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Review Article

A Review of Compost Produced from Biological Wastes: Sugarcane Industry Waste

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Abstract: Morocco is one of the largest growers of sugarcane with an estimated produced of around 500.000 tons in the marketing year 2014 due to the increase in the area sown sugar beet who spent 35,000 ha during the campaign 2012-2013 53,000 ha for 2013-2015 campaign. Composting is an efficient method of waste disposal, enabling recycling of organic matter. Composting is one of the most promising technologies for solid waste treatment. The organic substrates in solid waste can be biodegraded and stabilized by composting and the final compost products could be applied to land as the fertilizer or soil conditioner. The present review paper deals with the following topics: Composting, Composting of pollutants and various industrial wastes, Physical and chemical nature of raw pressmud, Biochemical changes during composting, Microbial enzymes and composting, Factors controlling composting and Characteristics of the compost and its application in agriculture.

Keywords: Composting Process, Morocco, Sugar Industry Waste, Bacteria and Fungi, Degradation of Hemicelluloses

1. Introduction

Agriculture is the root of human civilization. Parallel with the advent of industrialization and urbanization, agro-industrialization is also an inevitable phenomenon in human civilization. Some countries mainly depend on agriculture supportive industrialization.

Morocco produces on average of 500.000 tons of sugar-cane per year [1]. During the production process considerable amounts of by-products such as pressmud, bagasse and sugar–cane residue are produced part of these by-products can be utilized for the production of molasses and alcohol; however, there still remains a considerable amount of waste to be disposed. Therefore, there is considerable economic interest in the technology and development processes for effective utilization of these wastes [2]. As a result emphasis is now on aerobic composting, that converts wastes into organic manure rich in plant nutrients and humus [3] biodegradation of lingo-cellulosic waste through an integrated system of composting with bio-inoculants and vermicomposting have been studied [4-6].

Currently, the major methods of waste management are; a) recycling the recovery of materials from products after they have been used by consumer, b) composting an aerobic, biological process of degradation of biodegradable organic matter, c) sewage treatment a process of treating raw sewage to produce a non-toxic liquid effluent which is discharged to rivers or sea and a semi-solid sludge, which is used as a soil amendment on land, incinerated or disposed in a landfill d) incineration a process of combustion designed to recover energy and reduce the volume of waste going to disposal and e) landfill the decomposition of waste in a specially designated area, which in modern sites consist of a pre-constructed 'cell' lined with an impermeable layer (mam-made or natural) and with controls to minimize emissions [7].

The composting process always occurs in nature, however, many artificial measures have been developed to improve composting efficiency. Over the past decades, effective inoculation has been reported by several researchers. Various specialized inocula have been applied in practice. For example, Knežević et al. [8] studied the lignin-modifying enzymes from selected white-rot fungi that white-rot fungi played an important role in lignin degradation. Stanford et al. [9] reported that a thermophilic bacterium, *Bacillus licheniformis*, could effectively decompose protein and prevent the drop of pH values during composting; thus, it could stimulate proliferation of other thermophilic bacteria.

Rudnik [10] revealed that inoculation could increase the microbial population, formulate beneficial microbial communities, improve microbiological quality and generate various desired enzymes; and thus enhance the conversion of organics and reduce odorous gas emissions. The studies of Lei [11] indicated that the inoculated microbial populations and indigenous populations would evolve continuously, leading to variations during different composting stages. This could result in difficulties in describing the relevant inoculation mechanisms. It also indicated that inoculation did not significantly raise the rate of temperature increase, but did increase the time the composting high temperature remained. Chen et al. [12] also studied the enhancement of composting efficiency by adding solid and liquid inoculants. However, the inoculation efficiency was usually affected by competition with indigenous microorganisms. The composting system may not have the desired performance due to improper process operations. For instance, Steven Donald Ming [13] completed a study on microbial inoculation with mixed cultures of Bacillus sp., *Trichoderma reesei* and *Trichoderma harzianum* in composting fish wastes. The inocula, performed well overall but were not always significantly better than the controlled compost piles, depending on the season and combination of inocula.

