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Alternatives of Use Agro-Industrial Wastes Focusing in Soil Improvement: A Review

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ABSTRACT

Family farming is responsible for providing a significant proportion of some specific crops in the worldwide. In steps of harvesting and industrial processing, are produced large quantities of residues, which are called agro-industrial waste that generally are discarded in landfill. They are rich in lignocellulosic material, which represents a cheap and available feedstock in a great amount. Different processes can be used for their return to the soil, such as composting, fertilizers, biochar, among others. This contributes positively to soil fertility and yield of crop, besides having a beneficial effect to the environment. These residues are formed by straw, cob, husk and bagasse, which are usually directed to the animal feed production, or pass through the burning, with the polluting gases generation. This work aims to show up the main generated wastes and evaluate the different alternatives for their use on soil.

Keywords: Residues, Waste, Agro-industrial, Soil, Bioremediation, Family farming

INTRODUCTION

The Food and Agriculture Organization [1] defines family farming as "a mean of organizing agricultural, forestry, fisheries, pastoral and aquaculture production which is managed and operated by a family and predominantly reliant on family labor, including both women's and men's. The family and the farm are linked, co-evolve and combine economic, environmental, social and cultural functions" [2]. Otherwise, the Brazilian legislation considers the family farmer as a producer who does not have an area bigger than four fiscal modules; predominantly uses family labor for the activities; has a minimum percentage of the economic activities originated from their establishment or enterprise; and manages it with their family [3] Fiscal module was established in Brazil by Law n. 6.746 of December 10th, 1979, which has defined the minimum size of land economically viable by family unit. This is an agrarian unit of measure which varies geographically from 5 to 110 hectares depending on where the farm is located [4].

It is estimated that about 98% of all farms are managed by families [5], besides being responsible for providing 84% of the entire yam, rice, maize, cassava and beans produced in Fiji. In the United States of America (USA), family farmers generates 84% of all agricultural production [6] and in Brazil, these producers provide crops such as beans (67%), cassava (84%) and corn (49%) [5]. In addition, family farming contributes to the basic feeding of families, representing more than 60% of the food consumed by Brazilians [7].

According to Brazilian Geography and Statistics Institute, the main crops with destined areas for harvesting Brazil were soybean, corn, rice, wheat, cotton and beans, being the first one the crop with the largest production area [8]. Consequently, there is a high production of wastes that are generally not used, especially those generated both at harvesting and after the processing of the raw material in the industry.

Agro-industrial wastes represent an important source of lignocellulosic material; besides that increase soil microbial diversity; are a potential substrate available at low cost and are rich in beneficial plant nutrients such as Nitrogen (N), Phosphorus (P), Potassium (K) and Sulphur (S) [9,10]. In China, 700 million ton per year of agricultural residues are produced from different kinds of crops, like soybean, rice, wheat and corn, accounting for 20-30% of the worldwide production [11]. These wastes are defined based on their generation establishment and they may be composed by

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leaves, straws, cobs and stalks, which are known as agricultural wastes and also dreg, bagasse and husk/hull, being called industrial wastes [12]. Wheat, corn and rice straw reached around 600 million ton annual outputs in China. The worldwide cereal production is about 1.8 billion tons, which 500-600 million tons are from wheat, being the wheat straw represented by 170 million ton per year, which are mainly destined to burn [13]. Concerning to corn, the cob is the main residue from its harvesting. It is considered that about 20% of the total production of this vegetal comes from this residue [14]. Rice is the third most important crop in the world, behind only of the wheat and maize ones. During the grinding stage of this cereal, around 9 to 10% of bran and 20% of husk are produced [15].

Soybean is the crop with a largest production in the world. The USA is the major producers of this grain, followed by Brazil and Argentina. Its major byproduct is hull, which is obtained in processing (8-10% of grain) and during production of tofu or soybean milk, where are generated around 50% soybean dregs and after isolating soybean protein, around 30-40% of these residues are produced. Straw is another byproduct from soybean production, which is generated during the crop and this residue consists of stems, leaves and pods. Soybean straw has high polysaccharide content, but does not need an extensive grinding process before the pretreatment as other lignocellulosic material [14,16,17]. The main components present in the agro-industrial wastes cited above are detailed in **Table 1**.

Table 1. Main compounds on agro-industrial wastes.

