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Bioconversion of Mixed Fruit Waste as a Potential Source of Biogas and Organic Fertilizer

Olatunde Ajani Oyelaran[1]*, Ademola Ezra Adeleke[1], Olawale Monsur Sanusi[1] Bayode Julius Olorunfemi[1], Yusuf Yau Tudunwada[2]

[1]Department of Mechanical Engineering, Federal University Oye-Ekiti, Nigeria.
[2]Heavy Equipment and Machinery Development Institute, Bauchi, Nigeria

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Abstract: This paper investigates the bioconversion of mixed fruit waste as a potential source of biogas and organic fertilizer. The initial and final total solids (TS) of substrates were 19.15 and 8.76 % respectively. The volatile solids (VS) of the substrate before and after digestion were 95.11 and 54.94% respectively. The TS/VS lost in fermenter was found to be 0.16. On the sixtieth day of planting the maximum plant height was T_3 250.31 cm for 50:50 % NPK fertilizers and neither biogas residue, followed by 100% NPK fertilizer with 242.65 cm, control with no NPK fertilizer nor biogas residue of 241.73 cm while 100% biogas residue has the lowest with 203.65 cm. The result for 1000 grain weight shows that 50:50 % NPK fertilizer and biogas residue has the highest weight of 276.34 grams, followed by !00 NPK fertilizer with 254.78 grams, 100% biogas residue has 240.12 grams while the control with no NPK nor biogas residue added has the least weight of 188.56 grams. The study also shows that residue left after the production of biogas is a valuable organic fertilizer that can be used as an alternative to inorganic fertilizer in maize production and soil fertility. Yield of maize was significantly increased over that of the control. Markedly influenced by the application of organo-minerals, NPK fertilizer and their combination as observed from the increased plant height, diameter of plant stem, leaf area and Weight of 1000 kernels compared to the control. Biogas residue has therefore proved to be environmentally friendly and an effective fertilizer. The use of locally available, nutrient rich organic sources is an effective means for improving soil fertility and increasing crop yield in view of the escalating cost of inorganic fertilizers and low fertilizer use efficiency of crops.

Keywords: Digestion, biogas, co-digestion, cow dung, fertilizer, fruit wastes

1. Introduction

In today's fast-growing world, the rate of energy consumption is rising at surprising rates with each passing day, Nigeria is part of this global trend particularly over the last decade. To meet its growing energy needs, the nation has been investing hugely in developing its hydroelectric power and gas generating capacity. Over the last century, fossil fuel consumption, deforestation, and other unsustainable land use practices brought by land conversion and land use change (LCLUC) have resulted in a dramatic increase of carbon dioxide (CO2) emissions into the atmosphere. Most scientists believe the increase of CO2 emissions is the main cause of the human-induced climate warming [1]. Besides, the country also relies significantly on the fuel it imports to meet its energy demand. Development of renewable and sustainable energy source is the best solution to the country's energy demands. It is much desirable that the renewable energy to be developed has no adverse effects on the environment. Waste minimization is the recent emerging concepts. In a study by Gustavsson et al., [2] roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year. This inevitably also means that huge amounts of the resources used in food production are lost in vain, and that the greenhouse gas emissions caused by production of food that gets lost or wasted are also emissions in vain. This loss occurs throughout the supply chain, from initial agricultural production down to final household consumption. The causes of food losses and waste in low-income countries are mainly connected to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems including distributions, at e.g. wholesale markets, supermarkets, retailers and wet markets [3]. FVWs account in the total food waste varies with spatial and socioeconomic conditions. Fresh fruits, vegetables, and salads were found to make up the largest category of food waste [4]. The conventional energy resources are declining day by day, hence a suitable substitute for conventional resources need to be explored. Fruits and vegetable solid wastes (FVSW) represent a potential energy resource if they can be properly and biologically converted to methane. They are renewable and their net CO_2 contribution to the atmosphere is zero