Composting provides a good model of microbial communities to study ecological issues such as diversity succession and competition during the biodegradation and bioconversion of organic matter with thermal gradients. The typical batch composting process proceeds via four major thermal stages, i.e., the mesophilic, thermophilic, cooling and maturation phases, each of which has a particular microbial community structure developing in response to temperature and other environmental conditions. In the first stage, organic substances are decomposed by mesophilic microorganisms at moderate temperature. Then, the temperature is increased by self-heating as a result of vigorous microbial activity. In the thermophilic phase, the temperature reaches 80°C, which not only stimulates the proliferation of themophilic microorganisms, including mesophilic pathogens. After the themophilic progression of waste decomposition, the microbial activity lowers due to the limited availability of degradable organic substances. This cooling phase leads to a decline of temperature and allows mesophilic microorganisms to predominate again.

Composting converts organic matter into a stable substance which can be handled, stored, transported and applied to the field without adversely affecting the environment. Proper composting effectively destroys pathogens and weed seeds through the metabolic heat generated by microorganism during the process [14, 15]. Such composts are not only suitable for use as a soil conditioner and fertilizer, but can also suppress soil-borne and foliar plant pathogens [16].

Composting is a well-known system for rapid stabilization and humification of organic matter [17, 18]. As well as an environmentally friendly and economical alternative method for treating solid organic waste [19]. During composting, readily degradable organic matter is used by microorganism as a source of C and N. The end product (Compost) consists of transformed, slowly-degradable compounds, intermediate breakdown products and the cell walls of dead microorganisms, which are classified together as humic substances (H_2S). Numerous biological, microbiological and physic-chimical techniques have been developed to characterize the agrochemical properties and the maturity of compost.

This review outlines some important discoveries with regard to Composting of Waste Sugar Cane and Press Mud Mixtures, biochemical changes during composting organic matter decomposition, and also the factors affecting composting.

2. Why Composting

Composting is the controlled microbial bio-oxidative process involving biodegradable organic matter, conducted under controlled environmental conditions. The oxidation produces a transient thermophilic stage which is followed by a period of cooling of the now degrading organic matter. The material is held at ambient temperatures for maturation purposes which results in a stable, volume reduced, hygienic, humus-like material—the compost—that has retained mineral elements beneficial to soil and plants [20].

Compost is the product of the controlled microbial degradation of heterogeneous organic matter into a safe and beneficial humus-like material. Emphasizing a "controlled" process distinguishes composting from "uncontrolled" rotting or the simple putrefaction of organic matter. Furthermore, bio-oxidative metabolism of the microorganisms involved ensures that the bulk of the biodegradable carbonaceous matter will be dissimilated completely to CO_2 and water. Other components or organic matter, such as nitrogen and sulfur, will be assimilated into microbial cell mass, only to be liberated again after the cells die and degrade [21].

The oxidative metabolism of microorganisms is exothermic, and the heat produced is sufficient to increase the temperature of organic matter to between 60 and 75°C over a period of up to 10 days. This so-called "thermophilic stage" offers a self-sanitizing mechanism by which pathogens, seeds and heat-labile microbial and plant toxins (phytotoxins) will be destroyed (Figure 1). Not all organic matter will be degraded completely. For example, lignin in plant material will be modified and become part of the final stable product. These modification processes are slow and occur during the maturation stage. The final humus-like material, the compost, is a dark, crumbly, earthy material usually containing less than 2% (w/w) each of nitrogen, potassium, and phosphorus (N:P:K). When applied to soil, these minerals are available to plants while at the same time the compost offers improved soil structuring characteristics (conditioning) [22].

The related process of vermicomposting (i.e. composting which involves the use of earthworms to act in conjunction with aerobic microorganisms (bacteria, actinomycetes, and fungi) to bring about the bio-oxidation and subsequent stabilization of biodegradable organic matter) is also finding increasing applications on a large scale.

