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Environmental Impact Assessment of the Application of Pyrogenic Carbon in Soil

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ABSTRACT

World increasing population and use of energy for transportation and electricity are demanding more extensive and more efficient use of land for agriculture; aiming to both food and biofuel supplies. This communication assesses the possible improvements in soil fertility, capture of greenhouse gas, and rainfall, as a result of the large scale terrestrial application of pyrogenic carbon aiming for desert greening. Fossil hydrocarbon coke is taken into account for this proposal because of the exhaustion of light petroleum proven reserves that is leading to a scenario of abundant coke production from the processing of non-conventional reserves.

Keywords: Pyrogenic Carbon; Coke; Terra-Preta; Desert Greening; Albedo

1. Introduction

Coke is a form of pyrogenic carbon, actually by-produced from oil refining industry that employs thermic cracking processes such as delayed coking, etc., for upgrading low H/C molecular ratio feedstock's into the more desirable lighter fuels: gasoline and diesel gasoil. Such non-conventional low H/C includes deposits of the large reserves of Venezuelan heavy oils, Canadian tar sands, as well as the heavy oils requiring special recovery techniques that will be remaining in most world's oil wells when partially exhausted in the future. World production of petroleum coke is actually over 100 million tons per year, about 50% produced in the USA; however, due to economic circumstances at many petroleum refineries, coke is accumulated for sale. In contrast, coke production from coal, about 5 times larger than that produced from petroleum, is not a by-product but currently intended for particular applications: metallurgy and cement industries, thermoelectric generation, etc., implying high greenhouse gas emissions.

The other important form of pyrogenic carbon is that produced by carbonization of biomass, frequently referred to as biochar (or charcoal); man made for some domestic uses (heating and cooking) particularly in non-well developed communities, as well as naturally produced in forest fires. In addition, more recently developments for the integral processing of trees are also producing biochar, besides of electricity and biofuel.

Notice that pyrogenic carbon, originated from either fossil or biomass raw materials, can be included into the family of solid organic chemical compounds, having high C content, significant amount of elements O, H, N, S and several minerals elements in smaller amounts. Generally, cokes have smaller organic volatile matter than biochars because of the larger temperatures normally employed in coking processes. Another important characteristic of pyrogenic carbon, relevant to present communication is its black color offering very low albedo: *i.e.*, the sunlight reflection coefficient.

The objective of present communication is the assessment of the environmental impact of the large-scale application of pyrogenic carbon in soil aiming for desert greening and agroforestry developments.

2. The Terra-Preta-Nova Transformation

One option proposed for decreasing global greenhouse effects is the land applications of pyrogenic carbon [1]. In the case of biomass, this application is based on the agricultural technique "slash-and-char", probably employed by ancient Amazonian communities that created a soil, referred to as terra-preta ("black earth" in Portuguese), characterized by having very high organic carbon content and sustainable fertility [2-5]. Soil organic carbon (or rhizosphere carbon) represents the largest reservoir of carbon in most terrestrial ecosystems as depicted in **Figure 1** [6], and changes in this reservoir can influence the global carbon balance and therefore, the climate change [7,8]. Because of organic chemicals affinity, sequestering pyrogenic carbon in soil may improve soil fertility by preventing organic matter (particularly humus) from being rapidly mineralized and lixiviated.

The concept of terra-preta-nova [9,10] is used to refer to a soil artificially prepared with pyrogenic carbon to resemble the ancient terra-preta. A model of the required chemical structure of pyrogenic carbon for terra-preta-nova [11] supposes a dual porous structure: one structure formed by slit-shaped small pores (near 10^{-9} m width) featuring substituted graphene sheets containing nutrient elements (N, P, K, Ca, etc.), and another structure formed by large pores (near 10^{-6} m width) providing the space for the habitat of plant friendly microorganisms such as rhizobium bacteria and mycorrhiza fungi [12,13]. Another requirement for soil application of pyrogenic carbon is low volatile organic matter [14], in particular: volatile polyaromatic hydrocarbons. These properties may transform terra-preta-nova transformation into one component for desert greening; the other important component: irrigation.