*Corresponding author: ajanioyelaran@gmail.com

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[5]. Research and development efforts in biomass and other renewable energy technologies are prerequisite for continue improving their performance, launching techniques for precise measurement of output and reliably integrating them with other conventional generating sources [6]. An important step towards a sustainable waste management system is to augment the waste reduction, reuse and recycle paradigm with processes that actually reduce solid waste accumulation [7]. One of the compelling processes in this category is anaerobic digestion where little is done in this regard [8]. When fruit wastes (FWs) are collected at the outset, the operation would be easy to deal with. FVWs are known to contain highly biodegradable compounds (70 - >80% volatile solid) and moisture strongly supporting their use for anaerobic biogas digesters' input. These wastes therefore holdup significant energy [9] and manure resource. However, these resources are wasted and left to decompose where a related problem arises in other areas [2]. Due to the waste decomposition, huge amount of CH_4 and CO_2 (green house gasses) are emitted into the atmosphere together with NH_3 and H_2S-noxious gases, causing environmental and health problems. In addition, the wastes affect aquatic systems by depleting dissolved oxygen owing to the bio-chemical strength of the wastes if washed with floodwater.

Anaerobic digestion is the biological degradation by a complex microbial ecosystem of organic and occasionally inorganic substrates in the absence of an organic source. Methane fermentation is a complex process. The general process of anaerobic digestion is a series of processes like enzymatic hydrolysis, acidogenesis, acetogenesis and methanogenesis [10] and each metabolic stage is assisted by a series of micro organisms. Amongst the four stages, hydrolysis is the rate limiting stage for fruit vegetable waste [11, 12]. The main advantage in using anaerobic digestion is the biogas production, which can be used for steam heating, cooking and generation of electricity [13]. The effluent produced can be used as a bio-fertiliser or soil [14]. Fruit and Vegetable wastes are disposed in municipal landfill or dumping sites. Due to their nature and composition, they deteriorate easily and cause foul smell, causing serious environmental and health problems which are related to inadequate disposal. Consequently, the environmental problems, including the formation of methane gas from oxygen deficit condition occur. Methane gas is one of greenhouse gases which have 25 times higher potential to cause global warming than carbon dioxide [15]. Garbage dumped in open places cause heavy pollution due to soil, groundwater and surface waters [16]. Bioconversion processes are suitable for wastes containing moisture content above 50% than the thermo - conversion processes [17]. Vegetable wastes, due to high biodegradability nature [18, 19] and high moisture content (75 – 90%) seemed to be a good substrate for bio-energy recovery through anaerobic digestion process. A major limitation of anaerobic digestion of vegetable wastes is the rapid acidification due to the lower pH of wastes and the larger production of volatile fatty acids (VFA), which reduce the methanogenic activity of the reactor [20]. Similarly, the nitrogen and in some regions of farming the phosphorus in FVW are very low, and the carbon: nitrogen ratio is very much higher than the optimum for stable anaerobic digestion. For this reason, the FVWs have been used in co-digestions with other wastes for better biogas/methane yield and process stability. Hence the co-digestion of FVW was used in this work. Preliminary treatment is required to minimize organic loading rate, hence aerobic processes are not preferred for vegetable wastes [21].

The advantage of this process includes the following, first, is the need to apply a process to dispose organic solid wastes in a more environmentally friendly manner along with useful soil conditions. Secondly, the opportunity to obtain from this process a renewable fuel called biogas alternative to fossil fuel. Thirdly, the advantage of relatively low costs in starting up and managing this process as it mainly does not require oxygen supply, as well as, its feasibility of being even commercialized. Although converting these wastes to a renewable energy (biogas) and soil manure is proved to be brilliant, little is known on the potential of such wastes in the city. Therefore, this study is aimed at adding value to this agro solid waste by converting it to methane gas and fertilizer. Thus, this finding could help many stakeholders interested in an Integrated Solid Waste Management (ISWM) activity that is geared towards city sustainability in terms of energy and environmental management. Currently, interests in the use of biogas are increasing by the sub-Saharan African cities due to its economic and environmental benefits [22]. The interest of this study lies here, obtaining clean energy and soil nutrient.

