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Briquettes of plant remains from the greenhouses of Almería (Spain)

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Abstract

Since ancient times, plant biomass has been used as a primary fuel, and today, with the impending depletion of fossil fuels, these vegetal sources constitute a cleaner alternative and furthermore have a multitude of uses. The aim of the present study is to design a method of recycling and reuse of plant wastes from intensive agriculture under plastic, by manufacturing briquettes in an environmentally friendly manner. In Almería (SE Spain), agriculture generates 769,500 t year^{-1} of plant remains from greenhouse-grown horticultural crops, a resource currently used for composting and for producing electricity. With the machinery and procedures of the present study, another potential use has been developed by detoxifying and eliminating the plastic wastes of the original biomass for the fabrication of briquettes for fireplaces. The results were slightly inferior to the commercial briquette from other non-horticultural plant materials (no forestry material), specifically 2512 kJ kg^{-1}, in the least favourable case. On the contrary, the heating value with respect to the two charcoals was significantly lower, with a difference of 12,142 kJ kg^{-1}. In conclusion; a procedure, applicable in ecological cultivation without agrochemicals or plastic cords, has been developed and tested to reuse and transform plant materials from intensive cultivation into a stable non-toxic product similar to composite logs, applicable in commercial settings or in residential fireplaces.

Additional key words: biomass, contamination, horticulture, recycling.

Resumen

Briquetas de residuos vegetales procedentes de los invernaderos de Almería (España)

Desde antaño, la biomasa vegetal se ha utilizado como combustible primario, es más, hoy en día con la disminución de combustibles fósiles es una alternativa más limpia que éstos y con multitud de usos. El objetivo de este trabajo es diseñar un método de reciclado y reutilización de residuos vegetales procedentes de la agricultura intensiva bajo plástico, mediante la fabricación de briquetas, todo ello respetando el medio ambiente. En Almería (sureste de España), la agricultura es capaz de generar 769.500 t año^{-1} de restos vegetales procedentes de cultivos hortícolas en invernadero, siendo usados actualmente para la obtención de electricidad y compost. Con la maquinaria y procedimientos del presente estudio se ha desarrollado otro posible uso, destoxificando y eliminando los residuos plásticos de la biomasa original para la fabricación de briquetas, y poder destinarlas para combustible de hogares. Los resultados son levemente inferiores a la briqueta comercial procedente de otro residuo vegetal hortícola (no forestal), concretamente de 2.512 kJ kg^{-1}, en el caso más desfavorable. Por el contrario, el poder calorífico respecto a los dos carbones comunes es significativamente menor, con una diferencia de 12.142 kJ kg^{-1}. En conclusión, se ha desarrollado y experimentado un procedimiento que permite reutilizar y transformar, a partir de métodos de cultivo ecológico sin agroquímicos y rafias biodegradables, los residuos vegetales procedentes de los cultivos intensivos, en un producto estable, no tóxico, de características semejantes a las de las virutas procedentes de la madera y que puede tener aplicaciones comerciales, fundamentalmente como combustible para hogares.

Palabras clave adicionales: biomasa, contaminación, horticultura, reciclado.

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Introduction

In 1992, Abasaeed observed that briquettes from cotton stems constituted an ecological, rational, and socially acceptable source of fuel, and could help resolve the problem of waste elimination. Nevertheless, its chemical and heat potential should be evaluated (Frings *et al.*, 1992).

Hall and House (1995), saw biomass as an environmentally acceptable fuel for the future. This biomass is found in the traditional form of firewood, plant remains, and manure. If these are badly used, they can be harmful for the environment whereas if they are used efficiently and sustainably, the energy from the biomass has numerous environmental and social benefits in comparison with fossil fuels. The beneficial effects include: control of wastes, recycling of nutrients, creation of employment, the use of agricultural surpluses in industrialized countries, production of electricity in rural areas, improvement of land management, and reduction of CO_2 pollution.

Clearly, the reduction in the fossil-fuel supply is driving world research towards alternative sources of fuels, including the use of biomass such as agricultural wastes (Gomes *et al.*, 1997). Biomass in the form of firewood, since time immemorial, has been the main fuel, but only recently has it been considered a viable substitute for fossil fuels used to generate energy (Arbon and Bowell, 2000), although to be competitive, they need governmental subsidies (Arbon, 2002).

