Journal of Agricultural Chemistry and Environment, 2022, 11, 196-208
https://www.scirp.org/journal/jacen
ISSN Online: 2325-744X
ISSN Print: 2325-7458

Typology of Crop Residues and Energy Recovery in Heavily Agricultural Areas: Case of the Departments of Soubré, Daloa, Issia and Sassandra (Côte d'Ivoire)

Amenan Anne Mary Kouassi-Kouadio[1*], Pétémanagnan Jean-Marie Ouattara[1*], Talnan Jean Honoré Coulibaly[2], Franck Michaël Zahui[3], Lacina Coulibaly[1,4]

[1]Laboratory of Environment and Aquatic Biology, Department of Sciences and Environment Management, NANGUI ABROGOUA University, Abidjan, Côte d'Ivoire
[2]Laboratoire Géosciences et Environnement, Université Nangui Abrogoua, Abidjan, Côte d'Ivoire
[3]Department of Agronomic, Forestry and Environmental Engineering, University of Man, Man, Côte d'Ivoire
[4]University of Man, Man, Côte d'Ivoire
Email: *mimoyek@yahoo.fr, *jm_petemanagnan@yahoo.fr

How to cite this paper: Kouassi-Kouadio, A.A.M., Ouattara, P.J.-M., Coulibaly, T.J.H., Zahui, F.M. and Coulibaly, L. (2022) Typology of Crop Residues and Energy Recovery in Heavily Agricultural Areas: Case of the Departments of Soubré, Daloa, Issia and Sassandra (Côte d'Ivoire). *Journal of Agricultural Chemistry and Environment*, **11**, 196-208.
https://doi.org/10.4236/jacen.2022.113013

Received: June 2, 2022
Accepted: August 9, 2022
Published: August 12, 2022

Abstract

The valorization of crop residues could constitute an energy source (biogas) allowing to reduce the energy needs of populations in agricultural regions, improve their living conditions and slow down deforestation as well as greenhouse gas emissions. This work aims to determine the typology of agricultural waste in the departments of Soubré, Sassandra, Daloa and Issia, to determine the number of residues generated in these departments, and to assess the biogas potential of these departments said residues. Field observations were made to identify the different types of waste, then, based on agricultural statistical data from the Ministry of Agriculture and biogas productivity indexes, the quantities of agricultural residues and biogas were estimated. Agricultural residues consist of pods (50%), stalks (19%), cobs (3%), Straws (8%), stalks (2%), shells (9%), fibers (7%), husks (1%), and bunches (1%). In addition, these localities have 465266.3 t of pods, 173583.2 t of stalks, 84280.0 t of shells, 75,857 t of straws, 12,000 t of husks, 10,987 t of bunches and 6793.0 t of fibers. The departments of Soubré, Sassandra, Daloa and Issia contain a total potential energy of 235.87×10^6 m^3 of biogas. However, this is unevenly distributed among the localities. The volume of biogas recorded is higher in the department of Soubré (74.91×10^6 m^3) which is followed respectively by the departments of Daloa (62.27×10^6 m^3), Issia (52.77×10^6 m^3 and Sassandra (45.93×10^6 m^3). The departments of Soubré, Sassandra, Daloa and Issia have a very large potential for the production of agricultural residues that

may be of interest to economic operators for recovery in biogas production units.

Keywords

Agriculture, Crop Residues, Biogas, Sassandra, Daloa, Issia, Soubré, Côte d'Ivoire

1. Introduction

Since its independence, Côte d'Ivoire has focused its economic development on the agricultural sector, creating more than 47% of national added [1]. Annual productions are 1,300,000 tons of cocoa, 120,000 tons of coffee [2]. 131,000 tons of cotton, 300,000 tons of oil palm and 630,000 tons of cashew [3]. These farming activities generate large quantities of waste composed mainly of organic residues, of which the mismanagement constitutes a proven source of pollution of the components of the environment [4]. A study carried out on the method of managing agropastoral waste in the Sassandra watershed revealed that this waste was mostly incinerated in the open air or used to meet the energy needs of the populations [5]. However, incineration could lead to bush fires that would devastate surrounding plantations, plant cover as well as biodiversity. In addition, the smoke emitted would cause respiratory problems to populations. Thus, controlling the management of crop waste could constitute a major issue that would be part of an overall strategy to reduce environmental impacts. In addition, this waste could constitute a source of wealth for rural populations (waste producers) and a mine of raw materials for economic operators [6]. The departments of Soubré, Sassandra, Daloa and Issia constitute one of the main agricultural areas of the country [7]. These departments are teeming with several crops of cash crops (cocoa, coffee, oil palm and rubber) and food crops (rice, maize, cassava) [2] which could generate huge quantities of residues. This study aims to characterize the typology of crop residues, to assess their availability, and to quantify the volume of biogas likely to be produced in the different localities.