2. Methodology

2.1 Study area

Kano is the largest city in the Northern Region of Nigeria. It is located between latitude 12o 25 to 12o 40N and longitude 8o 35 to 8º 45E. Kano city has been an important commercial and industrial nerve centre of Northern Nigeria attracting millions from all parts of the country and beyond. The population growth rate of 3% is expected to continue to increase the population and waste stream in the years to come. The population is presently estimated at 3.5 million. With a population density of about 1000 inhabitants per km^2 within the Kano closed-settled zone compared to the national average of 267 inhabitants per km^2 [23]. The city also has a large migrant worker population which has been increasing at the rate of 30 to 40 per cent per annum [24]. The city also has the largest fruit and vegetable markets at Yanlemo and Yankaba. These markets generate a lot of waste daily, fruit and vegetable wastes are also created by marketing, processing, harvesting, transportation etc.,

2.2 Substrate collection and treatment

The substrate used for this research work is mixed fruit wastes (FW) and cow dung (CD). The mixed fruit wastes were collected fresh from Yanlemo fruit market in Kano, while the cow dung was collected from Kumbotso town, Kano State, Nigeria. The fruit wastes collected are made up of different fruits (mango, pineapple, banana, papaya, cabbage orange, tomatoes and water melon). The wastes were washed to remove sand and dirt, after which they were milled using milling machine.

2.3 Analysis of physical characteristics

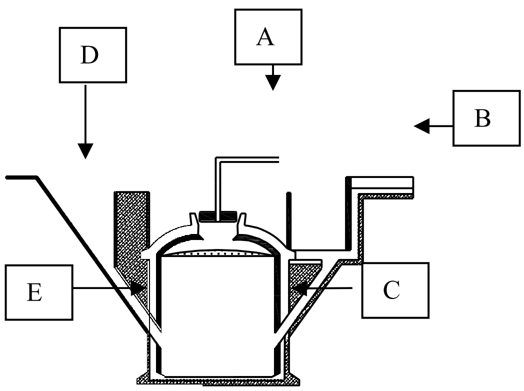
The physical characteristics (total solids; volatile solids; moisture content and ash content) were analyzed by a standard method for the examination of water and waste water [25].The temperature and the pH in each digester were measured at the start. The slurry was sampled at start-up and end of the digestion for the total solids (TS), volatile solids (VS), ash content and moisture content determination. While the average pH of the slurries was determined using pH meter.

2.4 Preparation of mixed wastes

Slurry of approximately 6 Kg of the mixed waste consisting of 50% each of FW and cow manure was prepared. Slurry obtained by mixing fresh cow manure and tap water in a 1:5 ratio by weight was used for start-up of the digestion for two days.

2.5 Feeding and operating to steady state

Before feeding into digester, the slurry was mixed by hand in a separate container and fed to the digester daily for five days. After feeding the mixed waste into the digester the mouse of the digesters were closed.



A	Out flow for biogas
B	To overflow tank
C	Outlet chamber
D	Slurry of waste fruit and dung mixture
E	Inlet chamber

Figure 1 Schematic diagram of biogas digester

2.6 Physico-chemical analyses

The pH of digester liquid, influent and effluent, temperature of gas production volume were observed. In addition to this, TS and VS of the manure after digestion were determined. The TS/VS lost in fermenter and efficiencies of VS conversion to gas was also monitored at the end of the study. These parameters were determined in accordance with APHA, [25].

2.7 Total solids (TS)

Total solids denote organic as well as inorganic matter in the feedstock [26]. TS were measured according to APHA [25]. A 20g of fresh feedstock was weighed (W_2) in an empty crucible (W_1) and dried in an oven maintained at 105°C for 24 hour (W_3). Percentage TS was calculated by using Equation 1 as shown below.

$$\%TS = \frac{W_3 - W_1}{W_2} \times 100 \quad (1)$$

2.7.1 Volatile solids (VS)

Volatile solids represent organic matter of the feedstock (excluding the inorganic salts, ash). This, too, was measured in accordance with APHA [25]. A 3g of oven dried sample was weighed (B) in an empty crucible (A) and heated to 550°C for 1 hour in the muffle furnace to constant weight (C). Percentage VS was calculated by using Equation 2.

$$\%VS = \frac{C - A}{B} \times 100 \quad (2)$$

2.7.2 Indicators of efficiency

The performance of the reactor and conversion efficiency of feedstock is calculated from the following indicators:

$$\frac{TS}{VS}\ lost$$

Initial TS/VS of the feedstock was determined before feeding into the reactor. After destructive sampling, the final TS/VS were determined. The difference between the initial (mass of TS/VS fed) and final TS/VS (residual TS/VS in the digested feedstock) gave the quantity of $\frac{TS}{VS}$lost. The $\frac{TS}{VS}$lost is calculated using Equation 3.

$$\frac{TS}{VS}\text{lost} = \frac{TS}{VS}\text{lost} = \frac{TS}{VS}\text{lost} \quad (3)$$

2.8 TS/VS to gas

The $\frac{TS}{VS}$ lost was determined after destructive sampling as mentioned above. It was presented as liters of biogas produced per gram TS/VS lost. This gave an index of process efficiency.