The potential of biomass from plant remains include wood from forests, remains from agricultural harvest, and vegetal matter from abandoned areas. It is vital to know this potential (Dolensek, 2004) as in the case of organic agricultural remains from unfavourable areas of India (Misra *et al.*, 1995; Chowdiah and Gowda, 2004), Ghana (Obeng *et al.*, 1997), China (Dai *et al.*, 1999), Peru (Mendoza *et al.*, 2004), Morocco (Debdoubi *et al.*, 2005), and Pakistan (Mirza *et al*., 2008), which can provide an economic resource for inhabitants of these areas in addition to a more environmentally sound energy source. Also, in more developed counties, such as Estonia (Muiste and Kask, 1998), Serbia (Danon and Stanojevic, 1998), Belorusia (Kakareka, 2002), Sweden (Olsson *et al.*, 2003), Poland (Nilsson *et al.*, 2006), and Lithuania (Katinas *et al.*, 2007), briquettes of vegetable origin are used for fireplaces.

The term "biomass" includes the organic matter produced by photosynthesis, as well as urban and industrial organic wastes. The combustion systems for biomass offer significant protection for the environment by reducing greenhouse gases, although the ashes and released other released can be pollutants (Demirbas, 2005). Some of these wastes can be burned in different types of factories, using organic fuels as an energy source for different processes (Bianchi *et al.*, 2006). Also, the use of biomass as a complement for coal at energy facilities has been shown to reduce emissions of CO, NO_X, and SO_2 (McIlveen-Wright *et al.*, 2007; Narayanan and Natarajan, 2007; Skoulou and Zabaniotou, 2007; Koa and Chang, 2008).

From the standpoint of emissions, methane (CH_4^-), one of the trace gases in the atmosphere, is considered to play a major role in the greenhouse effect. Among other sources, it comes from the storage and burning of biomass, humans are a major contributing factor to this problem (Heilig, 1994). In its natural form, methane and CO_2 emissions are produced by vertebrates due to the decomposition of biodegradable carbon composts attacked by anaerobic bacteria. Wihersaari (2005), in Finland, suggested that these emissions could be greater than those released by the production of biofuels, although Lombardi *et al.* (2006) pointed out a lack of knowledge concerning the emissions that these wastes produced when burnt. From methane derived from anaerobic fermentation of organic wastes, hydrogen can be produced for use in fuel pellets, thereby increasing the efficiency of generating electric energy in addition to mitigating the emissions of greenhouse gases (Tomasi *et al.*, 2006; Dowaki *et al.*, 2007; Duerr *et al.*, 2007).

Anton *et al.* (2005) demonstrated from the environmental standpoint that with greenhouse wastes the best approach, rather than incineration, is to classify them, recycle them, and reuse them, advising that plant remains be composted. Similarly, Dorais (2007) observed the need to develop sustainable development by ecological production systems of vegetables, which would increase consumer satisfaction at the same time as improving competitiveness of the producers. Also, Munoz and Riley (2008) have indicated that the reuse of agricultural wastes is becoming more widespread due to the environmental impact of generated waste.

In Spain, organic wastes are not valued for their energy. Only some solid urban wastes are used for fuel, despite that on a national scale the potential energy that they represent is some 6,000 MW, equivalent to six conventional nuclear plants. Energy-evaluation systems for waste are apt for energy production and simultaneously enable the reduction of greenhouse-gas emissions. Gasification appears to be the most suitable energy-conversion system for electricity production from biomass, although any such conversion system needs to be compatible with the type of waste to be treated (Elías, 2007).

The magnitude of the generated wastes from the greenhouses in the province of Almería (Spain) is large both in diversity as well as quantity (Callejón *et al.*, 2009; Figure 1), covering 27,000 ha (Sanjuán, 2004) of cultivation under plastic.

In addition, this plant waste is mixed with various materials, primarily soil, and agrochemical residues, and plastic cords for training crops, and thus is not a pure vegetal waste (Camacho *et al.*, 2000). In this sense, the tests of Angelini *et al.* (2000) confirm that the original plant fibres represent a potential substitute for materials of non-organic origin. It is important to highlight that the chloride content of plastic wastes of cords give rise to high rates of pollution during incineration (Hedman *et al.*, 2006).