In the case of starting with a desert land with almost zero organic matter, the main problem to prepare terra-preta-nova is the very high amount of carbon required, roughly 250 tons C per hectare [10]. Recently, the possibility of using fossil hydrocarbon coke as feedstock for soil application to promote renewable bioenergy has been proposed [11]. Indeed, partially replacing fossil fuels with biofuels derived from improved soil fertility by pyrogenic carbon application could diminish greenhouse effect due to CO_2 capture by photosynthesis, as depicted in the following sketch of simplified consecutive chemical reactions involving CO_2 recycling and biofuel use [15]:

Photosynthesis: $3CO_2 + 3H_2O$ + solar energy → $3CH_2O$(sugar) + $3O_2$

Fermentation: $3CH_2O$(sugar) → C_2H_5OH(ethanol) + CO_2

Combustion: C_2H_5OH(ethanol) + $3O_2$ → $2CO_2 + 3H_2O$ + renewable energy

Net: solar energy → renewable energy

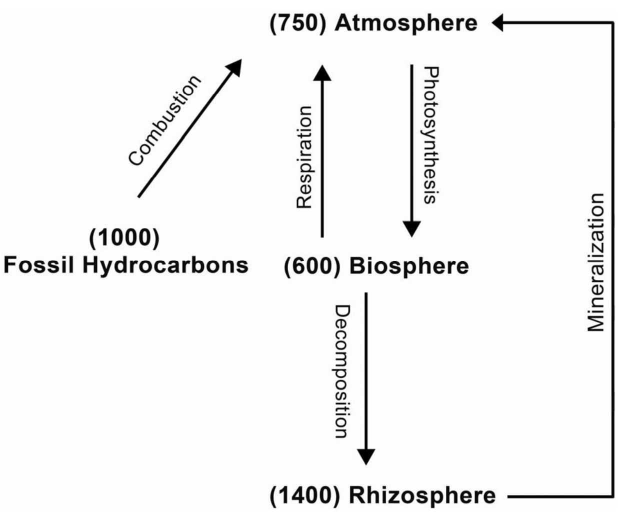

Figure 1. Sketch of elemental carbon flows in terrestrial ecosystems. Values in brackets are Gton C available in each reservoir. In the case of the fossil hydrocarbons, the value shown correspond to conventional reservoirs; about 3/4 is coal, the rest is petroleum and gas. It is not included non-conventional reservoirs such as bitumen, tar, shale, methane hydrates and deep off-shore deposits. Forest fires are not included: these will transform biosphere C into two fractions: one going to the atmosphere by combustion, and other to the soil by carbonization, according to burning condition: combustion dominates if enough wind, and carbonization dominates if none wind and/or high moisture. This figure does not include ocean participation.

3. Pyrogenic Carbon for Desert Greening

Sustainable global renewable energy supply, based on the harvest of lignocelluloses derived from greening (also referred to as afforestation) of world's degraded land like deserts may be realized in some decades [16]. Arid and extremely arid lands represent approximately one-third of total world's non-permafrost land as shown in **Figure 2** [17]; therefore, these desert lands would be promising sinks for atmospheric carbon if photosynthesis is activated for its transformation into fertile land by using both terra-preta-nova artifact and irrigation. Presently, desert greening is very difficult particularly due to irrigation requirements. This could be introduced in dry zones from water desalination and pumping using renewable energy [18-20].