2.9 Expected gas production level from TS and VS lost

A mass balance approach as used by Deressa et al., [24] was used to estimate the theoretical gas yield from the

$\frac{TS}{VS}$lost. The volume of the biogas produced was assumed to be equal to the amount of VS lost during the digestion. The difference between the observed and the theoretical yield of biogas gave as the $\frac{TS}{VS}$lost due to unbalanced ratio of microorganism to substrate, process inefficiency and physical leakage, or the other factors.

2.10 Experimental set-up for the effect of biogas residue on growth and yield of crop

A pot experiment was conducted to study the comparative effects of biogas residues, and NPK fertilizers on growth maize as the test crop. Soil was collected from farmland, sieved and the pots were filled with 10 kg of soil. Four seeds were sown in each pot which was thinned to 2 plants 12 days after germination. Pots were placed outside under natural conditions. Ground water was used for irrigations. Twelve experimental soil filled pot in a complete randomized block design was used comprising of three each for Control, biogas residues (BR), 50% BR plus 50% NPK and NPK fertilizers as follows-

T_0 = Control (No fertilizer + No BR),
T_1 = Full NPK fertilzer
T_2 = 50% NPK and 50% BR
T_3 = Full biogas residues (BR)

Data about Plant height, stem circumference were measured (cm) every 15 days. The number of leaves in each plant and leaf are done on 60th day of planting. Leaf area was calculated (cm^2) from the average length and width of the leaf (base, middle, and tip of the leaf). The plant height was measured using a measuring tape from ground level to highest leaf tip.

3. Results and Discussion

The mean values of the characteristics of FVW used for feed studied are shown in Table 1. The Table shows the results of the moisture content, total solid, volatile solid and ash content of the wastes used for the study. From the table it is seen that tomato had highest moisture content of 87.32% and banana has the least with a moisture content of 70.68%. The presence of high moisture content in the organic waste facilitates the anaerobic digestion [20]. The results obtained in this work is comparable with the work of Deressa, et al., [26] they reported that mango, tomatoes, papaya, and banana has moisture content of 83.65, 83.15, 78.65, and 81% respectively. The highest TS were recorded in banana 29.32%. The TS in all the waste used varies between 12.61 and 29.32%. The highest VS were recorded in pineapple with a value of 94.62%. [27] has reported that banana and tomato contain 29.5% and 11.8% TS, respectively similarly Working on food processing wastes including peels of mango, tomato, lemon, orange and pineapple, Nand and Krishna, [28] has reported that the TS content in them varied from 28.4% to 23.4%. The VS in all FVW used for the study varied from 89.54% (cabbage) to 94.51% (pineapple). The results obtained from this work for FVW wastes are comparable with values reported by Mital, [29]. The values for VS obtained in this work are also comparable to 92.73% reported by [28] for rotten fruits and vegetable wastes. Table 3 shows the mean values of the characteristics of wastes used for feed. From table 3 it can be seen that the characteristics of cow manure studied in this work are MC 79.38%, TS 20.62%, VS 89.70% and ash content of 10.30%. Some characteristics of CD reported by some researchers include: 77% moisture content and 16% TS by Nusara et al., [30], 9.3% TS and 80.3% VS Chua et al, [31] their results also agree with the values obtained in this work. Deressa et al., [26] mixed wastes of FVW and CD in the ratio 75:25, the characteristics of these waste was found to be TS 20.65%, VS 96%, ash content 4% and moisture content of 79.35%. These work also agreed with the findings of this work.