The aim of the present study is to design a method of recycling and reuse of plant wastes from intensive agriculture under plastic, by manufacturing briquettes in an environmentally friendly manner.

Material and methods

Location and volume of the wastes

The study area is located in south-eastern Spain (Figure 2).

The surface area covered by the greenhouses is roughly 30,000 ha and the greenhouses are mainly (96.5%) of the flat and gable types (Fernández and Pérez, 2004), with an overall agricultural production of some 1,500 million euros (Fundación Cajamar, 2006).

Among the wastes (Figure 1), the vegetal fraction averages 28.5 t ha^{-1} $year^{-1}$, or 114 m^3 ha^{-1} $year^{-1}$ (Manzano, 2007). Multiplication of this by 27,000 ha or greenhouses (Sanjuán, 2004) gives 769,500 t $year^{-1}$, for a volume of 3078,000 m^3 $year^{-1}$ of plant waste or biomass.

Nature of the wastes

The crops include tomato (*Solanum lycopersicon* L.), cucumber (*Cucumis sativus* L.), pepper (*Capsicum annuum* L.), courgette (*Cucurbita pepo* L.), melon (*Cucumis melo* L.), watermelon (*Citrillus vulgaris* Schrad), aubergine (*Solanum melongena* L.), and greenbeans (*Phaseolus vulgaris* L.). The vegetal wastes can have varying degrees of moisture and agrochemical residues and receive no prior treatment, forming a tangle of interlocked stems that make the mass unwieldy with other wastes mixed in. Camacho *et al.* (2000) classified such wastes as:

- A mixture of different horticultural plants (roots, stems, and leaves).
- Polyethylene cord and ribbon (one cord or ribbon per plant). Also, there were spools as well as hooks to hang the plants.
- Polyethylene hoops to train the plants. For each plant, there were 4 to 5 hoops. In some cases, a system to train the plants consisted of a strip of plastic clasped by metal staples
- Unharvested fruits in certain quantities.
- Soil adhering to the plant roots.
- Fragments of wire from the greenhouse structure.
- Other waste: plastic bags, plastic from the greenhouse cover, pieces of plastic irrigation pipe, fragments of wood, etc.

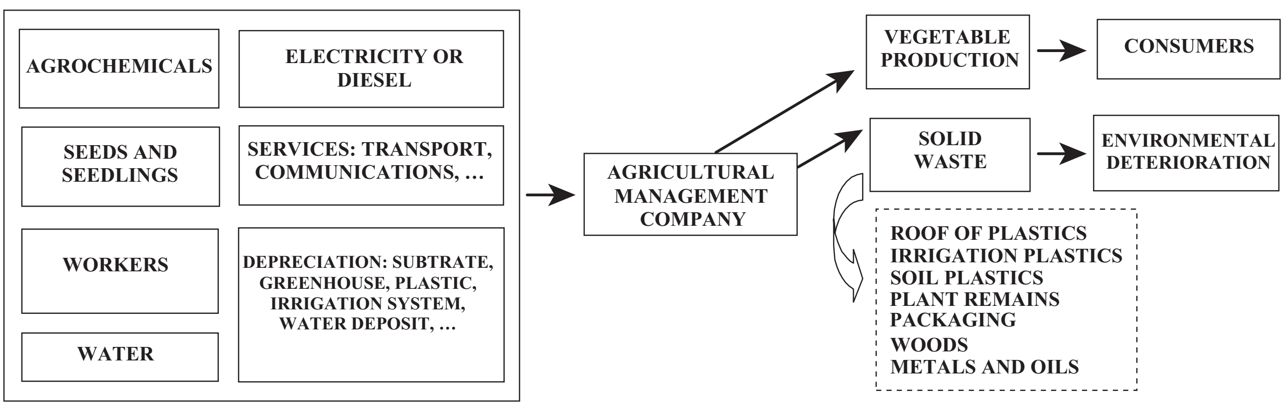

Figure 1. Flow diagram of model agricultural Almería (Callejón-Ferre *et al.,* 2009a).