Besides of water availability, highly developed agroforestry technique is a necessary condition for dessert greening. Underdeveloped countries are mainly located within Cancer and Capricornia tropics, where photosynthesis kinetics can be more intense all year allowing larger agroforestry yields respect to temperate latitudes, and in their way for development, it is implicit by looking at the first parameter indicated in **Table 1** that these countries are expected to increase fuel energy use much more rapidly than well developed countries, because these later are able to use more sophisticated energy sources (e.g., eolian, solar panels, etc), as well as clean fuels such as H_2 originated from coal gasification with underground CO_2 disposal, aiming for the use of efficient fuel cells. Certainly, in less developed countries the adoption of new technologies is slow respect to their population increase, implying the continuation of increasing demands of conventional fuels, converting the scenario of scarce petroleum supply into another scenario of land used for crop-

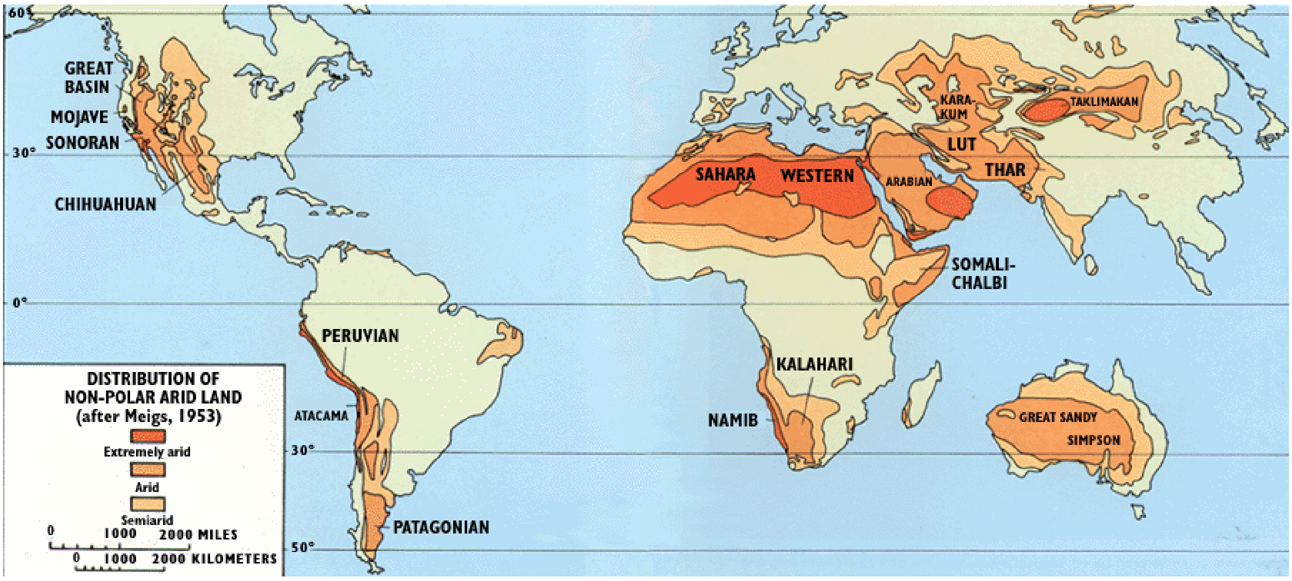

Figure 2. Distribution of non-permafrost arid lands [17]. Total non-permafrost land is about 12 × 10^9 hectares (12 Gha); arid lands are about 1/3 of this total.

Table 1. Parameters comparison between well-developed and under-developed countries. Adapted from [6].

Parameter (per year)	Holland	Ethiopia
Energy consumption (electricity, transport) (G.calorie/capita)	50	10
Food consumption (in wheat equivalent*) (ton wheat/capita)	0.8	0.2
Agriculture efficiency (ton wheat/hectare)	10	2

**i.e.*, related to food cost, not to food amount.

ping raw materials for the emergent fuels: ethanol and biodiesel.

Indeed, the production of the raw materials for biofuels would require the use of high efficiency agriculture (the third parameter in **Table 1**) in order to: on the one hand, to avoid raw material (e.g., corn, sugar cane, soy, etc) competing in both food and biofuel markets that could cause famine (related to second parameter in **Table 1**); and on the other hand, to avoid biodiversity destruction by tropical forest transformation into monoculture farming; already occurring within a significant extent in tropical Asia, and being in its initiating stage in the tropical Africa and America. Certainly, normative to favor desert greening instead of tropical forest transformation should be implemented globally.

