BIOCOAL OUT OF FIREBREAK AND AGRICULTURAL RESIDUE: BETWEEN FOREST PROTECTION MANAGEMENT AND LOCAL HOUSEHOLD FUEL SUPPLY

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ABSTRACT: Senegal contains approximately 1 millions hectares of land affected by bushfires, which are known as one of the major causes of deforestation. At the same time the rural population is using mostly biomass resources (wood and charcoal) as domestic fuel, increasing pressure on the forests. Moreover, before sowing Senegalese farmers usually burn agricultural residue to prepare the fields. All these factors lead to a loss of about 45 000 ha of forest and emissions of 7 millions tons of CO_2 in Senegal every year, which directly impact on the environmental and socio-economic situation. The German Senegalese Developing Aid Program PERACOD "Program for Rural Electrification and Sustainable Management of Household Fuels" executed since 1995 by GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit) on behalf of the BMZ (Federal Ministry of Cooperation and Economic Development) with its Senegalese partners, mainly the Ministry of Energy and Mines and the forestry department of the Ministry of Environment has been implementing activities in order to use the residue from annual firebreak maintenance and from land field preparation as a biomass resource for household fuel supply as Biocoal. A simple, small scale technology which can be locally produced and maintained has being developed and is now available. Farmers living around the forest, while maintaining firebreaks and preparing their fields for sowing can now produce their own domestic biomass fuel. Further advantages are that they generate extra income and the forest area is protected in a sustainable manner.
Keywords: Charcoal, Briquettes, Developing Countries, Agricultural Residues, Forestry Residues

1 CONTEXT

Senegal, like other Sub-Saharan countries, has faced forest degradation problems due to a combination of factors (clearing land for agricultural use, bushfires, overexploitation, overgrazing, and drought).It is estimated that between 1990 and 2000 Senegal lost 45 000 hectares (ha) every year of forest under those condition [1]. In the meantime, the forest is the largest source of household fuel (wood and charcoal) for more than 90% of Senegalese household and particularly in rural area [2]. Moreover forests supply many other products (fruits, seeds, honey, gum, medicinal plants…) which represent an important part of national economy as well as an income source for rural populations [3]. All in all, this situation leads to a severe degradation of the environment as well as living conditions of the rural population.

To solve this situation, various actions have been taken. In the beginning they focused more on reforestation over large areas. Then they focused on rural forestry and plantation of so-called "village wood" with the development of the participative approach. In addition to reforestation, good management practices in classified forest should lead to sustainable use of natural forest.

Experience with participative management of forestry resources has shown a strong natural regeneration, provided that there are no bushfires or illegal cutting. Moreover, it has been demonstrated that forest grazing causes less degradation than bushfires; on the contrary, it could have a positive impact as it reduces the herbaceous cover, lowering fires risks at the same time [4]. As for wood, non timber forest product (NTFP) production increases along with bushfire control and natural regeneration. Populations begin to obtain substantial income from collection, transformation and commercialization. Those activities give the forest a new economical appellation, that of a "Green Bank" [5].

Protection against bushfires is principally enhanced by the creation and annual maintenance of firebreaks. This prevention is the most effective for forest protection considering the lack of resources that can be mobilized to fight fires. However, firebreaks' annual maintenance represents a relatively high cost. Because the benefits created by the forest protection are hard to quantify (and to recover) by the different management organisms, it is often not possible to budget annually the maintenance of the firebreaks [6].

Meanwhile farmers clean their fields before sowing time by burning the agricultural residues that have been let in place after harvest [7]. These residues are mainly stalks and strokes of different crops: millet, sorghum and corn. In Senegal every year 1.1 million ha of crop are cultivated [8], which yield dry biomass residues of around 4.5 millions tons.

The burning of a big part of agricultural residues and the bushfires (1 million ha of land affected each year [9]) lead to emission of around 7 millions tons of CO_2 every year [10].

We propose to valorize those not used biomass residues coming out of the firebreaks maintenance and land field preparation into household fuel: Biocoal.