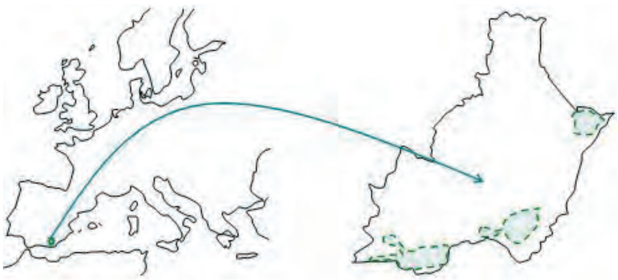

Figure 2. Location 80% of greenhouses in Almería (Callejón-Ferre *et al.,* 2009b).

Pilot plant

Figures 3 and 4 show a block diagram and units' distribution in the pilot plant. The plant wastes were fed into a shredding machine that cuts up the stems of the plants as well as mixed-in foreign elements.

The product was then passed through a homogenizing mechanism and vibrated, so that the vegetal material moved forward over a metal screen to separate the sand and fine components.

The homogenized product was discharged into a continuous washing module in which water with detergent eliminated the toxic residues and separated other impurities and solid particles adhering to the organic matter. For this the plant remains were stirred and moved forward by an endless screw through the washing tank. The water, pumped through an outlet in the bottom of the washing tank, was filtered on its way into a reactor, where it was purified. After purification, it was returned to the washing tank. Then, transferred to a continuous drying system, the vegetal matter was deposited over a belt that moved through a tunnel with a air current (from a hot-air generator) blowing against the direction of movement. Afterwards, if the vegetal matter was not sufficiently dry, it was sent to a batch drier equipped with a revolving cylindrical drum made of metal screen inside of which the plant remains were tumbled until the hot-air current dried them to the required moisture content. Then, the organic matter was ground as needed for the use of the product. Finally, the shredded is put into the briquetting where the product is converted in commercial briquettes.

Detailed components description

a) Shredding

A commercial shredder (Sant Andrea Novara, model G15/600, Spain) was used. Some of the basic characteristics are: i) shredding surface area 600 x 536 mm; ii) the size of the fragments or particles varied from 15 mm to 15 cm; iii) work capacity of 3,000 kg h^{-1}; and iv) electric motor of 11 kW.

Fragment size was made more uniform by changing the cutter blades to a type with more teeth. Also, for the characteristics of the shredding system used (shears and shredding by traction) was greatly facilitated by the feed, as once the shredding process was begun, the machine worked by self-feed, drawing in the tangle of vegetal material. The working capacity depends mainly

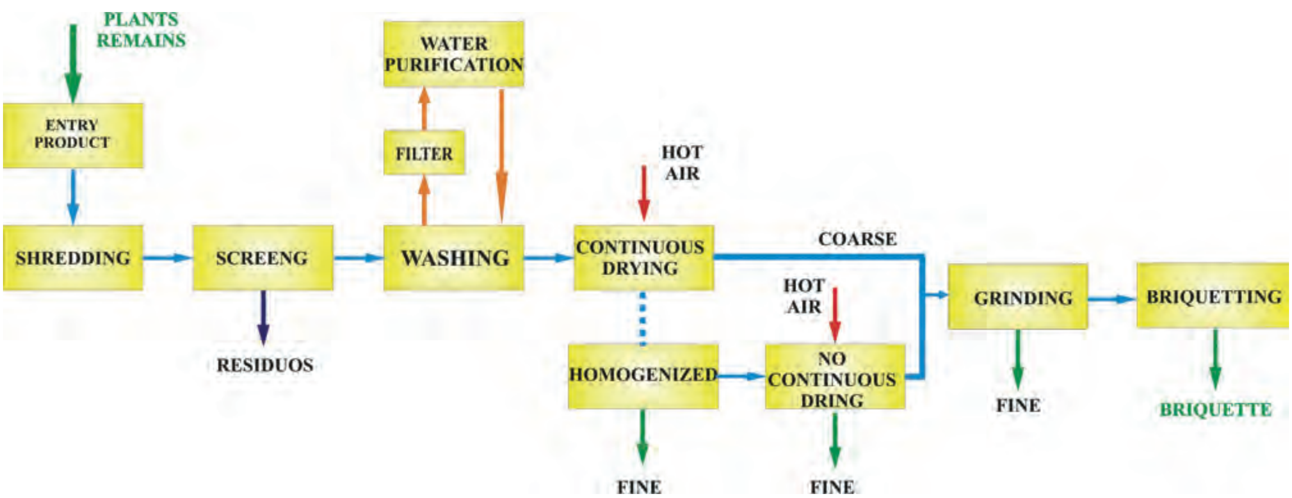

Figure 3. Block diagram of the waste treatment plant.