Crops	Agro-industrial waste	Composition (dry weight)	References
Rice	Straw	Cellulose: 30.5% Hemicellulose: 21.1% Lignin: 19.7% Ash: 12% (mainly silica)	Nascimento et al. [89]
	Husk	Cellulose: 35% Hemicellulose: 25% Lignin: 20% Silica: 20%	Zhang et al. [90]
Soybean	Straw	Cellulose: 35.3% Hemicellulose: 16.9% Lignin: 21.7% Ash: 10.6%	Cabrera et al. [16]
	Dreg	Protein: 12.07% Fat: 5.52% Total Dietetic Fiber: 69.41% Ash: 3.06%	Qu et al. [17]
	Hull	Cellulose: 39.7% Hemicellulose: 25.5% Lignin: 9.1% Ash: 0.6% Protein: 13.1%	Cassales et al. [14]
Wheat	Straw	Cellulose: 30% Hemicellulose: 50% Lignin: 15%	Sinclair et al. [91]
Corn	Cob	Cellulose: 38.8%	Liu et al. [92]

		Hemicellulose: 36.4% Lignin: 13.1% Ash: 3.2%	
	Stalk	Cellulose: 39% Hemicellulose: 42% Lignin: 7.30% Ash: 24.9%	Daud et al. [93]
	Stover	Cellulose: 38.9% Hemicellulose: 28.6% Lignin: 16.2% Protein: 4.5% Ash: 4.8%	Templeton et al. [94]
Cassava	Peel	Starch: 47.16% Lignin: 1.92% Protein: 2.40% Ash: 6.30% Cyanide: 9.30 mg/kg	Bayitse et al. [95]

Considering that 76% of the daily generated wastes are deposited in landfills and 60% of this amount is composed by organic waste [18], the use of agro-industrial wastes as substrates in bioprocesses, besides being economically feasible, contributes to the environmental problems reduction and it can be considered a potential source for the creation of new products with economic and social interests [19]. It is clear that this subject is extremely relevant, and in this review will be presented and critically analyzed some strategies (fertilizers, composting, vermicomposting, soil conditioners, mulching, biochar and bioremediation with enzymes) for the promotion of the recycling of different wastes and also their application in soil recovery and as a soil enhancer.

FERTILIZER

According to British Columbia Ministry of Agriculture [20] fertilizers are products that contain a C/N rate below 20:1 and act by supplementing significant amounts of nutrients to improve crop productivity. Several agricultural and industrial wastes may be used as organic fertilizer, having a low cost of acquisition and a simple application in soil [21].

Its advantages to the soil includes: decrease C/N rates, better soil aggregate stability and residual N effects in the following years, besides influencing its microbiota, such as changes in the community of nitrogen fixing bacteria, methanotrophic and cellulolytic bacteria [22,23].

Agricultural residues can stimulate the microorganism's proliferation and improve the N fertilizers immobilization, besides presenting positive responses with the addition of corn residues in relation to soil immobilization with this nutrient for the crop [24].

The incorporation of rice straw into the soil shows positive effects, because of its C/N ratio, it still increases the microbial biomass and N mineralization in long term. The study showed that the mixture of peanut residues with the rice straw increased the productivity of the rice crop [25].

The bagasse and rice husk were analyzed and obtained positive results in the soil [26,27]. The relation between them increased productivity and the improved content of some plant essential nutrients, such as P and K, was also verified in the soil and culture, reducing the need for the application of external inputs, besides being a cheaper alternative [28]. In cereal straw such as corn and rice, for example, about 75-80% of the potassium is retained in these residues [29,30]. In addition, the excessive use of inorganic fertilizers causes the soil acidification, the microbial biomass reduction and its diversity [23].

Therefore, the use of organic fertilizers in cropping systems is the most viable option for farmers to keep their field in a productive state [31].

COMPOSTING

Agricultural residues are ideal for composting because they are rich in lignocellulosic components, which have been shown to be an important source of soil carbon and for contain low moisture content [32,33]. Composting is defined as a biological process, which can be natural or controlled, from raw materials of animal or vegetal origin and may be enriched with minerals or agents able to improve their physical, chemical or biological properties without forbidden substances by the organic rules [34] obtaining a stable compost which can be used as an amend in soil [35]. Through the microorganisms action the reduction from organic matter in simpler components happens, making them more accessible to the plant [36].

To assure an adequate composting, it is important to provide favorable conditions to the microbial activity, like pH, moisture, aeration rate and temperature, besides to substrate variable, like nutrient content, particle size and C/N rate, with duration about 180 days to complete the different process stages [36,37].

Some physicochemical parameters, such as the C/N rate ranging from 25-30, the moisture between 45 and 50%, pH next the neutrality and the porous structure must be found to ensure adequate composting [38].

During this process, there is a temperature increase, which can reach 70°C, promoting the pathogens elimination. Thus, there is the permanence from thermophilic microorganisms, responsible for the organic matter decomposition [39].

Soybean residues, for example, have an important property for composting. Most part of proteins (90%) present in soybean dreg are storage protein, which can increase the soil enzymatic activity and besides, be able to act by accelerating the organic matter decomposition [40]. The wheat straw as a suitable raw material for this process, since this residue was converted to an amendment in 75 days [41].