As a cause of concern, if fossil fuels consumption continues at present rate (7 Gton C/year), atmospheric carbon (actually 750 Gton C, see **Figure 1**) could duplicate within this century, implying fateful predictions of climate change. Certainly, intensifying photosynthesis by desert greening would contribute to offset the increase of atmospheric carbon concentration. According to calculations published elsewhere [11], using 20% of the total conventional fossil hydrocarbon reservoirs (1000 Gton C shown in **Figure 1**) would be enough to transform 1 Gha of desert lands into terra-preta-nova. Greening of this extension of desert (equivalent to 1/4 of total world desert land: 4 Gha) by mean of either afforestation with fast growing trees or crops like sugarcane, could respectively capture enough C from atmosphere to offset actual global C emission from fossil fuel use (7 Gton C/year), or yield biofuels enough to substitute world petroleum production (30 Gbbl/year). In addition, desert greening would encourage human migration creating new communities in the arid lands promoting the use of solar panel and/or eolian energies. Notice that the calculated percentage shown above (20%) would be significantly much smaller if taken into account the total non-conventional world's fossil hydrocarbons.

One effect of the application of pyrogenic carbon is that it makes soil darker. Amazonian terra-preta color is something in between sandy yellow and carbon black as shown in **Figure 3** [8]. As sun light terrestrial reflection (*i.e.*, the albedo) is smaller in darker soils, inter-phase heat transfer between soil and the atmosphere must be affected favoring exothermic processes, probably favoring water condensation over the darker soils. In agreement with this, previous publications [21-25] indicate that rainfall would increase when albedo decreases, as seeing in **Figure 4**. This figure also suggests that savannas or

Figure 3. Albedo values: desert earth (left), terra-preta (center), pyrogenic carbon (right). Adapted from [8]

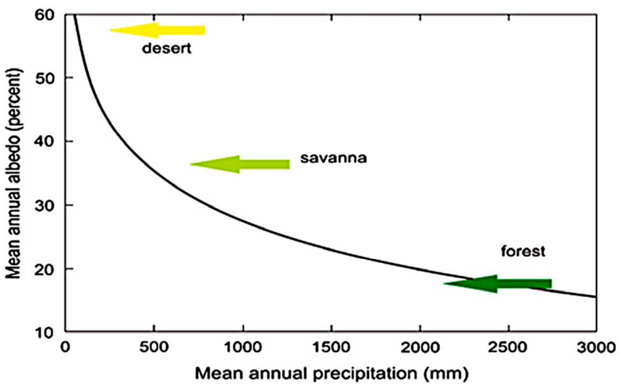

Figure 4. Albedo—Rainfall correlation. Adapted from [22, 23].

grasslands could be considered as a starting point for either desertification or afforestation; assuming that these land changes are mainly influenced by rainfall decreases and increases respectively. Accordingly, one may assume that if the yellow tone of an arid zone is converted into a darker one by covering or mixing the soil with pyrogenic carbon, this zone would experience rainfall increases improving vegetable life. Afterwards, the zone converted into green should produce, by albedo decrease also, more rainfall than its parent yellow one. Nevertheless, this issue needs more scientific evidence, particularly regarding the size area over which the albedo should be altered to create a noticeable effect in re-vegetation.

4. Closure

Desert greening is very difficult particularly due to irrigation requirements. Theoretically, improvement of rainfall as a result of albedo alteration by land application of pyrogenic carbon would facilitate desert greening, but experimental confirmation in large geographical areas will be necessary. The proposed application of coke for desert greening is favored by the fact that the exploitation of low H/C ratio fossil hydrocarbon world deposits by-producing large amount of coke is expected to increase because of the exhaustion of the highly demanded light petroleum world reserves. Discouragement of industry because of burying a high BTU product could be offset if the presently proposed terra-preta-nova transformation is converted into a credit after carbon market consolidation in the global low-carbon revolution faced now.

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