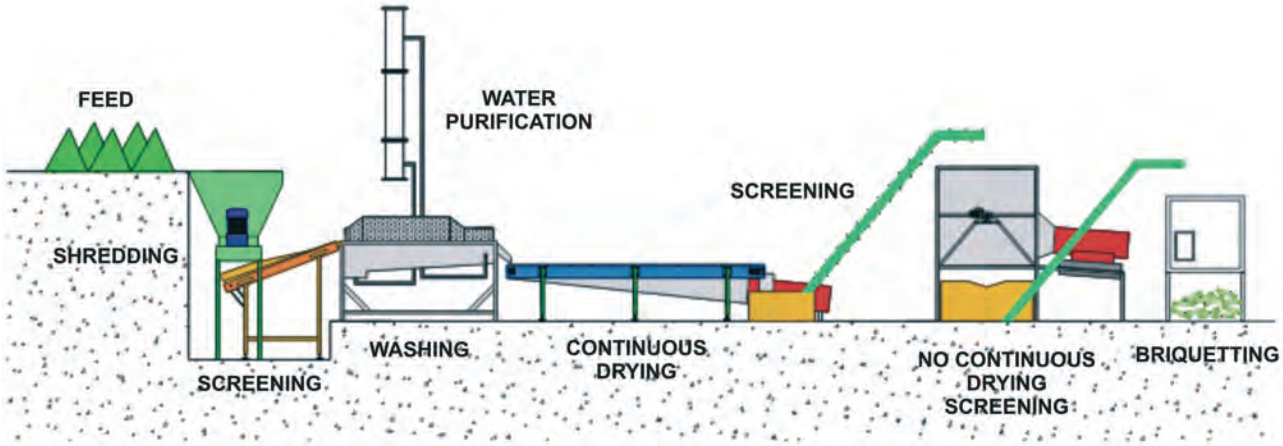

Figure 4. Distribution of the machinery of the pilot plant.

on the model used and how the material is fed into the system.

b) Screening

The shredded remains were passed over a tilted metal screen, which vibrated enough to separate the soil from the plant material. The inclination and the vibration caused the remains to move forward. Some of the basic characteristics are: i) screening surface = 700 x 1,700 mm. ii) diameter of the grid openings = 8 mm; iii) electric motor of 0.735 kW at 146.61 s^{-1}; and iv) eccentricity of the axis= 3 mm.

Figure 5. Coarse and fine remains.

c) Washing

The remains were deposited in a tank for continuous-washing comprised of a rotating drum made of screen, partially submerged in water. The revolving drum, which had an endless screw inside, stirred the vegetal remains in the water, causing them to advance through the tank during the time needed for an effective cleaning. Some basic characteristics are: i) capacity of washing tank = 310 dm^3; ii) electric motor of 0.735 kW; iii) drum rotation velocity = 3.1416 s^{-1}; iv) drum diameter =600 and 400 mm; and v) washing course = 2,000 mm.

The water used to wash out the toxic residues contained a surfactant concentration in the range of 100 to

Figure 6. Briquettes of plant remains.

1,000 mg dm^{-3}. Since the water became soiled and deteriorated in quality during the washing, and given that the aim was to provide vegetal material without producing further pollutants, a water-purification system was developed so that the same water could be reused.

For the water purification, the tank constituting the washing module was equipped, in its lowest part, an drain that enabled water to be pumped through a filter to the reactor, where it was purified. For this, the water was passed to a bubble-column tank reactor which, though a nozzle situated in the base, was injected continuously with ozone generated by electric arc over gas oxygen. Simultaneously, a basic pH (8.0 to 9.5) was maintained by the addition of NaOH, while adding, every 10 min, 5 mL of oxygenated water per 300 L of water to be treated. This optimised the generation of hydroxyl radicals that, with their greater oxidizing power, mineralized the contaminants present to CO_2 and H_2O after 3 h of oxidative treatment (Chiron *et al.*, 2000). As a control of this purification process, periodical acute-toxicity analyses were performed by the Daphnia magna ecotoxicity test following the analysis protocol ISO 6341 (Dutka, 1989), and the effectiveness of the water-purification process was confirmed after successive cycles in a closed-circuit connecting the tank reactor to the wash tank.