2. Materials and Methods

2.1. Study Area

Figure 1 presents the areas surveyed in this study. These areas belong to the southern agricultural watershed basin of Sassandra, particularly in the center-west (Daloa and Issia) and south-west (Soubré and Sassandra) of Côte d'Ivoire. The departments of Daloa and Issia are located between longitudes 5˚75 and 8˚16 West and latitudes 5˚56 and 9˚75 North [8]. The respective populations of these localities are 591.693 inhabitants (Daloa) for an area of 38.76 km^2 and 327.901 inhabitants (Issia) for an area of 5.658 km^2. As for the Sassandra and Soubré departments, they are located between longitude 7˚08 and 6˚12 West and latitude

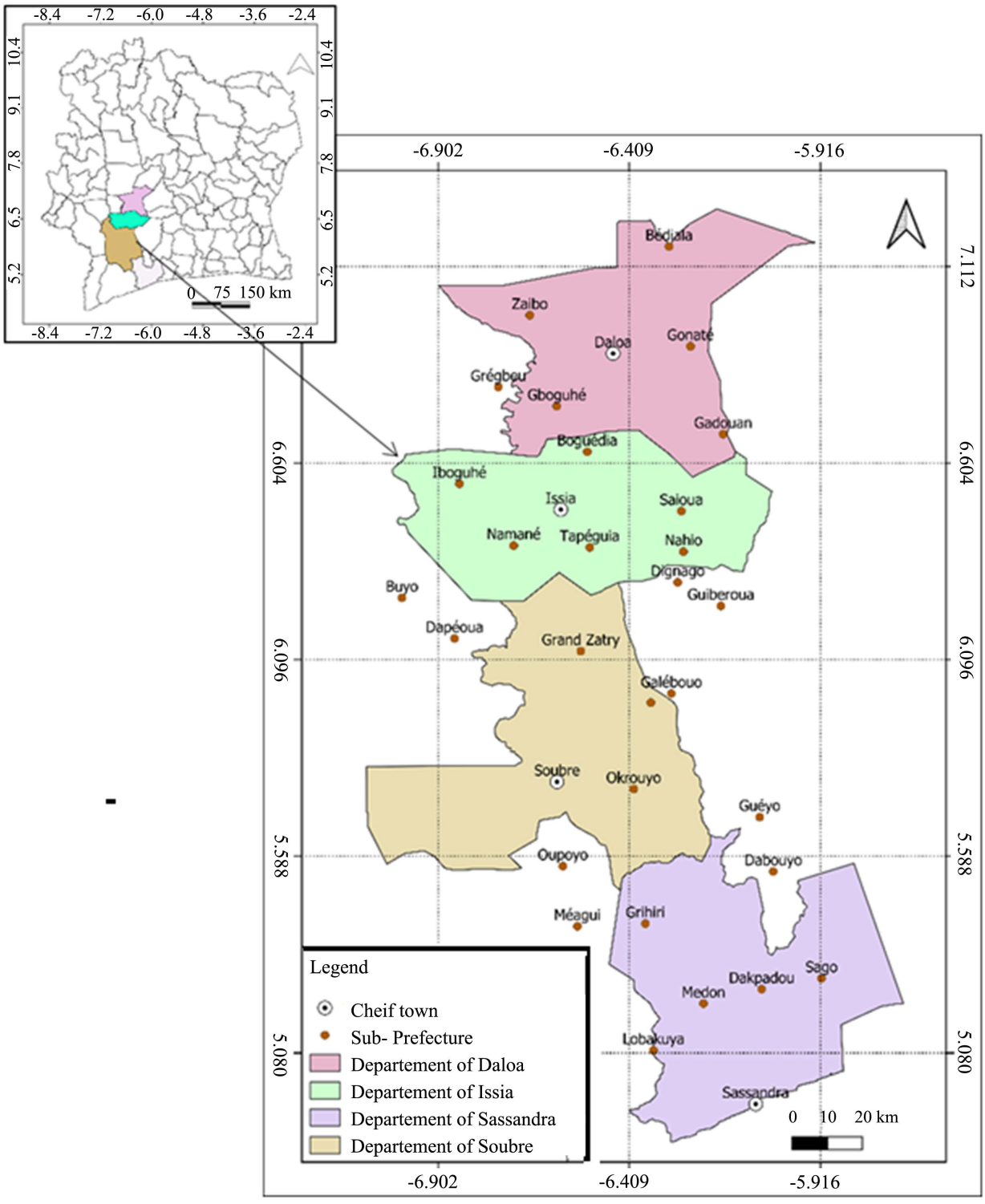

Figure 1. Location of the study area.