The average pH in each digester ranged from 6 to 7.2 which are comparable with the optimum range of pH for production of biogas [26]. This result showed that the microorganisms in the anaerobic digesters were not affected by the pH of the slurry in the digester. Therefore, no inhibition of biogas production from wastes mixed with cow dung due to effect of pH. The temperature in all digesters ranged from 26 to 320C which is in the range of mesophilic, 25-450C which is allowed for production of biogas. A steady state occurs after 4 days of the start- up process. During the steady state, the reduction efficiencies of averages of total solids (TS) and volatile solids (VS) was 10.39 and 40.17 respectively. This result is in agreement with the works of Deressa et al., [26] which reported reduction efficiencies of averages of total solids (TS) and volatile solids (VS) was 10.69 and 40.00 respectively. This is an indication that the mixed wastes are converted to biogas thus necessitating addition of further substrate into the digester. The initial TS/VS of the mixed waste were 0.20 and after the anaerobic digestion of the mixed waste, the final TS/VS of the residue waste dropped to 0.16. The difference (reduction) between the initial mass of TS/VS residue was 0.04 as shown in Table 4 (The mean values of the efficiency of Total Solids and Volatile Solids Reduction). This result is also in agreement with the works of Deressa et al., [26] which reported the difference (reduction) between the initial mass of TS/VS residue as 0.04

Table 1 The mean values of the characteristics of FVW used for feed

Waste	MC %	TS%	VS%	AC%	TS/VS
Papaya	79.15	20.85	91.89	8.11	0.23
Mango	83.39	16.61	94.51	5.49	0.18
Tomatoes	87.32	12.68	91.87	8.13	0.14
melon	87.10	12.90	93.74	6.26	0.14
Banana	70.68	29.32	91.85	8.15	0.32
Cabbage	78.17	21.83	89.57	10.43	0.24
Pineapple	76.39	23.61	94.62	5.38	0.25

Table 2 Composition of biomass used in the study

Biomass	% Used
Papaya	10
Mango	10
Tomatoes	10
Water melon	10
Banana	10
Cabbage	10
Pineapple	10
Cow dung	20
Total	100

Table 3. The mean values of the characteristics of wastes used for feed

Waste	MC%	TS%	VS%	AC%	TS/VS
CD	79.38	20.62	89.70	10.30	0.23
FVW	83.14	16.86	93.67	6.33	0.18

Table 4 The mean values of the efficiency of Total Solids and Volatile Solids Reduction

	TS%	VS%	TS/VS
Initial	19.15	95.11	0.20
Final	8.76	54.94	0.16
Reduction	10.39	40.17	0.04

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3.1 Biogas Production

The generation of biogas in all the digesters was apparent since a pressure build-up in the empty space of each digester was noticed after 4 days of start up. The total volume of gas so generated was measured by water displacement method was found to be 0.031ml/g (31ml/g). However, the expression of the ratio of TS/VS lost is 0.029l/g (29ml/g). This result is in agreement with the works of Deressa et al., [25] the ratio of TS/VS lost from Fruit and vegetable wastes mixed with cow manure is 0.037l/g (37ml/g) while the biogas produced from Fruit and vegetable wastes mixed with cow manure measured by water displacement as 0.031ml/g (31ml/g). The difference of biogas measured by ratio of TS/VS and displacement method tell us of leakage of gas [26].

3.2 Effect of biogas digester residue on maize plant Height of plant

The statistically analyzed data for maize plant height as seen on Table 5 shows the height of maize plant at different day's intervals and their response to different treatment. It can be seen from the table that different levels of treatment resulted in significantly different plant heights. Maximum maize height occurred with T_2 (31.05 cm) after the first fifteen days of sowing, whereas T_1 (100% F) resulted in plant height of 30.51 cm, T_3 (100% BR) 30.22 cm with T_0 having the least of 26.24 cm height. From Table 5 it can be seen that the plant height of T_2 after the thirtieth day of sowing was still the highest of 99.45 cm. The highest height of the plants after forty-fifth day of sowing was T_3 having 204.53 cm height. On the sixtieth day the maximum plant height was T_3 (250.31 cm), followed by T_2 (242.65 cm), T_1 (241.73 cm), and T_0 the lowest with 203.65 cm. The result is in agreement of the study carried out by Morsy [32] who concluded that organic waste materials increased the plant height

Table 5 Effect of treatments on Plant Height (cm)

	T_0	T_1	T_2	T_3
After 15 days	26.24	30.51	31.05	30.22
After 30 days	90.68	97.47	99.45	100.33
After 45 days	178.22	188.84	190.30	204.53
After 60 days	203.65	241.73	242.65	250.31