2 TECHNOLOGY

In collaboration with Malian Ministry of Energy and the Regional Program for Promotion of Alternative Household Energy in the Sahel (PREDAS – Programme Régional de promotion des Energies Domestiques et Alternatives au Sahel [11]), the "3 barrel" carbonization technology has been transferred and adapted in Senegal. Longer lasting tests were made to also carbonize residues from forest activities, from firebreaks and from field cleaning in order to insure the technical and economical feasibility as well as social viability of a new household fuel called Biocoal.

2.1 Carbonization technology

Amongst all available carbonization technologies, we have adapted a technology primarily developed in Mali for carbonization of cotton stalk. This technology, called "3 barrel", is characterized by the use of a metallic and moveable steel kiln made of retrieved barrels (figure 1). Three of those barrels are used for the cylinder, i.e. the body of the steel kiln, hence the term "3 barrel". Two other barrels are used to design the cover and the chimney. The steel kiln capacity is around 2 m^3 of biomass material.

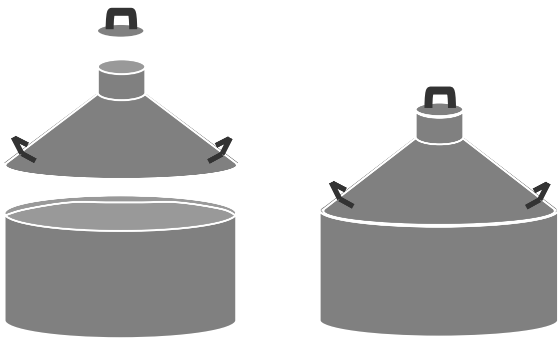

Figure 1: "3 barrel" steel kiln

The choice of this type of steel kiln is linked both to the characteristics of the biomass raw material to be carbonized and to the dispersal of this resource. Biomass residues coming from firebreaks maintenance are often composed of small and weak elements (branches, sprigs, straw, various herbs…).

In order to reduce the possible losses during the discharge of carbonized material, carbonization should be done in an enclosed space. This is not possible if traditional pits are used. Furthermore, steel kiln is easily moveable in comparison with other carbonization technology which means that carbonization operation can follow biomass availability. For example, this can happen along the progression of firebreaks maintenance or in the different field. Moving the kiln is easier and cheaper than transporting the biomass to a faraway carbonization site.

This type of kiln is very easy to build with a local metal workshop. The use of retrieval material reduces also investment cost. A kiln costs approximately 70 000 FCFA in Senegal.

2.2 Briquetting technology

The carbonized material can generally not be used directly as fuel as it is often too fragile and too weak. It is necessary to compress it into briquettes in order to harness this energy. Many technologies exist in this form and most of them use a binder in order to briquette the carbonized particle and strengthen the briquettes. Depending on the strength of the carbonized material, in some cases a grinding process is also required in order to homogenize the carbonized material into a so called "coal powder" before the briquetting process.

2.2.1 "Rotor Press"

We investigated and developed a small extruder, that users have called a "Rotor Press" (figure 2). The Rotor Press presents many advantages for users:

- It is operated manually and does not need any power to function. It can be therefore operated in remote area where access to electricity is nonexistent or too expensive. However, it is very easy to motorize it, and this improves the productivity.
- Its construction is quite easy completed by a skilled metal worker and much easier if simply a replica of a preexisting one is made. Replacement and maintenance are then enhanced, also allowing the possibility of adaptation depending on local context and local biomass.
- All kinds of carbonized products can be processed through the Rotor Press for briquette production. It means that it is possible to make use of different biomass resources in the same place using the same machinery. Moreover, if the carbonized material is not too strong (for example, coal made from straw or small branches), the Rotor Press allows one to process it without preliminary grinding.
- With the Rotor Press, a binder has to be used; tests have shown that all kind of binder (at least those found in Senegal) can be used. The choice for the binder is then not dependent on the technology but on the availability and comparative advantages / disadvantages of each binder.