5˚19 and 6˚34 north. Sassandra covers an area of 25.800 km^2 with an estimated population of 299.500 inhabitants [9]. On the other hand, Soubré has 464.554 inhabitants for an area of 8.500 km^2. The economic activities carried on these different localities are: agriculture, trade and transport. However, agriculture re-

mains the main economic activity, practiced by 60% of the population [9]. Agricultural dynamic is essentially based on cash crops (coffee, cocoa, rubber and oil palm) and food and market gardening crops.

2.2. Material

The equipment used for the preparation of this study is composed of a cameras for taking pictures of the various types of crop wastes, agricultural statistical data 2015 provided by the Department of Statistics, Documentation and Information Technology of the Ministry of agriculture of Côte d'Ivoire. The quantities of agricultural residues generated as well as the equivalent volume of biogas for each type of residues were estimated using productivity indexes [10].

2.3. Method

2.3.1. Wastes Identification

To identify crop wastes produced in the departments of Soubré, Sassandra, Daloa and Issia, different farms were visited. The types of wastes identified were photographed.

2.3.2. Estimation of the Quantities of Crop Wastes

The quantities of residues (QR) from the crops were determined from the relation (1) described according to [10]

$$QR = m \times Cres \quad (1)$$

where:

m: Mass of the production for the considered crop (kg),

Cres: Coefficient relating to the quantity of residues generated according to agricultural production.

2.3.3. Quantities of Biogas Estimation

The potential of annual biogas production from agricultural residues was estimated from the quantity of dry matter (QMS) of said residues. This quantity of dry matter was calculated according to the relation (2):

$$QMS = m \times Cres \times Cms \quad (2)$$

The potential of agricultural residues biogas (PAg) was evaluated according to the Equation (3).

$$PAg = QMS \times Ip \quad (3)$$

where:

Cms: Proportion of dry matter contained in the residue,

Ip: Productivity index.

The values of Cms, Cres and Ip used are consigned in **Table 1**.

3. Results and Discussion

3.1. Typology of Crop Residues

Crops residues are made up of bunches, fibers, shells, pods, straws, husks, cobs,

Table 1. Cms, Cres and Ip values [10] [11].

Wastes typology by culture		Values and references		
		[10]	[10]	[11]
Cultures	Wastes	Cres	Cms	Ip (m^3/t of MS)
Rice	Straw	1.757	0.87	360
	Husk	0.267	0.98	300
Maize	*Stalk*	0.20	0.89	300
	Cob	0.273	0.93	300
	Stem	2.00	0.85	295
Palm oil	*Cluster*	0.23	0.50	300
	Fibre	0.14	0.60	300
	Shell	0.065	0.90	300
Cocoa	*Pods*	1.00	0.85	300
Coffee	*Shell*	2.10	0.85	300
Cassava	*Stem*	0.062	0.85	300

stalks and stems. These wastes come from cocoa (pod), coffee (shell), oil palm (cluster, fiber, shell, straw), manioc (stem), maize (cobs, stem, stalk) and rice (straw, husk, stem) **Figure 2**. This typology of wastes is similar to that obtained by Coulibaly *et al.* [12] in the Comoé watershed.

3.2. Quantities of Crops

Quantities of Crop Residues Available

The quantities of agricultural wastes available by locality of the BVS are presented in **Figure 3**. These wastes come from cash crops such as cocoa, coffee and oil palm and from food crops such as rice, manioc and maize. We note that the quantities of wastes vary between 190 and 291 thousand tons. However, the quantity of food crop waste is greater in the department of Daloa (217.5 t). As for the residues from cash crops, they are more important in Soubré (276.5 t) followed respectively by these of Issia (176.2 t), and Sassandra (157.2 t). The aggregate production of agricultural residues of the entire southern BVS, amounts to 930,221 t. Overall, the department of soubré is full of more than (290,668 t) waste followed respectively by the departments of Daloa (236,123 t), Issia (205,061 t) and Sassandra (198,221 t). This result could be linked to the surfaces of the differentes localities. Indeed, the surface of the differentes localities would make vast cultivated lands available to the populations. In addition, the declassification of certain reserves in the department of Soubré would have favoured greater agricultural production. This corroborates the results of the report of the CCC coffee and cacao [2] which indicates that cocoa production in Soubré represents 19% of the national production.

Figure 2. Illustration of some crops residues, (a) = rice straws; (b) = dry pods; (c) = cobs of maize; (d) = husk of maize.