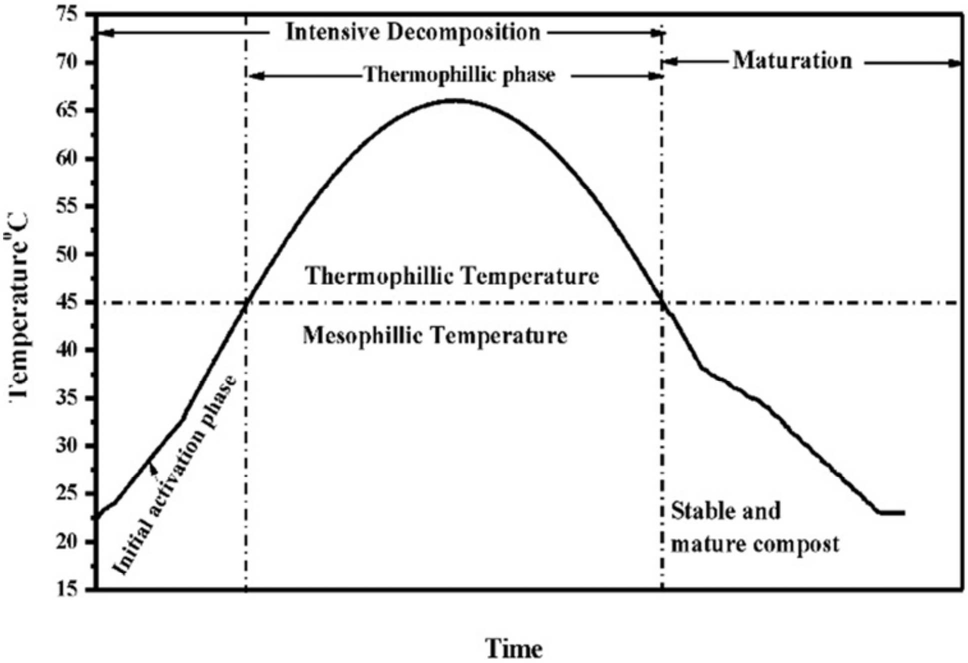

Figure 1. The different phases of the composting process.

3. Composting of Industrial Wastes

The past 200 years has seen a rapid increase in populations worldwide resulting in the need for even greater amounts of fuel and development of industrial chemicals, fertilizers, pesticides and pharmaceuticals to sustain and improve quality of life [23]. Although, many of these chemicals are utilized or destroyed, a high percentage is released into the air, water and soil, representing a potential environmental hazard [24]. Environmental pollution has become unacceptable for technological societies as awareness of its effects on the environment has increased. Unfortunately, it is not possible to replace all the industrial processes generating polluting wastes with clean alternatives. Therefore, treatment both at source and after release, whether accidental or not, must be considered as alternatives in many cases [25].

Composting, the biotransformation of organic matter, minimizes or even eliminates such risks by means of the biological and physicochemical conditions that exist during the process. Biological activity leads to high temperatures that can destroy pathogens if it lasts long enough [26] and to the decomposition and transformation of organic components into stable humic substances [27]. The production of antimicrobial compounds may contribute to this activity as well. On the other hand, several authors describe a limitation in the bioavailability of pollutants such as heavy metals or pesticides throughout the composting process [28].

Composting is an aerobic process that relies on the actions of microorganisms to degrade organic materials, resulting in the thermogenesis and production of organic and inorganic compounds. The metabolically generated heat is trapped within the compost matrix, which leads to elevations in temperature, a characteristic of composting [29]. Odukkathil and Vasudevan [30] divided the composting process into four major microbiological stages in relation to temperature. With these changes in temperature, there are related changes in the structure of the microbial community. With increases in the respiratory activity, there is an increase in temperature resulting in a decrease in mesophilic microbes and an increase in thermophiles and it is at these higher temperatures that most of the microbial decomposition takes place. In the third phase, there is a cooling effect due to the decrease in microbial activity as most of the utilizable organic carbon has been removed, resulting in an increase in mesophilic microorganisms.

It is important to differentiate at the onset the dissimilarity between compost and composting [31]. Composting is the process by which compost is produced, i.e. the maturation of, for example straw and manure [32]. Compost is the resultant product of composting, with the exception of horticultural potting composts. Thus, a composting bioremediation strategy relies on the addition of compost's primary ingredients to contaminated soil, wherein the compost matures in the presence of the contaminated soil. In contrast, compost can be added to contaminated soil after its maturation. These distinct approaches are discussed separately [4]. Because of the above characteristics, composting is considered the most suitable technique for transforming organic wastes into usable agricultural amendments.

Raju et al. [33] assessed the physicochemical and cellulase activity in waste dump sites. The experimental results indicated that, most of the physicochemical properties such as silt, clay, electrical conductivity, water holding capacity, organic matter and total nitrogen contents, microbial population and cellulase activities were significantly higher in the test sample than in the control. Furthermore, though the application of effluents substantially increased the cellulase activity, but was declined at high effluent concentration. Nevertheless, enzyme activity was gradually dropped upon prolonged incubation period in all three samples, such as control, test and effluent a mended samples.