Figure 2: "Rotor Press"

2.2.2 Binder

There are various binders available in Senegal:

- Clay
- Molasses
- Tree gum (Arabic gum and relatives)
- Starch (from various starchy root such as cassava or collected as flour in flour mills)

The binder plays an important role in the final quality of the Biocoal briquettes. Each binder has a steady effect on (table I):

- Briquette solidity (important in case of transportation)
- Sensitivity to moistness (important in case of long storing)
- Mineral matter content
- Market price

All this aspects also have a relative impact depending on the percentage of binder in the final product.

Table I: Comparison of different binders found in Senegal (+ Advantage, 0 Neutral, - Disadvantage)

Binder & percentage used in briquettes	Solidity	Moistness sensitivity	Minera l matter content	Price
Clay (17%)	+	-	-	+
Molasses (33%)	+	-	-	-
Tree gum (7%)	0	0	+	-
Starch (7%)	+	0	+	-

Since the process should be developed in a rural area and because of the relative expensive price or unavailability of certain binders (starch, molasses and gum), we choose to use clay, despite the fact that it is not the best one from a purely technical point of view. The main disadvantage of the clay is its high percentage in the final product and its high mineral matter content which results in a lot of ashes. Biocoal users have often pointed to these ashes as a problem during cooking.

3 TECHNOLOGICAL RESULTS AND LESSONS LEARNED

3.1 Carbonization

A few tests were made in order to verify the reliability of implementing the “3 barrel” carbonization technology in the Senegalese context and with various heterogeneous local biomass resources like firebreaks maintenance residue and agricultural residue (figure 3). Relevant results concerning carbonization yields and production as well as process duration are compiled in the following tables (Tables II, III and IV).

Table II: Production and yield for carbonization of firebreaks maintenance residue using “3 barrel” technology

Firebreaks maintenance residue	
Load - dry matter	107,1 kg
Carbonized material	31,8 kg
Carbonization yield	**29,7 %**
Percentage of material not carbonized	3,7 %

Table III: Production and yield for carbonization of agricultural residue using “3 barrel” technology

Agricultural residue	
Load - dry matter	145,0 kg
Carbonized material	49,2 kg
Carbonization yield	**33,9 %**
Percentage of material not carbonized	1,7 %

Even if biomass raw material is very heterogeneous with a mix of relative big woody pieces and a large amount of “straw” pieces, the quality of the carbonized material produced is very interesting (figure 4). Basically everything (small and big pieces) is well carbonized. The uncarbonized part listed in the tables represents a small space in the bottom of the kiln which is very difficult to carbonize. This part is reused in the next carbonization.

The difference shown between agricultural residue and firebreaks maintenance residue is due to the higher density of agricultural residue, which is mainly a mix of millet, corn and sorghum straw and stalks as opposed to firebreaks maintenance residue; which is composed mainly of high herbs, small branches and 1-year grown again shrub.

Table IV: Time cycle of one batch carbonization using “3 barrel” technology

Process duration	
Loading	30 minutes
Carbonization	60 minutes
Cooling	4 hours
Unloading	30 minutes
Total process time	**6 hours**

The process duration allows for carbonizing twice a day with one kiln if one of the cooling last overnight. It’s often not a problem as carbonization is done in non-fire sensitive spaces like the center of a firebreak or a field. Only one person is necessary to follow the carbonization process for each kiln but two are required for loading and unloading. This means that 2 skilled persons can easily operate four kilns, completing a total of eight carbonizations per day. Such a unit can produce each day around 240 kg of carbonized material out of firebreak maintenance residues and 400 kg out of agricultural residues.

Figure 3: “3 barrel” kiln in operation

For every carbonization, the moisture level of the raw material is an important factor influencing carbonization rate and duration. Raw material should be the driest possible in order to optimize those both parameters. A high moisture level could make carbonization fail. Firebreaks maintenance is done during the months of December and January (the beginning of dry season). At this time biomass material is generally dry and carbonization can be done in an effective manner. Nevertheless in case of counter season rainfall, it's better to delay carbonization and wait until the biomass dries again.

It's very important to pay attention to the risks of reigniting, especially when storing. Depending on the density of the biomass material and the effectiveness of the cooling, carbonized material could reignite and start a fire. The damage could be limited to loss of carbonized material, but it could also result in larger fire.