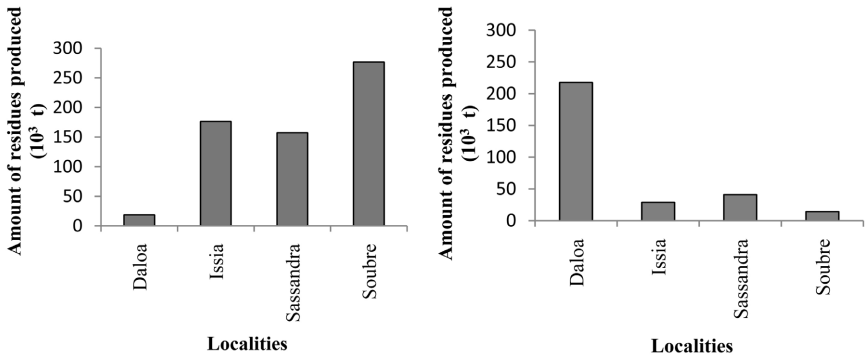

Figure 3. Quantities of wastes available in the localities studied, (a) = Quantity of cash crop residues; (b) = Quantities of food crop residues.

Figure 4 shows the quantities of residues generated according to the type of crop considered. Regarding cash crops, the quantity of residues from cocoa cultivation is higher at soubré (272,265 t) and Issia (132,244 t). As for the residues from coffee, the highest quantities are recorded in the departments of Sassandra (34,497 t) and Issia (41,538 t). Residues from oil palm are recorded in the department of Sassandra (78,094 t). As for residues from food crops, they are present in almost all localities; the maize cultivation generates more residues with a tonnage of 212,200 t, then that of rice with a production of residues of 87384.8 t and finally these of cassava, with a production of residues 1732.7 t. By

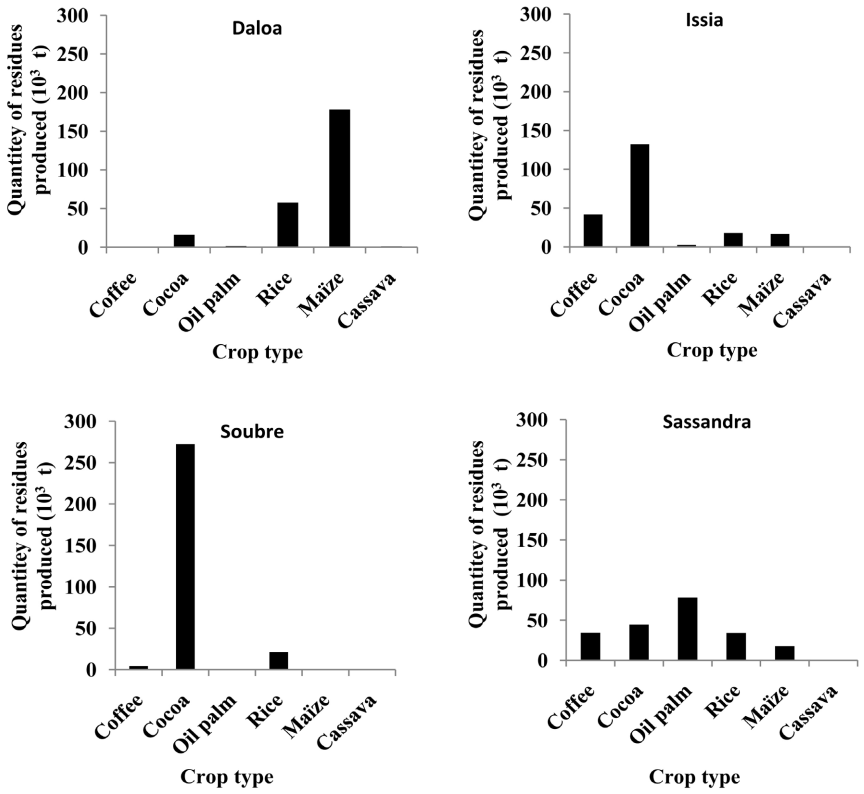

Figure 4. Quantities of waste available by crop type.

considering the residues by type of crop, we note that the residues resulting from the highest cultivation activities come from the cultivation of cocoa for cash crops and maize for food crops. The high production of pod residues is said would be due to the high production of cocoa in the agricultural watershed of Sassandra and also to the agricultural policy of the Côte d'Ivoire which encourages the practice of this crop. In addition, the south Sassandra is an agro-ecological area favorable to cocoa and corn crops [13].