Thus, composting is considered an adequate method for the organic management waste, besides providing beneficial effects to soil and having a cheap operation cost [42].

VERMICOMPOSTING

Vermicomposting is a well-known process for utilization of organic waste. Vermicomposting and composting are widely used to produce manure for the soil and are an important source of nutrients to the plants [43]. The vermicompost is formed by the organic matter conversion into a manure rich in nutrient, carried out by the interaction between earthworms and microorganisms [10,44]. This has a high moisture retention capacity, contains minerals, auxins and cytokinins (hormones that act on plant development), improves soil structure and fertility, reduces its acidity, protects against erosion, increases its porosity and reduces the C/N ratio [10,45].

Compared to composting, the nutrient content is generally higher in the vermicompost, which is rich in nitrogen, potassium, phosphorus and calcium, there is a higher amount of nitrogen in the soil due to the great of nitrogen bioconversion process by earthworms and it needs to be conducted in a specific range of temperatures (25-40°C), in a high humidity (70-90%) to earthworm maintenance and this process takes around 261 days to finalize [46,47].

Cassava peel could be used for vermicomposting despite cyanide toxicity [48]. The incorporation from this residue (with a high phosphorus content) and charcoal showed beneficial results in improving soil nutrient status, through the input of phosphorus, besides providing an appropriate condition for earthworm development. In the study it was highlighted the ability of earthworms to reduce the cassava peel toxicity, producing a more adequate vermicompost [49].

Wheat and millet straw and reused them was used for the production of a vermicompost. The final product presented an increase in the N, P, K and Calcium (Ca) contents and reduced the organic carbon content, indicating that they are good substrates for conversion by this process [50].

The straw and the rice husk was compared, evidencing that the rice straw obtained better results, as much in relation to the amount of nutrients in the compound as in the earthworm biomass [51]. In another study the quality of the vermicompost formed from different agricultural residues (sugarcane, soybean, sorghum, peas, wheat and sunflower) was analyzed. Among the different vermicompost, soybean residue was the one with the best quality, with high levels of N, P and K [52].

Residues of rice, wheat and maize were analyzed. The wheat residues resulted in a biomass with greater weight (50%) and rice with higher yield of grains planted with the vermicompost, obtaining different results varying according to the agricultural residue used [53]. In another study, different agricultural residues (cow manure, elephant manure, coconut husk, watermelon husk, soybean meal and ground coffee) were evaluated for vermicompost and earthworm biomass production, being the vermicompost of the soy residue the highest quality and with the highest biomass [54]. Vermicompost application has better responses regarding the physical, chemical and soil fertility properties [55].

SOIL CONDITIONERS

The conditioners give the soil the physical properties which are necessary to enable the proper plant growth aiding in its structural stability. A soil with a good structure must present some characteristics, including: porosity, permeability, friability and nutrient flowability, which allow an adequate growth of the plant and prevention against erosive processes. In addition, to be considered as soil conditioner the product must contain a C/N rate greater than 30:1 [20,56].

They may be made of synthetic or natural origin and materials such as manure, green manure, humic substances, peat, leaves and inorganic materials including gypsum, sulfur and hydrophilic polymers such as hydrogels [57-59]. Hydrogels can be produced from polysaccharides, which are biodegradable and non-toxic to the environment, becoming a suitable form for use in soil; however, other materials can be used for their production, such as acrylamide [60,61]. In a study, a hydrogel was produced with rice husk and polyacrylamide, which resulted in an improvement of the water retention in the presence of the residue and proved be adequate to be used as soil conditioner [62].

Nevertheless, it has been seen in many studies that residues such as rice hulls have been used with the aim of improving some soil properties, such as density, porosity and moisture retention, which resulted in a higher productivity of crop added with this residue [63,64].

Humic acids and biochar are products that can also be used as soil conditioners. Humic acids are produced by chemical and biological decomposition of organic matter, are biodegradable, less expensive, yet have influence on crop growth and yield. These are formed during the soil humification process [65,66].

Rice husk can act as a biosorbent. Considering this property, this residue was used in a study with the purpose of removing humic compounds in peat swamp waters, where there is a great presence of them [51]. This rice husk demonstrates to be an approach for the treatment of contaminated water and agriculture [67].

Therefore, the addition of these components can promote an efficient improvement of the soil, being possible to use the residues generated in agriculture with this function, improving its quality and protecting against erosive processes, besides being an environmentally correct practice [68,69].

MULCHING

Mulching is a strategy for residues retention above the soil after harvesting the crop. It is considered a soil management sustainable technique that forms a physical barrier, acting in the retention of soil moisture, improvement of the structure, erosive process control; weed growth suppression, organic matter increase and carbon and nitrogen contents; and reducing the need for external inputs [70,71]. Besides that, the presence of pores in the soil contributes to the water drainage capacity increase [72].