Figure 4: Carbonized Biomass, inside view of a "3 barrel" kiln

The biggest carbonized pieces could be used directly as charcoal; the smallest are necessarily processed into Biocoal through briquetting.

3.2 Briquetting

A few tests were made in order to verify the reliability of implementing the "Rotor Press" technology for briquetting various carbonized materials produced by the "3 barrel" carbonization technology.

Even if Biocoal briquettes have been produced with a different binder, mostly for fuel performance comparison (see chapter 4 Biocoal Tests) we focused on the production of briquettes using clay as binder. Clay indeed has piddling advantages for a decentralized and small scale production unit. It is easily to collect anywhere in Senegal and it has no direct cost.

Relevant results concerning briquetting are presented in the table V.

Table V: Operational characteristic of the Rotor Press

Rotor Press / daily production	
Carbonized biomass	50 kg
Added clay	10 kg
Added water	30 liter
Biocoal briquettes produced after drying	**60 kg**
Daily working hours	6 hours

First clay and water are mixed together in order to obtain a soft mixture, which is then added to the carbonized material. The carbonized material looks like a rough dust because of its weakness. When the water-clay mixture is added, the whole mixture becomes a kind of paste which is easily moved through the Rotor Press. Basic mass proportions are 1 part clay, 3 parts water and 5 parts carbonized material.

Briquetting operation is quite easy. 3 persons can operate 2 Rotor Presses and produce 120 kg of Biocoal briquettes (mass dry equivalent).

The process can be improved by motorizing the Rotor press, which will increase the productivity. The carbonized material can also be ground into a "coal powder"; it also increases productivity and allows the use of less clay for the briquetting (around 8% of the final briquettes – dry mass basis). However, a power engine is needed in order to make these two improvements.

After briquetting, Biocoal briquettes have to be dried. In Senegal sun-drying is the easiest and cheapest way. It can be done on a cover smeared on the soil. Briquettes can also be put on a grid tilted towards the sun, optimizing the drying process through better ventilation. After two or three days, Biocoal is ready for sale.

Briquettes can become slightly moist again Depending on climatic conditions, the storing place and the binder used. A short drying before use is therefore recommended when it is humid or when one has just taken out the briquettes after along period of storage.

4 BIOCOAL TESTS

4.1 Water boiling tests

Water boiling tests have been done in order to compare Biocoal with Charcoal. The methodology used is based one various experiences [12, 13].

Results of the test show that the required time to bring to a boil is longer with Biocoal than with charcoal, around 1.5 times longer (Figure 5).

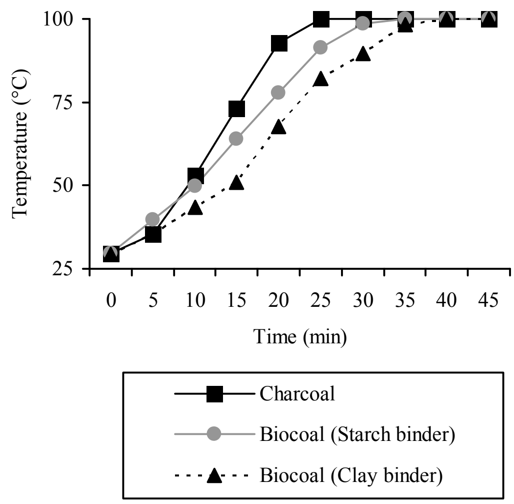

Figure 5: Temperature evolution during the high power phase – cold start of the Water Boiling Test for different fuels

The binder used also plays a role: Biocoal using clay takes more time than Biocoal using starch. The reason is the higher percentage of clay (17%) than starch (7%) in Biocoal and the non-combustible character of the clay (mineral matter) in comparison to the starch (organic matter).

Table VI: Some fuel characteristics during the boiling phase (high power phase – cold start)

Fuel	Burning Rate (g/min)	Specific Fuel Consumption (g/liter)
Charcoal	10,5	289
Biocoal (Starch binder)	13,3	219
Biocoal (Clay binder)	3,0	327

The burning rate indicates the mass of fuel burned per minute during the boiling phase. The specific consumption indicates the mass of fuel required to produce one liter (or kilogram) of boiling water. As a result of the comparison of both characteristics for the 3 tested fuels (table VI), we can say that Biocoal made with starch burns faster and is more efficient than charcoal, which burns faster and more effectively than the Biocoal made with clay.