d) Drying

The drying process consisted of two phases. In the first, the continuous drying, the outer moisture from the previous washing of the vegetal remains was removed together with the part of the inner water. This process was carried out by passing the plant remains on a belt made of metal screen moving through a tunnel and where a current of hot air (c. 150ºC) was blown in the direction opposite to the movement of the belt. Some basic characteristics are: i) length and width of the belt = 3,300 x 650 mm; ii) tunnel height =100 mm; iii) electric motor of 0.184 kW with a reducer and frequency dial; and iv) diesel stove, model lo Kroll GP-80, with fuel consumption of 6.78 kg h^{-1}, heating power of 80 kW, and ventilation flow of 3.100 m^3 h^{-1}.

When the vegetal remains were not sufficiently dry for the intended industrial application, they were transferred by a belt to a batch drier equipped with a rotating cylindrical drum made of metal screen inside of which the plant matter was tumbled for the time needed for the hot-air current (c. 130ºC) to eliminate the moisture to the required level. Some basic characteristics are: i) capacity = 400 dm^3; ii) electric motor of 0.184 kW with a reducer and frequency dial; iii) and diesel stove, model Kroll GP-40, with fuel consumption of 3.63 kg h^{-1}, heating power of 43 kW, and ventilation flow of 1.600 m^3 h^{-1}.

e) Briquetting

The dry plant remains (less than 18% humidity) are introduced into the briquetting feeding tank (model GP-50) using the transport belt. The briquetting feeding tank includes a mixer that assures a constant flux to the pre-compression chamber. Afterwards, the hydraulic piston put the material into the compression chamber, where another hydraulic piston compresses the material. Some basic characteristics are: i) feeding tank capacity = 1 m^3; ii) work capacity of 40-60 kg h^{-1}; iii) electric motor of 5.5 kW; iv) briquettes' diameter of 50 mm.

All of the systems with movement had a mechanism to measure and regulate velocity and to adapt the working capacity of each to make the different modules compatible.

Heating value

The upper heating value was determined in the laboratory in heating-pump assays using criteria of Suarez *et al.* (1999), with 5 replicates and samples of less than 1 g.

Results

By the above-mentioned process, approximately 80% of the weight of the original waste was reduced, resulting in a stable product (Figure 5), which was classified in coarse and fine according to particle size:

- Coarse. These were larger particles that resembled wood shavings. Comprised of caulinary remains, they were of greater size and came from the more lignified parts of the plant.

- Fine. These were smaller particles mainly from the leaves of the plants.

Both products, free of toxic substances, mixed together or separately, are apt for certain industrial applications related to wood (particle board, incineration, etc.). As a possible application, the use of the coarse and fine particles were tested for use in manufacturing compacted cylinders or briquettes (Figure 6) which could be used as fuel in fireplaces.

The results in the analyses were very similar to those of briquettes made from other similar products. Figure 7 shows the heating value of the commercial briquette (REF) used as a reference, two briquettes made from this product (BRI-1 and BRI-2) and two common charcoals (CAR-1 and CAR-2).

The results were slightly inferior to the commercial briquette from other non-horticultural plant materials (no forestry material), specifically 2512 kJ kg^{-1}, in the least favourable case. On the contrary, the heating value with respect to the two charcoals was significantly lower, with a difference of 12142 kJ kg^{-1}. With regard to the gases emitted, the charcoals have not been analysed.

It is important to highlight that in the process of making briquettes, the water used in the washing and the elimination of the toxic residues was treated and purified for reuse in a closed circuit, and therefore it generated no type of contaminant and the cost of the water was very low, so that the process can be considered to be clean technology.