To provide effective protection against soil erosion processes, the soil should have 30% to 50% of its area covered by residues [20]. This practice can be done using synthetic or natural materials such as polyethylene, paper and agricultural waste. Although plastic sources are considered low cost, their use for this purpose presents difficulties in their complete withdrawal from the field [73]. Different types of mulch, including rice husk and polyethylene; was evaluated. The residues presented better results in relation to soil moisture and temperature maintenance; the plastic had an impact on the temperature rise and may have a negative influence on the plants growth [74].

The type of residue applied as mulch can have a significant influence on soil carbon retention [70]. The use of maize residues for this purpose, for example, promotes a reduction in soil pH, mainly due to the carbon dioxide presence (CO_2) of the microbiological activity, resulting in greater availability of nutrients and higher crop yield planted later [75]. Mulching of corn and rice promoted an increase in crop growth rate and yield corn grains and also suppressed the weeds development [76]. Soil residue retention shows an improvement in moisture content and nutrient storage, increasing yield from maize crops by 37% [77].

Its use is inexpensive and easy to perform, since different agro-industrial residues can be used, such as rice husk, sugarcane bagasse, coffee husk, among others, favoring the development, increase of productivity, availability of nutrients, organic matter and nitrogen [78,79].

BIOCHAR

Another alternative for the management of agricultural residues is the production of biochar (thermally converted biomass) and its use as soil fertilizer [80]. Biochar is a carbonized substrate, produced from the thermochemical decomposition of the biomass (pyrolysis) in a limited oxygen environment. When applied to soil, it can improve water and nutrient retention capacity, pH, reduce density, increase carbon content and can also be used for soil remediation, improving microbial activity and plant-soil interaction, besides acting as a soil carbon sequestered [81,82]. However, its cost is high because of the high industry demand and energy expenditure [82].

Pyrolysis is a thermochemical decomposition process that can be used for the generation of gas (biosyngas), bio-oil and biochar, the first two being biofuels and the last ones used as fertilizer in the soil. In this process the biomass is heated between 400 and 900°C in the absence of oxygen [24].

Conversion of raw materials and agricultural residues available locally into biochar may also be important in smallholder systems and their use may have applications in agricultural production. Pruning residues, agricultural residues and fruit peels are what lead to increased biochar formation [40]. Generally, charcoal is used as feedstock, but woody materials, agricultural residues and animal manures can also be used [83].

The incorporation of biochar in the soil can be used as a conditioner to improve its fertility due to its high capacity of retention of water and nutrients [84]. In a study, the addition of biochar to the raw material of the compost had an impact on reducing carbon emissions and also resulted in a higher plant growth medium compared to unmodified compounds, that is, without the addition of biochar [85]. Rice husk and wheat straw presented a high production of biochar and carbon content [86] and maize stalks were used in another study, obtaining positive results in relation to the increase of carbon sequestration [87]. Besides that, wheat straw biochar resulted in a product rich in N, P and K and can be used to improve soil fertility and plant growth in limestone [88].

In **Table 2**, the main advantages and disadvantages of the different strategies to use the agroindustrial wastes mentioned above are detailed.

Table 2. Characteristics of the different strategies to use the agro-industrial wastes.

Strategies to use the agro-industrial wastes	Characteristics	References
Fertilizer	[A] Cheap method [A] Simple application [D] Low content of nutrients [D] High amount of material used to be efficient	UFLA [96]
Composting	[A] Low cost processing [D] Long duration to transformation of material [D] Nitrogen as a limiting factor	Arvanitoyannis and Tserkezou [97]
Vermicompostig	[A] High content of humus [A] Have all nutrients necessary to plant [D] Long duration to transformation of material	Kokhia [98]
Soil Conditioer	[A] Wide choice of materials	Liu et al. [57] Zia-Ur-Rehman et al. [59]
Mulching	[A] Erosive process control on soil [A] Suppression of weed growth	Koucher et al. [71]
Biochar	[A] Uses less oxygen [A] High content of nutrients [D] High cost [D] High necessity of energy	Latawiec et al. [81] Pereira et al. [82]

[A] *Advantages;* [D] *Disadvantages*

CONCLUSION

As seen, the agro-industrial wastes are potential sources of renewable biomass, demonstrating beneficial in soil quality and their crop productivity, as well as being a cheap source and rich in important nutrients for the soil like P, C, N and lignocellulosic material. The strategies demonstrated in this work presents a potential use these residues in soil, showing different forms to take advantage some residues and a significant amount of works confirming the relevance from your utilization. The strategies have different process of treatment and some require a bigger energy use, such as biochar and therefore have a high cost or as the composting that has a larger period to transformation the organic matter in an amendment. So, the choice to management of these residues must be done thinking about the time, cost and desired effect with this.

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