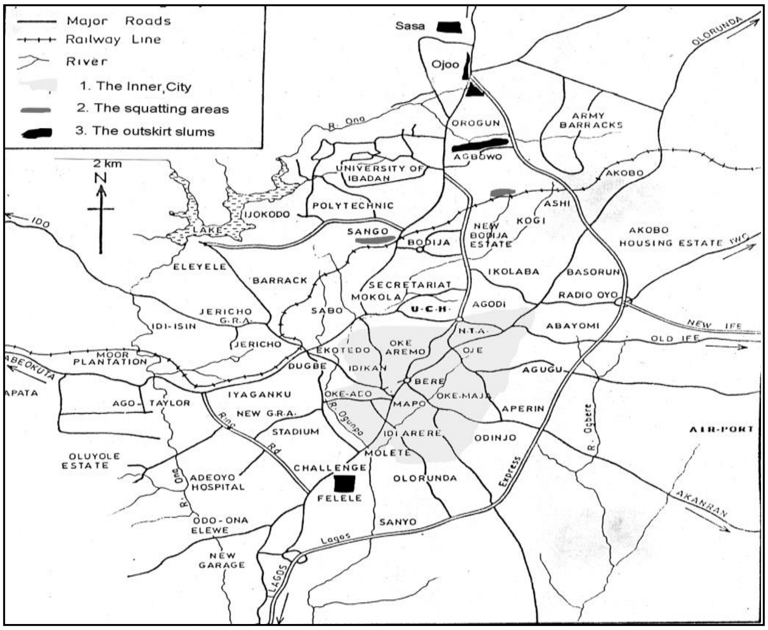

Figure 1: Map of Ibadan Metropolitan area Source: Ministry of Lands, Oyo State (2009)

Ten different agroforestry/organic wastes obtained from various locations within Ibadan metropolis, namely: Coconut shell (CS), Cocoa pod (CP), Plantain peels (PP), Sugarcane bagasse (SB), Coconut fibre (CF), Antiaris toxicaria (Wd1), Cordia millenii (Wd2), Khaya senegalensis (Wd3), Milicia excels (Wd4) and Saw dust (SD) (Figure 2) were utilized in this study. Botanical authentication of the selected wood species was ascertained at the Department of Botany, University of Ibadan, Nigeria. Other materials used included: muffle furnace, oven, toledo mettle weighing balance (± 0.001 g detention limit), pH meter, mercury in glass thermometer, filter paper, glass wares and distilled water. Samples of each waste were air dried for 10 days and then pulverized using a laboratory blender, mortar and pestle, depending on the composition of the sample.

Figure 2: Cross section of some of sun-dried waste (A- coconut shell; B- plantain peel; C- cocoa pod; D- sugar cane bagasse and E- Coconut fibre)

Determination of moisture and ash contents

Moisture Content (MC) was determined using hot air oven method and Ash Content (AC) was determined by subtracting the masses of the crucibles and their contents (dried sample/ ash) before (W2) and after (W3) ashing in a pre-heated furnace at 550- 600 ^{O}C, for 2 hours.

$$\% \text{ Ash content } = \frac{\text{Ash weight (W3)}}{\text{Dried sample wt.(W2)}} \times 100$$

Determination of mineral elements in agroforestry/organic waste ashes

The following elements were analysed in each of the waste ash sample: Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na), Zinc (Zn), Lead (Pb) and Iron (Fe). One gram of finely sieved (through 2mm sieve mesh) ash samples of each waste was weighed into a 25 ml volumetric flask and 10 ml of 0.1 N HCL was added. The solution in the conical flask was corked and shaken vigorously to ensure complete mixing. The mixture was filtered through Whatman No. 41 filter paper into a 50 ml and made up to 25 ml mark with distilled water. The solution obtained was then used in the determination of K, Ca, Mg, Na, Zn, Pb and Fe using the Atomic Absorption Spectrophotometer (GBC 902).

Extraction of solid potash from agroforestry/organic waste ashes

Three methods of extracting solid potash from the waste ashes were compared for their efficacy. The methods tested were:

i. cold water extraction,
ii. hot water extraction, and
iii. steam extraction.

The general procedure used for the various methods followed those described earlier in previous studies (Adewuyi et al., 2008; Ogundiran et al., 2011; Kumar, 2013). Twenty gram of each ash sample was placed in a 1 litre transparent plastic bottle and 267 ml of distilled water was added at 34 ^{O}C (for cold water extraction) and 90 ^{O}C (for hot water extraction). The bottle was corked, shaken vigorously and allowed to stand for 12 hours. The resulting clear liquid solution was filtered into the plastic bottle through a filter paper (Whatman No. 41 filter paper) and the alkali components of the extracts were collected. For the steam extraction method (i.e. heating of dissolved solute), 20 g of ash and 267 ml of distilled water were poured into a beaker and stirred with a metal rod for 2 minutes. The mixture was heated slowly on hotplate for a period of 15 minutes and allowed to stand for 12 hours. The comparison of the three extraction methods was carried out on cocoa pod ash which had the highest potassium concentration while cold extraction method was used for the rest of the wastes.