Figure 5 shows the quantities of residues available by locality. Pods are available in large quantities (272295.6 t) in Soubré and Issia (132.2 t). As for stems (145058.29 t) and straws (33.4 t), they are more available in Daloa than in the other towns. However, shells (41900.44 t) and fibers are more important in Sassandra. The results concerning the quantities of crop residues by locality, showed that the area of Soubré has the highest production of cocoa residues. This would explain the high production of pods (272,265 t) in this locality. This result is of the same order as the results of the CCC [2]. This production of waste from cocoa would also present some possible ways for recovery for composting and/or biogas production [14]. This city could be considered as a waste warehouse where recovery units can be installed. Relatively, the low production of clusters from oil palm cultivation in the watershed would be due to the fact that it is only in the Sassandra area that palm plantations have been recorded. In addition, we note in this locality the presence of a palm oil processing unit. The husks produced during rice husking are estimated at between 15% and 20% of

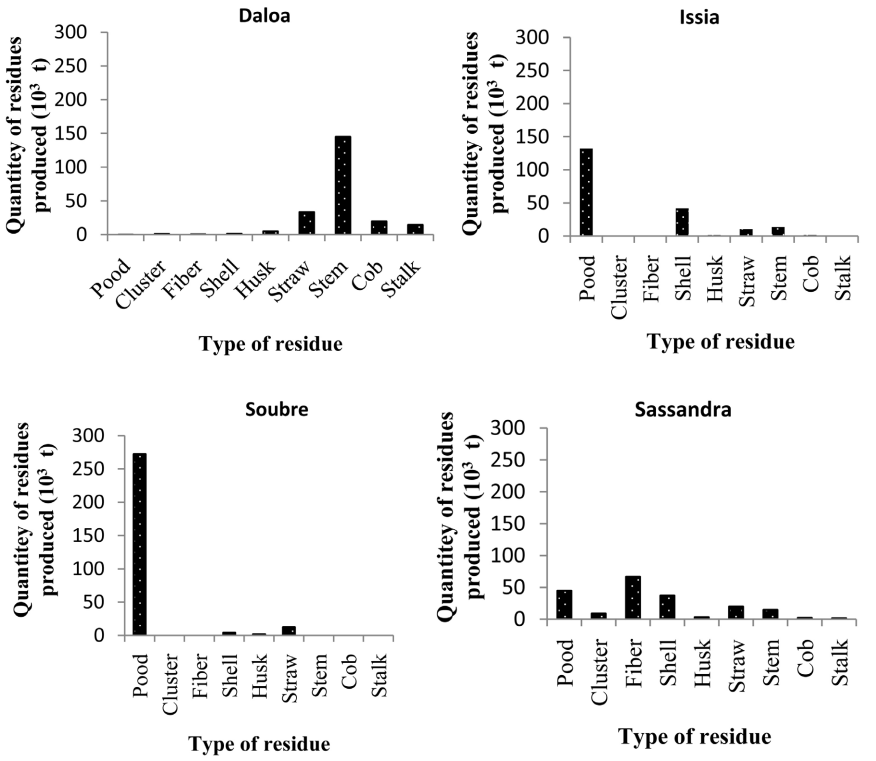

Figure 5. Quantities of crop residues available in the basin.

the total weight of the paddy. The work of Kumar *et al.* [15] showed daring rice hulling could be used for the production of bio-charcoal [16]. Rice hulls have made it possible to reduce the use of firewood, by limiting the pressure on the forest, thus slowing deforestation and, in turn, greenhouse gas emissions [17] [18].

3.3. Volume of Biogas Estimated

3.3.1. Volume of Biogas Estimated from Food Crops

Figure 6 shows the variations in the volume of biogas resulting from the residues of the various food crops grown in the departments of Soubré, Sassandra, Daloa and Issia. In general, we note a strong contribution of residues from rice and maize crops (99%) in gas production in the departments. The maximum volume of biogas is obtained at Daloa (58.2×10^6 m^3) while the minimum volume was recorded at Soubré (4×10^6 m^3). With the exception of Daloa where the contribution of maize residues in the total production of biogas is greater (66%), in the other localities, this production is dominated by the contribution of rice residues. The contribution of residues generated by cassava cultivation is negligible in all localities. However, this contribution is very low (1%). Regarding the biogas potential from food crops, rice and corn residues are the most used (99%) in gas production in the departments. This result is similar to that of [19] [20] who showed that in Germany the highest biogas potential is obtained by residues from the cultivation of maize. The total volume of biogas estimated from the residues of rice and maize is 81.27×10^6 m^3.