Discussion

The process functions and it is possible to produce briquettes with reseanably good heating value and that could be used in fireplaces in the same way as firewood. However, the briquettes, being made from plant remains from Almería greenhouses, contain small quantities of plastics; as noted by Camacho *et al.* (2000), the product is not pure. The plastic comes from the cords used to train the plants and that are often tangled with the plant material and are not separated at the end of the harvest. The main problem with these plastics are their emissions in the combustion process (Hedman *et al.*, 2006) in addition to the emissions of the plant material itself, the latter being much less harmful than the combustion

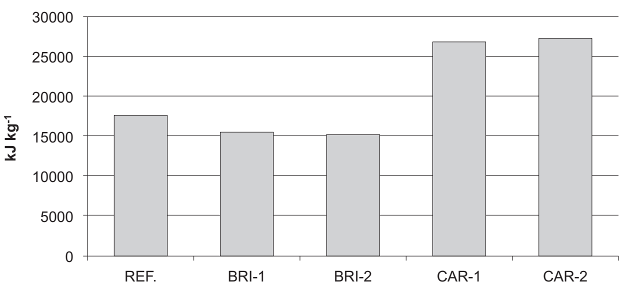

Figure 7. Heating value of various materials.

of any fossil fuel (Abasaeed, 1992; Hall and House, 1995; Misra *et al.*, 1995; Obeng *et al.*, 1997; Danon and Stanojevic, 1998; Muiste and Kask, 1998; Dai *et al.*, 1999; Arbon and Bowell, 2000; Kakareka, 2002; Olsson *et al.*, 2003; Chowdiah and Gowda, 2004; Mendoza *et al.*, 2004; Debdoubi *et al.*, 2005; Bianchi *et al.*, 2006; Nilsson *et al.*, 2006; Katinas *et al.*, 2007; McIlveen-Wright *et al.*, 2007; Narayanan and Natarajan, 2007; Skoulou and Zabaniotou, 2007; Koa and Chang, 2008; Mirza *et al.*, 2008). However, the emissions exist (Demirbas, 2005) and should be evaluated (Frings *et al.*, 1992; Dolensek, 2004; Elías, 2007). For the evaluation, both the emissions of CH_4 from storage (Heilig, 1994; Wihersaari, 2005; Lombardi *et al.*, 2006) as well as from the burning of plant remains should be taken into account. This fact is important because it brings up the question of the emission of CH_4, which the vegetal remains can produce without being burnt; that is, it could be more harmful to store plant remains in the open air than their controlled burning. This would obligate a rapid manipulation of the plant residues, and the treatment system described here could be a solution.

Nevertheless, although the rapid manipulation of the remains and the final production of briquettes reduces the CH_4 and CO_2 emissions from storage, the emissions of the plant material itself by combustion, more or less accepted, would be highly harmful by the burning of the remains of the plastic cord, as commented above, and not by CH_4 and CO_2, which in both cases could be used to make hydrogen (Tomasi *et al.*, 2006; Dowaki *et al.*, 2007; Duerr *et al.*, 2007) although all these processes would be very costly and would necessitate subsidies (Arbon, 2002).

Clearly, to make briquettes from this type of waste from greenhouses and for the fuel to be environmentally friendly, the plastic remains must be removed. For this, there are two solutions. The first is to require the farmers to separate the plastic from the plants at the greenhouse, but this is a labour-intensive operation. The second would be to use biodegradable cord from vegetable fibres (Angelini *et al.,* 2000), which can be obtained near the greenhouse areas, to reduce the cost with respect to the price of plastic cords. In addition, if the biodegradable cords are accompanied by the practice of a more ecological type of agriculture (Dorais, 2007) with lower rates of agrochemical application, the vegetable remains would be easier to treat chemically and the final briquettes made for combustion could compete environmentally with the composting suggested by Anton *et al.* (2005), the briquettes being a reusable product, as indicated by Munoz and Riley (2008).

Finally, as observed by Gomes *et al.* (1997), the decrease in fossil fuels is encouraging research on alternative energy sources, with agricultural products playing a major role, although, if their fundamental characteristic that defines a fuel as such is its high heating value, the results indicate that the briquettes from the greenhouse plant remains could be considered as a more or less average fuel. That is, the heating value is a function of the material, as demonstrated in the test in which the charcoal and the commercial briquette had higher heating values than the briquette assayed.

In conclusion; a procedure, applicable in ecological cultivation without agrochemicals or plastic cords, has been developed and tested to reuse and transform plant materials from intensive cultivation into a stable non-toxic product similar to composite logs, applicable in commercial settings or in residential fireplaces.

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