Namita Joshi et al. [34] analyzed the physical and chemical characteristics of raw pressmud, its compost prepared by using thermophillic bacteria and it's vermicompost which is prepared by using species Eisenia foetida. while comparing physical and chemical characteristics, it was found that vermicompost have lower temperature, water holding, pH and carbon content but higher electrical conductivity, available phosphorus and moisture content as compared to raw pressmud and its compost.

Bhosale et al. [35] tested the physical and chemical characteristics such as pH, NPK organic carbon, organic matter, moisture content etc. of raw pressmud as well as pressmud from which the wax is extracted by solvent recovery. It was found that the water holding capacity of soil containing dewaxed pressmud was high as compared to waxed pressmud and in the range of 58.39 to 92.43% in the dewaxed pressmud where as for wax containing pressmud it was 49.39 to 86.63%. The C: N ratio of dewaxed pressmud was high and was 18.54% as compared to that of waxed pressmud. The composting processes improve the physical structure and lower the C: N ratio of the pressmud and leads to reduction in C: N ratio i.e. 16.53% of dewaxed pressmud after composting.

4. Physico-Chemical Nature of Raw Pressmud

Pressmud or filter cake, a waste byproduct from sugar factory is a soft, spongy, amorphous and dark brown to brownish material which contains sugar, fiber, coagulated colloids, including cane wax, albuminoids, inorganic salts and soil particles. The composition of pressmud was found to vary depending upon the quality of cane and process of cane juice clarification. There are two processes, i.e., carbonation and sulphitation by which the cane juice is cleaned before its conversion to sugar crystals. Sulphitation processed pressmud being organic in nature could serve as a store house of macro and micro nutrients and the chemical analysis showed an organic carbon of 35- 37 per cent, 1.0 to 1.5 per cent nitrogen, 2.5-3.5 per cent phosphorus and 0.5-0.8 per cent potash [36]. Pressmud contains many valuable micronutrients. When this material is digested under anaerobic condition, the lignin, cellulose and waxes are converted to release micronutrients from pressmud that are freely available for plant growth [37].

Singh et al. [38] compared the nutritive value between sulphitation and carbonation processed pressmud cakes and reported that the nitrogen, phosphorus and potassium contents in sulphitation processed pressmud cane were 2.43, 2.95 and 0.44 percent. While carbonation processed pressmud cake contained 0.88, 0.93 and 0.53 per cent of N, P and K.

Dotaniya et al. [39] found that the pressmud obtained from both carbonation and sulphitation processes was alkaline in nature. The organic carbon content of pressmud obtained from carbonation process was low (15.07%) as compared to that from sulphitation processed (26.0%). Nitrogen, phosphorus and potassium contents of sulphitation filter cake were 2.38, 2.62 and 0.62 per cent respectively, whereas carbonation process cake contained 0.86, 1.02 and 0.60 per cent N, P and K respectively.

According to J. Benton Jones Jr. [40], the quantity of pressmud available in Tamil Nadu was around 6.83 lakhs tonnes. Earlier this material was dumped in heaps in the vicinity of sugar factories since its use was not known. Various authors [41] have reported the usefulness of pressmud as valuable organic manure.

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5. Biochemical Changes During Composting Organic Matter Decomposition

When organic materials are biodegraded in presence of oxygen, the process called aerobic composting [42]. During aerobic condition, living organisms utilize oxygen, decompose organic matter and assimilate some of the carbon, nitrogen, phosphorus, sulphur and other elements for synthesis of their cell protein. Carbon serves both as an energy source and for building protoplasm and a greater amount of carbon is assimilated than nitrogen. A great deal of exothermic energy is released during the oxidation of carbon to CO.

The overall reaction likely to occur during aerobic composting maybe represented as follows (Figure 2).

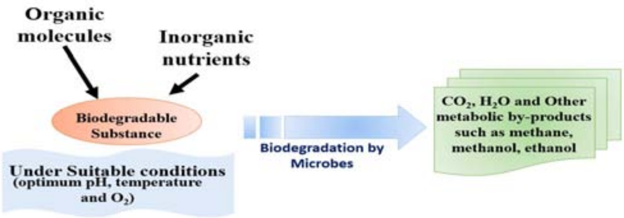

Figure 2. *Aerobic biodegradation of organic matter.*

5.1. Cellulose Degradation

Cellulose is a basic component of all plant materials and its production exceeds that of all other natural substances. Plant residues in soil consist of 40-70 per cent cellulose. Cellulose is made up of chains of β-D-Glucose consisting of about 1900 glucose units (monomers) (Figure 3). The enzymatic cleavage of cellulose is catalyzed by cellulases. The cellulase system consists of at least three enzymes viz., Endo -1, 4 glucanases, Exo- 1,4 glucanases and -glucosidases.