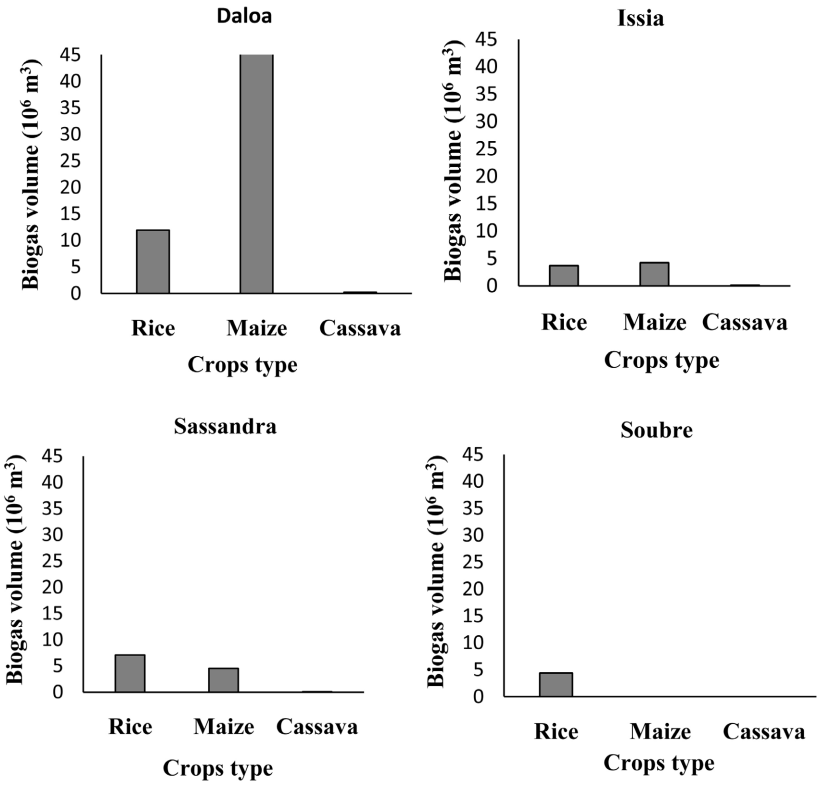

Figure 6. Annual volume of biogas produced from food crop residues in localities.

3.3.2. Volume of Biogas Estimated from Cash Crops

Figure 7 shows the variation in the volume of biogas resulting from the residues of each type of cash crop cultivated in the departments of Soubré, Sassandra, Daloa and Issia. It is found that the biogas potential of cash crops is dominated by residues from coffee and cocoa crops. In Issia and Soubré, this potential is dominated by cocoa residues while in Sassandra, it is mainly due to oil palm residues. The biogas potential obtained from coffee residues is recorded in the localities of Sassandra and Issia. The volume of biogas recorded in the localities is higher in the department of Soubré (70.5×10^6 m^3) which is followed respectively by the departments of Issia (44.7×10^6 m^3), Sassandra (34×10^6 m^3) and Daloa (4×10^6 m^3). For cash crops, the biogas potential relies mainly on coffee and cocoa crops. This result would be linked to the high production of these types of residues. The maximum estimated biogas production in the departments of Soubré, Sassandra, Daloa and Issia would therefore be influenced by a significant contribution from cash crop residues, especially coffee and cocoa.

3.3.3. Volume of Biogas Estimated from All Crop Residues

Figure 8 shows the variation in the potential volume of biogas estimated from all agricultural residues of WS. A high proportion of biogas resulting from cash crop waste (74% - 94%) is observed in the towns of Issia, Sassandra and Soubré. However, in Daloa, the trend is reversed. In this locality, the contribution of residues generated by food crops dominates the production of biogas (93%). the results obtained show the importance of agricultural residues as a substrate for