Stem circumference

The development of stem circumference in maize according to the treatment is shown in Table 5. As observed from the table T_3 has the largest stem of 3.15 cm, while T_1 and T_2 has 2.90 cm with T_0 having the least of 2.70 cm, higher slurry nitrogen was associated with larger stem circumference [31]. On the thirtieth day, T_2 has larger stem circumference (5.45 cm), as compared to the control T_0 (4.42) and 100% fertilizer (5.34 cm). The stem circumference after forty-fifth day of sowing also shows T_2 having the largest (8.10 cm) with T_0 having the least of 6.15 cm. On the sixtieth day T_2 with 9.05 stem circumference was the largest with T_0 having the least of 7.08 cm, while T_1 and T_3 has 8.84 and 8.52 cm respectively. The findings on the stem circumference is in agreement with the findings of Al-Turki et al., [33] that, biogas slurry clearly influenced the growth and production of maize fodder, but an excessive level (82 kg of slurry N ha-1) of biogas slurry negatively affected stem circumference. This result is also in agreement with the findings of the Islam et al. [34] who also reported that maize plant height and stem circumference were significantly ($p< 0.01$) influenced by the application of 50% N from biogas slurry.

Table 6: Effect of treatments on Plant Stem Diameter (cm)

	T_0	T_1	T_2	T_3
After 15 days	2.77	2.90	2.90	3.15
After 30 days	4.42	5.34	5.45	5.30
After 45 days	6.15	7.88	8.10	7.80
After 60 days	7.08	8.84	9.05	8.52

Leaf number and area

There was no difference in the number of leaves per plant between the treatment groups the number of leaves per maize plant is 12. In the case of average leaf area, differences were observed between the treatment groups. T_2 recorded the largest area of 48.13 cm^2, followed by T_1 with 47.85 cm^2. The T_3 and T_0 have areas of 43.45 and 38.56 cm^2 respectively. Application of biogas residue increased the average leaf area as in the case of T_2, but average leaf area was decreased at higher application of residue as in T_3, indicating that T_3 might have had an inhibiting effect due to the high N level of biogas residue. The finding is in agreement with Kibria et al. [35], whom wrote that the application of 50% NPK+50 PM proved most effective in ensuring good performance in terms of growth and fresh fruit yield of ladies finger. Olaniyi et al. [36] reported a similar trend, that growth of okra (ladies finger) plant was markedly influenced by the application of organominerals, NPK fertilizer and their combination as observed from the increased plant height and number of leaves compared to control.

3.3 Weight of 1000 kernels

The result for 1000 grain weight (gm) shows that T_2 has the highest weight of 276.34 grams, followed by T_1 with 254.78 grams, T_3 has 240.12 grams while the control T_0 has the least weight of 188.56 grams. T_2 (50% NPK and 50% BR) possessing of highest 1000 kernels weight could be due to balanced supply of food nutrients from the sample throughout development of the maize plant.

4. Conclusions

It is a known fact that the use of green technologies like anaerobic digestion, can avoid the emission of harmful greenhouse gasses and make a positive contribution to environmental targets. Hence, the present work examined bioconversion of mixed fruit waste as a potential source of biogas and organic fertilizer. The total volume of gas so generated was found to be 0.031ml/g (31ml/g), the ratio of TS/VS lost is 0.029l/g (29ml/g). The work shows that BR is a valuable organic fertilizer that can be used as an alternative to inorganic fertilizer in maize production and soil fertility. Application of biogas residue increased the plant height, stem circumference, average leaf area and weight of 1000 kernels over the control which has neither organic nor inorganic fertilizer added to the soil. However the 50% NPK fertilizer and 50% biogas residue (T_2) proved most effective in ensuring good performance in terms of the plant height, stem circumference, average leaf area and weight of 1000 kernels over the control, 100% NPK fertilizer and 100% biogas residue. Biogas residue has proved to be environmentally friendly and effective fertilizer as compared to chemical fertilizer because though the best results were observed in combination with chemical fertilizer. The continuous application of chemical fertilizer alone to soil, without the addition of organic fertilizer, has been found to have detrimental effect on soil quality in the long term due to constant loss of humus and micronutrients. The use of BR also directly saves money for both farmer and government.

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