The optimal yield of the three methods was determined by relating the weight of solid potash with potassium concentration in the potash at a constant weight of 3.45 g as follow:

$$\text{Optimal yield} = \frac{\text{K wt. (g) X SP wt}}{\text{Constant SP wt}}$$

$$\text{\% Optimal yield} = \frac{\text{Optimal yield}}{\text{Constant SP wt}} \times 100$$

Where:

K wt = Potassium concentration in gram
SP wt = Weight of Solid potash recovered after ash extract concentration in gram
Constant SP wt= Constant Weight of solid potash utilised at titration (3.45 g)

Estimation of solid potash yield in relation to agroforestry/organic wastes

In relating the solid potash extracted obtainable from each waste, quantity of solid potash was weighed (W1) and the percentage potash yield from each of the waste ash was thus:

$$\text{\% Solid Potash in waste ash } = \frac{W1}{W2} \times 100$$

Where:
W1= Weight of solid potash
W2= Weight agroforestry/organic waste ashes

Results and Discussion

Results of ash and moisture contents of the selected wastes are presented in Table 1. The highest ash content was observed in CP (11.62±0.3 %) and the least value was found in CS (1.26±0.1 %). In terms of moisture content, 82±2.64 % was found in SB while the least was found in SD (5±0.5 %). Table 2 shows results of mineral element (K, Na, Mg, Ca, Zn) composition of the wastes. All the wastes exhibited a similar pattern in order of the magnitude of elements they composed of (K > Na > Mg > Ca). As such, potassium was found highest in all the waste especially in CP (8,387.50 ± 2.00 $mg \cdot kg^{-1}$), followed by PP (7,880.01 ± 4.50 $mg \cdot kg^{-1}$). This agrees with the findings of Ayeni (2010) in which K had the highest percentage among other elements. Also Oluremi et al. (2012) revealed highest concentration of K in plantain peel among other plants they analysed. Nwoko (1980) and others (Kuye and Okorie, 1990; Onyekwere, 1996; Onyegbado et al. 2002) showed that agroforestry wastes ash extracts consisted chiefly of potassium hydroxide with some quantities of sodium hydroxide, while other metallic ions constituting about 2 % were Ca^{2+}, Cr^{2+}, B^{3+} , Zn^{2+}, Fe^{3+}, Pb^{2+} and Ni^{2+}.

Coconut shell had the highest value of Na (881.03 ± 1.00 $mg \cdot kg^{-1}$) followed by CF (683.41 ± 5.78 $mg \cdot kg^{-1}$) and SD (313.51 ± 2.01 $mg \cdot kg^{-1}$). In addition, *Khaya s* (Wd3) contained highest value of Mg (1,140.03 ± 3.00 $mg \cdot kg^{-1}$) while Ca was found highest in Wd2 (708.34 ± 2.01 $mg \cdot kg^{-1}$). The Zn was virtually absence in the ashes of all the wastes while lead and iron were not found at all. Trace concentration of Zinc metal was observed only in plantain peel, saw dust and *Antiaris toxicaria* wood specie at values as low as 0.01 mg/L, 0.04 mg/L and 0.01 mg/L respectively (Table 2). On the contrary, Oluremi (2012) recorded Zn concentration for plantain peel as high as 30.70 $mg \cdot kg^{-1}$; the higher concentration might be due to the soil where the plantain was grown and the materials used in enriching the soil. Similarly, absence of Pb and Fe in all the waste ashes is not consonance with the findings of Oluremi (2012) in which Pb was detected in a trace quantity (0.02 $mg \cdot kg^{-1}$) in plantain peel. This is an indication that the use of these waste ashes in soap production may not pose risk of heavy metal bioaccumulation to the end users.