Cellulose is degraded and utilized well in aerated soils by aerobic microorganisms. The fungi play a significant part in the degradation of cellulose under aerobic condition. They are more successful than bacteria in acid soils and in the degradation of cellulose embedded in lignin. The fungi actively involved in cellulose degradation are species of Fusarium, Chaetomium, Aspergillus fumigatus, Aspergillus nidulans, Botrytis cinerea, Rhizoctonia solani, Trichoderma viride and Myrothecium verucaria.

Cellulolytic microorganisms are commonly found in the field and forest soil in manure and on decaying plant tissue. They include both aerobic and anaerobic fungi and bacteria, many of which grow under extreme conditions of temperature and pH. Among the fungi, white-rot, brown rot and soft-rot fungi are more capable of degrading cellulose materials. The enzyme mechanisms involved in cellulose degradation have been well studied by Van Bogaert et al. [43]. Some cellulose materials are associated with lignin and hence they also become somewhat recalcitrant and resistant to bioconversion. The crystalline cellulose was found to be a superior carbon source for induction of cellulase enzyme in thermophilic fungi than its amorphous or impure form. Yang et al. [44] stated that in addition to the crystalline and amorphous regions, cellulose fibers contain various types of irregularities, such as kinks of twists on the micro fibrils or voids such as surface micro pores, large pits and capillaries.