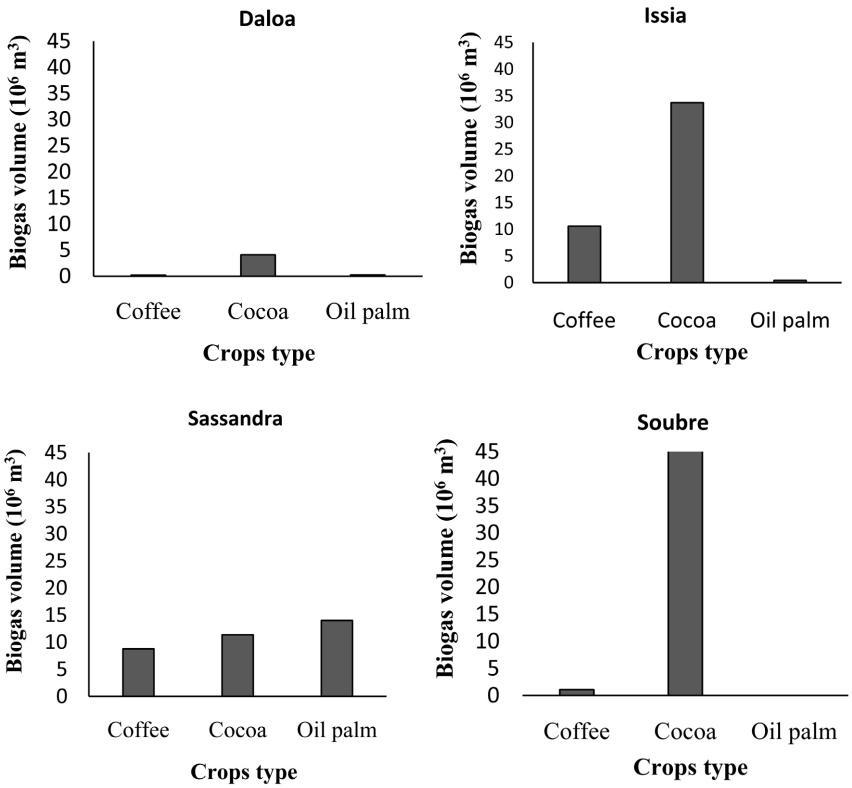

Figure 7. Annual volume of biogas produced from cash crop residues in localities.

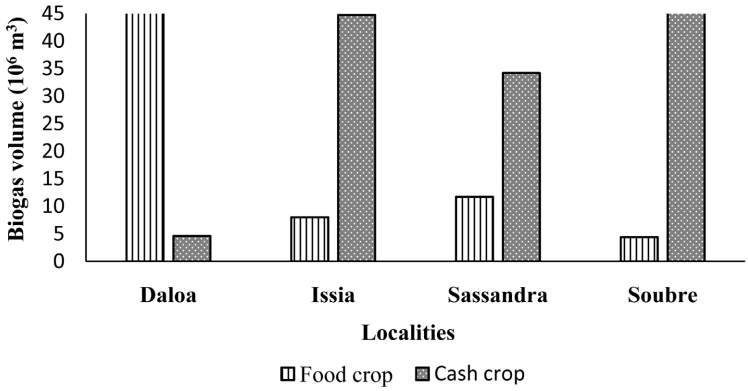

Figure 8. Annual volume of biogas estimated from agricultural residues in different localities.

biogas production [21]. The absence of a biogas production unit in the departments of Soubré, Sassandra, Daloa and Issia while the potential in organic substrates for the production of this type of energy in the said departments is enormous, could be explained by the absence of a policy of popularization and dissemination of biogas production unit in rural areas as well as in Nepal, China and India [22]. This situation could help guide technological choices and the methodology for installing biogas units to recover this waste. In the departments of Soubré, Sassandra, Daloa and Issia, the exploitation of this substrate in rural areas could be done in small biogas units to partially meet the domestic energy

needs of rural areas. However, it will be necessary to take into account the cost of transporting said waste in order to properly assess the economic profitability of production [23]. This approach has been used successfully in Nepal, China and India [22]. The results obtained show that agricultural waste contained a large volume of biogas, the implementation of which would slow down deforestation and greenhouse gas emissions. However, the recovery of the mentioned waste into biogas is a relatively complex technology which requires grinding before digestion. In addition, the use of people equipped in the field is necessary.

4. Conclusion

At the end of this study, it emerges that in the departments of Soubré, Daloa, Issia and Sassandra, there are several types of crop waste, namely: straw, clusters, stems, ears, stalks, shell, pods, husk and fibers. The estimated quantities for perennial crop residues are 465266.3 t for cocoa, 82022.7 t for oil palm ones, and 81175.0 t for coffee ones. As for food crop residues, they are 212493.9 t for maize, 212493.9 t for rice and 1732.7 t for casava. Agricultural wastes are unevenly distributed between the localities of the watershed. Overall, the department of soubré is full of more waste (290,668 t) followed respectively by the departments of Daloa (236,123 t), Issia (205,061 t) and Sassandra (198,221 t). Regarding biogas potential, the volume of biogas recorded is higher in the department of Soubré (74.91×10^6 m^3) which is followed respectively by the departments of Daloa (62.27×10^6 m^3), Issia (52.77×10^6 m^3) and Sassandra (45.93×10^6 m^3). The biogas deposit of crop residues can provide a significant amount of energy. Harnessing this energy source would save large areas of forest and alleviate the suffering of women in search of biomass.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Esso, L.J. and Yeo, N. (2014) Transformations structurelles et développement sectoriel en Côte d'Ivoire. Rapport PNUD, Cellule d'Analyse de Politiques Economiques du CIRES, Côte d'Ivoire, 70 p.

[2] CCC (2014) Programme quantité-qualité-croissance «2QC» 2014-2023. Document de référence et d'orientation de la filière café-cacao, Ministère de l'agriculture, Côte d'Ivoire, 17 p.

[3] FIRCA (2009) La Filière du Progrès-Palmier à Huile, Bulletin FIRCA, n˚5-3e trimestre, Côte d'Ivoire. 45 p.