Table 1: Ash and moisture contents of the agroforestry/organic wastes

Sample	Ash content (%)	Moisture content (%)
PP	9.72 ± 0.22	67.00 ± 1.50
CF	6.64 ± 0.14	34.00 ± 2.60
CS	1.26 ± 0.10	8.00 ± 0.50

CP	11.62 ± 0.3	76.00 ± 2.00
SB	2.96 ± 0.03	82.00 ± 2.64
SD	4.18 ± 0.03	5.00 ± 0.50
Wd1	1.86 ± 0.02	10.00 ± 0.50
Wd2	3.56 ± 0.02	9.00 ± 0.40
Wd3	1.47 ± 0.03	11.00 ± 0.20
Wd4	6.77 ± 0.20	11.00 ± 0.20

Key:
PP = Plantain peel **CP**= Cocoa pod **Wd1**= *Antiaris toxicaria*
CF= Coconut fibre **SB**= Sugarcane Bagasse **Wd2**= *Cordia millenii*
CS= Coconut shell **SD**= Sawdust **Wd3**= *Khaya senegalensis*
Wd4= *M excelsa*

Table 2: Mineral composition of the agroforestry/organic waste Ashes ($mg \cdot kg^{-1}$)

Sample	**K**	**Na**	**Mg**	**Ca**	**Zn**
PP	7,880.01 ± 4.50	47.68 ± 1.01	0.40 ± 0.10	0.21 ± 0.01	0.01 ± 0.0
CF	5,960.07 ± 5.02	683.41 ± 5.78	118.37 ± 1.00	70.9 ± 0.41	0.00 ± 0.00
CS	5,907.49 ± 3.03	881.03 ± 1.00	4.28 ± 0.11	0.34 ± 0.01	0.00 ± 0.00
CP	8,387.50 ± 2.00	71.35 ± 1.99	11.71 ± 0.12	0.20 ± 0.00	0.00 ± 0.00
SB	5,393.58 ± 4.01	109.69 ± 2.98	258.37 ± 9.23	33.41 ± 1.00	0.00 ± 0.00
SD	5,186.84 ± 2.90	313.51 ± 2.01	56.39 ± 1.00	536.82 ± 1.64	0.04 ± 0.00
Wd1	5,095.39 ± 1.15	75.05 ± 1.00	840.02 ± 1.99	557.12 ± 1.52	0.01 ± 0.00
Wd2	1,653.52 ± 2.32	28.23 ± 0.56	420.17 ± 2.64	708.34 ± 2.01	0.00 ± 0.00
Wd3	3,497.10 ± 2.00	106.04 ± 2.04	1,140.03 ± 3.00	594.91 ± 1.15	0.00 ± 0.00
Wd4	2,981.56 ± 5.16	113.02 ± 2.01	493.39 ± 1.14	119.05 ± 2.00	0.00 ± 0.00

Key:
PP = Plantain peel **CP**= Cocoa pod **Wd1**= *Antiaris toxicaria*
CF= Coconut fibre **SB**= Sugarcane Bagasse **Wd2**= *Cordia millenii*
CS= Coconut shell **SD**= Sawdust **Wd3**= *Khaya senegalensis*
Wd4= *M excelsa*

The pH of the ash extract, the weight of solid potash and potassium concentration of the solid potash obtained from the three extraction methods when applied to CP ash are presented in Table 3. The pH of ash extracts from the cold, hot and steam extraction methods were: (11.4±0.2), (11.5±0.3) and (11.6±0.2) respectively. The steam method had the highest pH value while cold extraction had the lowest pH value. The pH measures the concentration of H+ and hydroxide (OH^-) ions thus increase in temperature might have caused a slight reduction in hydrogen. Also, the hot extraction had the highest weight of solid potash (5.79±0.01 g) while the cold extraction had the lowest weight of solid potash (5.75±0.10 g). However, in terms of the K concentrations in the solid potash extracted and, consequently, percentage optimal yield, cold extraction method was found the best with 12.21±0.10 $g \cdot dm^{-3}$ and 88.44±0.74 % respectively. It could be inferred from this observation that temperature had effect on the pH of the various extracts; the higher the temperature, the higher the pH of the extract.

The above observation also implied that pH, but not the quantity of solid potash, could influence the concentration of K obtainable from each extraction method and its percentage optimal yield. This is in line with reports of EPA (1980) and Izquierdo and Xavier (2011) that low pH favours the leaching of most trace metals in their study on the behaviour of ash particles in water. In this study although cold water had the least pH value its potassium concentration was the highest. Similarly, Dodson (2011) reported that potassium extraction from wheat straw ash at 30 ^{O}C, which is very close to 34 ^{O}C used for cold water extraction in this study, gave higher potassium concentration (94 %) in comparison to potassium concentration extracted at 60 ^{O}C which gave a lower concentration. On the other hand, a similar procedure was conducted by Kumar (2013) coffee husk ash, where he revealed that hot water extraction gave the highest yield, this disparity may be due to the type of waste
sample been utilized for the experiments, for this study cocoa pod was used while Kumar (2013) utilized coffee husk ash, thus the impact of temperature on aqueous potassium extraction from ash may be dependent on the substrate been utilized.

Using cold extraction methods for all the wastes, there was variation in the pH of the extracts, solid potash contents and percentage of solid potash obtainable form each waste as well as actual K concentration in each waste (Table 4). Figure 4 depicts K recoverable potential of each waste solid potash with cocoa pod had the highest potassium recovery potential (55.91±0.20 %) whereas *Antiaris toxicaria* had the lowest potential (1.29±0.1 %).