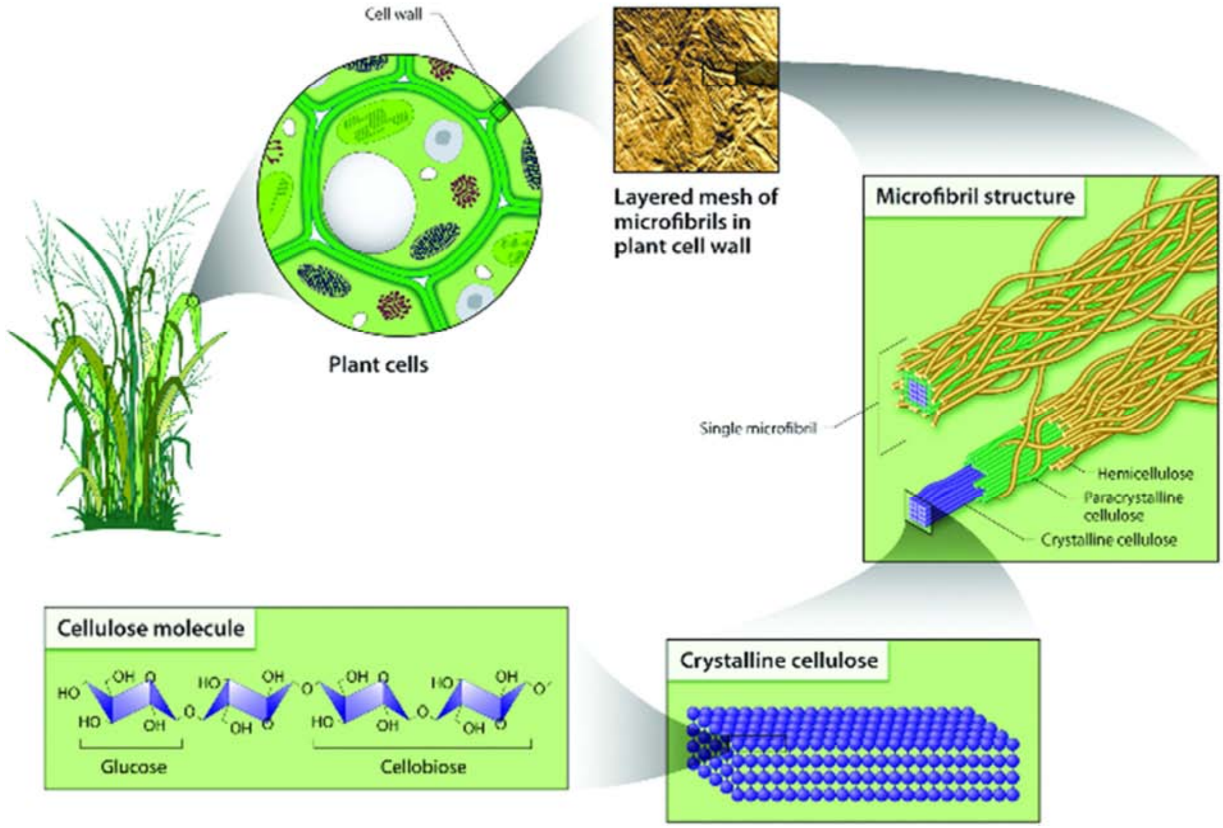

Figure 3. *Structural organization of the plant cell wall. Cellulose is protected of degradation by hemicelluloses and lignin. Source: Office of Biological and Environmental Research of the U. S. Department of Energy Office of Science.*

5.2. Degradation of Hemicelluloses

Hemicelluloses are a complex group of cell wall polysaccharides. The hemicellulose is acted upon by a group of enzymes known as hemicellulases. The hemicellulases complex consists of the enzymes viz., xylanases, arabinases, galactanases and mannanases. Wide array of glucosidases are involved in the breakdown of the non-cellulosic structural polysaccharides of the plant cell wall.

Hemicellulose includes xylan, mannan, galactan and arabinan as main heteropolymers. Xylan contains D-xylose as its monomeric unit and traces of L-arabinose. Galactan contains D-galactose and mannan is made up of D-mannose units while arabinan is composed of L-arabinose (Figure 4). The capacity to degrade these carbohydrates present in the major fungal groups includes the members of the classes, Deuteromycetes, Phycomycetes, Ascomycetes and Basidiomycetes. Pleurotus sp. are known to colonize and degrade a variety of lignocellulosic materials including crop residues and improve their food, feed and fuel value. Rajarathanam et al. [45] studied the decomposition of hemicellulose in soil and reported that any process increasing the surface area of the debris before its incorporation into the soil increased the decomposition rate. They have observed that incorporation of hemicelluloses into soil resulted in approximately 70 per cent of the carbon being evolved as CO after 48 days incubation, whereas fine grinding of the hemicellulose prior to incorporation increased the decomposition to 80 per cent.

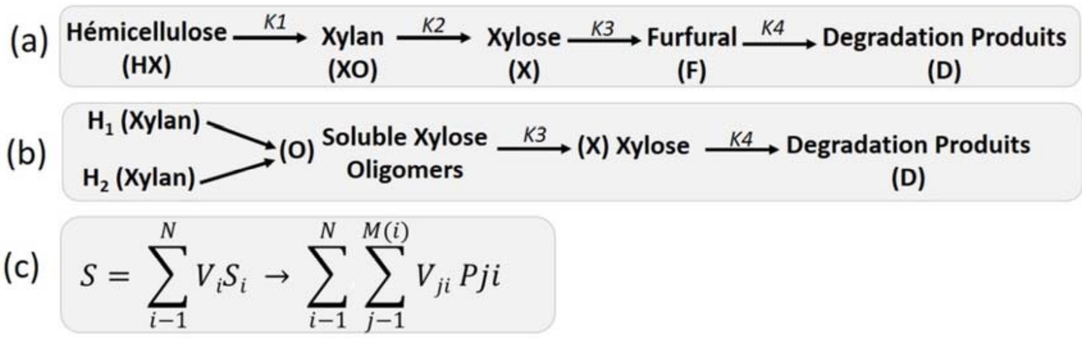

Figure 4. *Mechanisms for degradation of hemicelluloses during acid pretreatment.*

(a) Accounts for the formation of furfural and from there other degradation products (Morinelly et al., 2009) (b) Accounts for different hemicelluloses hydrolysis reactivities (fast and slow) (Chen et al., 1996; Esteghlalian et al., 1997; Grohmann et al., 1985; Lee et al., 2000; Schell et al., 2003) (c) lumped system approach. A reaction system (S) is composed of N subsystems producing M final products P.