4.2 Viability test

The viability tests was performed with 18 households and 5 specials users (restaurants, dyers…) in 3 sites : Kassack Nord, a small village in rural area, Ross Béthio, a village with good connection to transportation in rural area; and Saint Louis, a well developed urban area [14]. Results are summarized in table VII.

Table VII: Fuel comparison result after viability test

Fuel	Ignition	Smoke	Ashes	Smell
Charcoal	Quick	Few at the start	Few at the end	No
Biocoal (Starch)	Slow	Much at the start	Few at the end	A bit
Biocoal (Clay)	Slow	Much at the start	Much at the end	A bit

Smoke at the start is due to the ignition material used (paper, small pieces of wood…). Biocoal requires a longer ignition time than charcoal, it results in a greater use of ignition material and consequently more smoke. Since ignition smoke disappears relatively quickly, it does not really affect product viability.

Large amounts of ashes found after combustion of Biocoal using clay as the binder is due to the clay used during the briquetting process. Clay, which is mineral matter, does not burn. This can result in problems with cooking and fire extinction, as it blocks the stove's air ventilation. The stove needs to be shacked often in order to clean it. On the other hand clay allows for a better heat conservation. Biocoal is then better for slow cooking that requires a long simmering phase.

Biocoal use is not the same like charcoal one. Nearly all households were rejecting Biocoal for the first three days, but after those learning days they were very happy with it. Restaurants were particularly happy with it because Biocoal allows keeping the heat under the pot. Restaurants clients also came away with a good impression, they all said that the taste of the cooking was better during the viability test.

Figure 6: Cooking the national dish "Ceeb u jën" with Biocoal

We proposed the price of 100 FCFA/kg (0.15 euros) for Biocoal to beat the normal charcoal price: 200 FCFA/kg (0.30 euros) in Saint Louis, 150 FCFA/kg (0.23 euros) in Ross Béthio and 125 FCFA/kg (0.19 euros) in Kassack Nord. At this price, 85% of surveyed households would use Biocoal as their primary fuel for cooking purposes. Households that refused it are those in urban areas using also gas and cooking inside their houses. They were not ready to change their habits and sacrifice some comfort and time to cook with Biocoal. The most eager households were those living in the remote rural area of Kassack Nord, where households are using wood or cow dung when there is a lack of other fuels (or a lack of money).

5 ECONOMICS

5.1 Biomass potential

The main period for firebreak maintenance lasts 3 months, December – February, at the end of the rainy season and before bushfire season (figure 7). The width of a firebreak is around 20 meters. Maintenance is done by cutting annual re-growth on a 2 meter width on both sides of the firebreak; the collected biomass is then put in the centre of the firebreak, where a controlled fire is produced. Using this method, big trees can be left in place because they do not have an influence on bushfire progression; on the contrary, they help to slow down the wind, which is a great fire activator and disperser. The quantity of firebreak residues, which can be recollected, is estimated to around 2 tons (dry matter) per ha.

Field preparation for crop sowing lasts around 3 months, April – June, just before the first rains (figure 7). Agricultural residues are often left in place after harvest in order to protect soil from wind erosion. Just before sowing, those residues are recollected in a pile, which is burned in the field. The quantity of crop residues (stalks, strokes…) is estimated to around 1.5 tons (dry matter) per ha.