Table 3: The pH of the solid potash extracts and efficacy of the extraction methods

Sample	**pH Value**	**% Solid Potash yield**	**Solid Potash content in dry mass (mg·kg^{-1})**	**K Conc. (g·dm^{-3})**
Plantain peel	11.71 ± 0.3	70.60	68500	9.47±0.89
Coconut fibre	11.34 ± 0.2	31.90	4000	2.97±0.43
Coconut shell	10.57 ± 0.3	28.40	3500	11.68±0.95
Cocoa Pod	11.44 ± 0.3	57.50	66800	12.51±0.20
Sugarcane		1.60		7.81±0.1
Bagasse	9.66 ± 0.2		500	
Saw dust	12.02 ± 0.3	11.80	4900	9.88±0.1
Antiaris toxicaria	8.58 ± 0.4	20.70	3800	0.48±0.09
Cordia millenii	10.39 ± 0.3	3.10	500	5.87±0.1
Khaya s	9.34 ± 0.2	1.60	200	5.64±0.2
Milicia excelsa	10.94 ± 0.3	8.70	5800	3.39±0.1

Table 4: Characteristics of potassium in relation to the dry agroforestry/organic waste residues

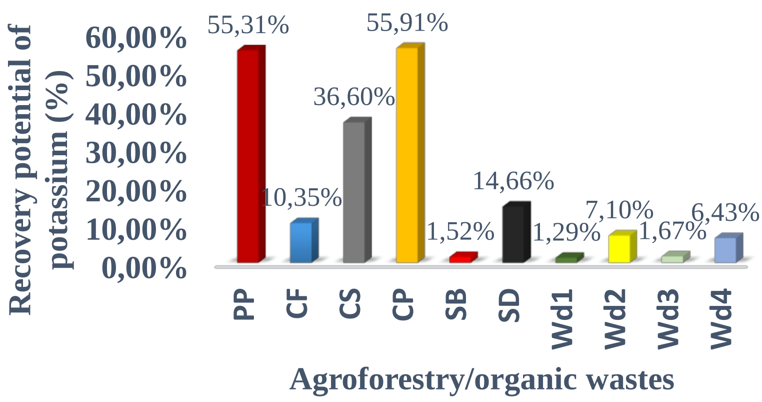

Figure 3: Percentage potassium recovery potential in relation to total potassium concentration in the selected agroforestry/organic wastes

Key:

PP= Plantain peel **CP** = Cocoa pod **Wd1**= *Antiaris toxicaria*

CF= Coconut fibre **SB**= Sugarcane Bagasse **Wd2**= *Cordia millenii*

CS= Coconut shell **SD**= Sawdust **Wd3**= *Khaya senegalensis*

	pH	Solid potash Yield (g)	K Conc. (g·dm^{-3})	% optimal yields
Cold Extraction	11.44 ± 0.2	5.75±0.10	12.21±0.10	88.44±0.74
Hot Extraction	11.51 ± 0.3	5.79±0.01	11.49±0.07	83.28±0.50
Steam Extraction	11.58 ± 0.2	5.76±0.41	10.92±0.01	79.11±0.07

Wd4= *M excelsa*

The outcome of Spearman's rho correlation coefficient (r) test between ash content, solid potash content, crude potash content and potassium concentration is presented in Table 5. A significantly positive correlation existed between Ash content and solid potash content (r = 0.539) while a weak correlation existed between solid potash and potassium concentration (r = 0.298).

Table 5: Correlation matrix for ash content, solid potash content and potassium concentration

Variables	Ash content %	Solid potash content %	Potassium conc. %
Ash content %	1		
Solid potash content %	0.539**	1	
Potassium conc.%	0.187	0.298	1

****Correlation is significant at the 0.01 level (2-tailed)**

Conclusion

Cocoa pod, plantain peel, among the organic wastes, and Cordia millenii, among the agroforestry waste, are very good sources of wastes for local production of potassium both in terms of solid potash yield and potassium recovery potential. Cold extraction is the most effective method of extracting potassium from agroforestry and organic waste ashes due to its high optimal yield. By increasing the temperature, pH of the extract increases which consequently reduces the concentration of potassium obtainable from any of the three common extraction methods: cold, hot and steam extraction as well as percentage optimal yield of the potassium. The more the quantity of ash content contained in the waste, the more the quantity solid potash extractable from such waste. However, high quantity of potash ash does not indicate high level of potassium that can be recovered from agroforestry or organic waste. Development of a suitable local technology which can be used to extract potassium locally is recommended to complement the substantial quantity of potassium being utilized in agricultural and industrial sectors and conserve Nigerian foreign reserve.

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