The models in Figure 4b, reported activation energies in *k1* and *k2* varied between 50 and 250 kJ $kmol^{-1}$ depending on the reactor employed and the feedstock used. The highest values were reported for continuous reactors at pilot plant scale using corn stover and the lowest for wheat straw in a batch reactor. High activation energies may serve as an indication that the system follows a chemical reaction-limited kinetics rather than a mass transport limited kinetics. Some interesting conclusions from the diverse dilute sulfuric acid kinetic studies are: (i) xylose yields are favored at high temperatures and short times; (ii) selectivity defined in terms of either Arrhenius constants ratios or activation energies ratios shows that high temperatures have an enhancing effect on the hemicelluloses breakdown to oligomers (i.e., in Figure 4a, $E1/E2 > 1$), however, the hydrolysis of oligomers is less favored than the formation of degradation products (i.e., in Figure 4a, $E2/E3 < 1$); (iii) high solids concentration is desirable because in addition to help the process economics, less degradation of xylose to furfural is obtained, and these solids act as a barrier that protects monomers from degradation, though the main drawback of is slow reaction rates; (iv) total carbohydrates yields are lower at pilot scale than they are in laboratory scale, demonstrating the importance of pilot plant scale measurements in the scaling up of the process; (v) countercurrent shrinking bed reactors result in solubilisation of both cellulose and hemicellulase, but selectivity of desired monomers is better than with other reactors because of lower residence times; and (vi) no direct comparisons among different studies can be made due to important differences in reaction conditions.

5.3. Degradation of Lignin

Lignin comprises 20 to 30 per cent of the dry weight of vascular plant. The lignin molecule contains only three elements viz., carbon, hydrogen and oxygen but the structure is aromatic rather than being of the carbohydrate type as typified by cellulose and hemicellulose. The molecule is a polymer of aromatic nuclei with either a single repeating unit or several similar substances as the building blocks. Lignin is linked to cellulose and other carbohydrate polymers. As such lignin carbohydrate complexes limit both the rate and proportion of carbohydrate digestion by microbes, particularly under anoxic condition. The economic applications of microbiological process for producing solvents, alcohols and methane from biomass requires, among other things, that rapid and complete substrate under anaerobic conditions.

Menardo et al. [46] showed that pretreatment of biomass with alkali at high temperature greatly increased its digestibility and gave increased yields of methane. During subsequent fermentation, chemical analysis of lignin subjected to heat and high pH showed that simple aromatic compounds were released by the treatment and such compounds were readily metabolized to methane by populations of anaerobic bacteria.

Degradation of lignin and related compounds by microorganisms has been studied extensively with an expanding range of organisms known to have this property. In particular, fungi classified as white rot under Basidiomycetes and Deuteromycetes are well known to degrade lignin. Some bacteria are also known to degrade lignin completely, acting synergistically with fungi. The oxidative pathways of lignin degradation by such aerobes have been reported by Guerriero et al. [47].

Microbial Enzymes and Composting: Composting is an effective organic matter degrading process when the appropriate conditions for microbial activity are given. It is a well known fact different types of microorganisms dominate as degradation proceeds [15]. Pressmud is a solid waste by-product from sugar industry. The value of pressmud as an organic manure has been well recognized for utilizing in agriculture as it contains valuable plant nutrients and besides being very effective soil ameliorant [48]. However, pressmud and other lignocellulosic materials are not easily degraded due to the lignin, crystalline and structural complexity of cellulose matrix [49]. Therefore, many treatments have been tested to improve the susceptibility of lignocelluloses through chemical, enzymatic and microbial degradation and alkali, steam and acid treatments are few of the most commonly used pretreatments on lignocellosic materials to increase the sugars, the enzyme, the enzyme activity and biomass yields and the digestibility of the substrate [50].

Pressmud can be degraded by variety of microorganisms such as bacteria, fungi and some actinomycetes. Primary decomposition of pressmud is carried out by mesophilic populations using available simple sugars and the metabolic energy is dissipated as heat, temperature increases up to the thermophilic range from 40 to 70°C. A second group of organisms capable of degrading polymers and utilizing intermediate fermentation products becomes active during this themophilic period. The proper composting process in which, conditions were provided for adequate transfer of oxygen inside the piles was became a good quality compost [51].

Van den Brink et De Vries [52] reported hydrolytic enzyme production by nonsporic isolates of Phoma enigue and Graphium penicilliodies obtained from Phaseolus aureus and Cyamopsis tetrgonolobus. Gupta et al. [53] reported the production of pectinolytic and cellulolytic enzymes during growth stages of Phellorina inquinans. Cellulolytic enzyme systems are produced by a number of different types of microorganisms, such as aerobic bacteria, mesophilic and thermophilic fungi on wide spectrum of lignocellulosic substrate such as wheat straw [54], baggase [55], pretreated wood [56]. Of all the cellulolytic organisms, fungal cellulolytic enzyme systems have been well studied with respect to their components, induction and secretion, molecular biology and their structure [57].