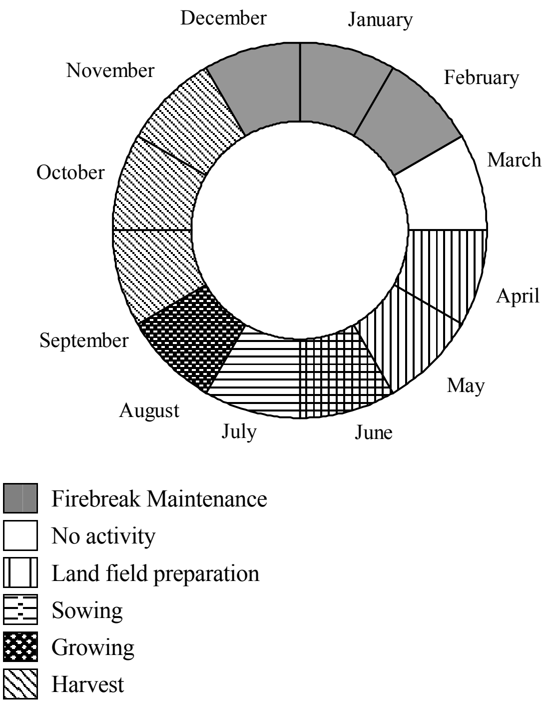

Figure 7: Rural activities calendar (agriculture and firebreak maintenance)

5.2 Production

Economics calculations are made on the basis of a unit of 2 persons equipped with 4 kilns associated with a unit of 6 persons operating 4 Rotor Presses. The people work 8 hours a day and 5 days a week during activities periods. The virtual working year begins the first of December.

During the 3 months (around 65 working days) of firebreak maintenance, kilns produce 15.6 tons of carbonized material out of residues. The briquetting unit needs around 80 days to transform all this material into almost 19 tons of Biocoal briquettes. Some carbonized material is stored until briquetting; it is processed in March, when carbonizations are on standby.

The land field preparation allows the production of around 26 tons of carbonized material in 3 months. This material is transformed into around 31 tons of Biocoal briquettes in 130 days, 6 months.

During one year such units produce around 50 tons of Biocoal briquettes and create work for 8 persons. Investment costs for all the equipment (4 “3 barrel” kiln, 4 Rotor Presses, storing and drying facility…) are around 1 million FCFA (1 500 euros). Annual depreciation and equipment maintenance could be estimated to half of the investment: 0.5 million FCFA (725 euros). With a selling price of 100 FCFA/kg (0.15 euros); the annual turnover is 5 million FCFA (7 600 euros). The monthly income for each person is then around 45 000 FCFA (70 euros), which must be compared to the 2005 average salary in rural areas: between 42 415 and 59 166 FCFA/month (between 65 and 90 euros) [15]. It can also be compared to the monthly minimum salary (SMIG): 36 243.3 FCFA (55 euros) and the monthly minimum salary for agriculture (SMAG): 31 710.7 FCFA (48 euros).

The numbers chosen for calculation is not representative of the diversity in jobs that people do. Indeed often people have more than one activity. It may be more realistic to take in account the fact that more people would probably work in the same unit with a quicker worker turnover. The sustainability of such a unit is then enhanced by investors, who would be owners/shareholders of the unit or by a cooperative functioning.

In order to function, this unit needs 55.7 tons of biomass residues during the firebreak maintenance period and 75.4 tons of agricultural residues during the land field preparation period. It represents the cleaning of respectively 14 km of firebreak and 19 ha of fields. This length of firebreak allows for the effective protection of nearly 2 000 ha of forest, in the case of the Dankou forest, under survey by the PERACOD since 1995. Moreover the 50 tons of Biocoal produced prevent the production of around 40 tons of charcoal, which means 125 ha of forest is preserved from firewood exploitation.

CONCLUSION

The “3 barrel” carbonization technology in association with the “Rotor Press” briquetting technology allows for a sustainable production of domestic fuel based on the valorization of biomass residues. Farmers and other people living around the forest, while maintaining firebreaks and preparing their fields for sowing, can produce their own domestic biomass fuel. These technologies can be locally produced, operated and maintained. A further advantage is that they generate extra income by developing a new activity. If this activity develops on a large enough scale, the forest area will be protected in a sustainable manner and CO_2 emissions will decrease.

To summarize, 1 ton of Biocoal has the following impacts:

- The maintenance of 700 m of firebreak or cleaning of 0.6 ha of agricultural land
- The replacement of approximately 800 kg of charcoal
- The preservation of 2 ha of forest from firewood exploitation
- The reduction of 14.5 tons of CO_2 emission

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