[4] Traoré, A., Ahoussi, K.E., Aka, N. and Soro, N. (2015) Niveau de contamination par les pesticides des eaux des lagunes Aghien et Potou (sud-est de la Côte d'Ivoire). *International Journal of Pure & Applied Bioscience*, **3**, 312-332.

[5] Coulibaly, L., Ouattara, J.M.P. and Tiho, S. (2012) Potentiel en biogaz des résidus agro-pastoraux et des excréments humains du bassin versant du fleuve Sassandra

(Côte d'Ivoire). *The International Journal of Biological and Chemical Sciences*, **6**, 6003-6016. https://doi.org/10.4314/ijbcs.v6i6.28

[6] Mancini, F. (2006) Traitement des déchets issus de la biomasse pour la création d'énergies. Thèse de Doctorat d'Etat génie des procédés, Université de bordeaux I, Bordeaux, 129 p.

[7] Ruf, F. and Agkpo, J.L. (2008) Etude sur le revenu et les investissements des producteurs de café et de cacao en Côte d'Ivoire: Rapport final. 115 p.

[8] Girard, G., Sircoulon, J. and Touchebeuf, P. (1971) Aperçu sur le régime hydrologique. In Le Milieu Naturel de la Côte d'Ivoire, Edition O.R.S.T.O.M., 293 p.

[9] Institut National de la Statistique (2014) INS Statistique de la population de la Côte d'Ivoire.

[10] FAO (1998) Proceedings of the Regional Expert Consultation on Modern Application of Biomass Energy. FAO Regional Wood Energy Development Programme in Asia, Report 36, Bangkok, 22 p.

[11] Billaud, V. and Varagnat, F. (1983) Les dossiers du biogaz, Dossier A: La fermentation métha-nique. Cellule Biométhane du GERES, Paris, 72 p.

[12] Coulibaly, L., Ouattara, J.M.P. and Agathos, S. (2012) Biogas Potential of the Agro-Pastoral Residues and Human Excrement in the Comoé River Catchment (Côte d'Ivoire). *Journal of Sustainable Development in Africa*, **14**, 18-31.

[13] Ardoin, B.S. (2004) Variabilité hydro-climatique et impacts sur les ressources en eau de grands bassins hydrographiques en zone soudano-sahélienne. Thèse de Doctorat de l'Université de Montpellier II, Montpellier, 330 p.

[14] Pénot, R. (2011) Valorisation énergétique du typha. Rapport de projet de fin d'études Ingénieur 3ème année, 51 p.

[15] Kumar, A., Purohit, P., Rana, S. and Kandpal, T.C. (2002) An Approach to the Estimation of the Value of Agricultural Residues Used as Biofuels. *Biomass and Bioenergy*, **22**, 195-203. https://doi.org/10.1016/S0961-9534(01)00070-8

[16] PNUD (2001) Biogas Technology in Agricultural Regions, Tanzania. Project: Promotion of Low Cost Biogas Technology to Resource Poor Farmers in Tanzania. 3 p.

[17] Chanakya, H.N., Rajabapaiah, P. and Modak, J.M. (2004) Evolving Biomass-Based Biogas Plants: The ASTRA Experience. *Current Science*, **87**, 917-925. https://www.researchgate.net/publication/237353105

[18] Weilland, P. (2013) Production de biogaz par les exploitations agricoles en Allemagne. *Sciences Eaux & Territoires*, **12**, 14-23. https://doi.org/10.3917/set.012.0014

[19] Ngoma, P.M., Hiligsmann, S., Zola, E.S. and Ongena, M. (2015) Potentiel d'élimination des déchets végétaux (feuilles de Mangifera Indica et de Manihot Utilissima) par méthanisation à Kinshasa (République Démocratique du Congo). *VertigO—la revue élec-tronique en sciences de l'environnement*, **15**, 1-20. https://doi.org/10.4000/vertigo.15944

[20] Koulibaly, B., Traoré, O., Dakuo, D., Zombré, P.N. and Bondé, D. (2011) Effets de la gestion des résidus de récolte sur les rendements et les bilans culturaux d'une rotation cotonnier-maïs-sorgho au Burkina Faso. *International Journal of Biological and Chemical Sciences*, **6**, 184-189.

[21] Chanakya, N.H., Bhogle, S. and Arun, S.R. (2005) Field Experience with Leaf Litter-Based Biogas Plants. *Energy for Sustainable Development*, **9**, 49-62. https://doi.org/10.1016/S0973-0826(08)60492-5

[22] USAID (2007) Biogas: Retrospect and Prospect, Georgia, Rural Energy Program. 43 p.

[23] GBN (2020) Partnership Ready Côte d'Ivoire: Gestion et recyclage des déchets organiques. 8 p. https://www.giz.de/en/downloads/GBN_Sector%20Brief_CIV_Bioabfall_FR_Web.pdf