Maheswari et al. [58] reported that the thermophilic fungi produce multiple forms of the cellulose compounds. However, two different strains of Thermoascus auranticus produced one from each of endoglucanase, exoglucanase and -glucosidase, but it forms the two strains had somewhat different properties. The multiplicity of individual cellulose might be a result of post translational and for post secretion modifications of a gene product or might be due to multiple genes. The endoglucanase of thermophilic fungi were thermostable with optimal activity between 55°C and 80°C at pH 5.0-5.5 and carbohydrate count of 2-50 per cent. The exoglucanase were optimally active at 50-75°C and are thermostable.

The major hemicellulosic constituents of pressmud residues are the hetro-1,4-xylans. The hydrolysis of the xylans in these residues requires the participation of xylanases as well as cellulases and -glucosidases. Many organisms are known to elaborate extracellular xylanases during growth on cellulosic residues. A mixed culture process has enhanced cellulose and xylanase production under the optimal fermentation conditions [59]. The capabilities of the xylanolytic systems of different organisms to remove the substituents of the xylan backbone (acetyl, arbinosyl and 4-methyl glucuronosyl groups) were variable. Trichoderma reesi culture filtrates contained all of these enzyme activities [60].

Mishra et al. [61] reported that multiple forms of xylanases differ in stability, catalytic efficiency, absorption and activity on substrates. A possible role for the production of xylanase isoenzymes of different molecular size might be to allow their diffusion into the plant cell walls of highly variable structures. The majority of xylanases have pH optima were ranging from 4.5 to 6.5. Thermoascus auranticus and Thermoascus lanuginosus were optimally active at 70 to 80°C.

Maheswari et al. [58] reported that xylanases of thermophilic fungi are receiving considerable attention because of their application in bioleaching of pulp in the paper industry, wherein enzymatic removal of xylan from lignin-carbohydrate complex facilitates the leaching of lignin from the fiber cell wall, obviating the need from chlorine for pulp bleaching in the brightening process. A variety of materials such as pure xylan, xylan rich natural substrates, such as sawdust, corn cob, wheat bran, sugar beet pulp and sugarcane baggase have been used for induction of xylanases.

Lynd and Zhang [62] reported cellulose hydrolysis limits the rate of microbial cellulose utilization under most conditions as may be inferred from the observation that maximum growth rates on soluble sugars were usually several fold faster than on crystalline cellulose. Thermophilic cellulolytic and thermo tolerant cellulolytic microbes exhibited substantially higher growth rates on cellulose than do any of the mesophiles.

Thermostability of cellulases and xylanases is due to the presence of an extra disulfide bridge which was absent in the majority of mesophilic xylanases and to an extent of an increased density of charged residues throughout the protein [58]. Important enzymes involved in composting process include cellulase, protease, lipases, phosphates and arlyl sulphatases. High levels of protease, lipase and cellulose activities have been detected throughout the active phase of composting [63].

Oviedo-Ocaña et al. [64] reported that the activities of cellulases, xylanases and proteases were maximum between 30 and 60 days of composting in various wastes. Similar trend was observed with respect to mesophilic bacterial and fungal population. Various quality parameters like C:N ratio, water soluble carbon (WSC), CO evolution and level of humic substances were compared after 90 day composting. Statistically significant correlation between C:N ratio, CO evolution, WSC and humic substances were observed.

6. Factors Affecting Composting

Organic by-products are mostly used for composting. Poultry, cattle and pig manures, food processing waste, sewage sludge, leaves, plant and grass clippings, sawdust and other by-products of wood processing industries etc., are commonly used materials for composting [23]. The quality of the finished compost will be determined by the combination of feedstock quality and compost management.

Several factors should be regulated to overcome operational problems during composting including odours, dust, and ensuring good quality of the final product. The desirable conditions are fundamental requirement to achieve an aerobic composting procedure and to have, anaerobic fermentation. Over recent decades, research has focused on the complex interaction between physical, chemical and biological factors during composting. Controlling factors such as temperature, pH, moisture, bulk density, porosity, particle size, nutrient content, C/N ratio, and oxygen supply, have been proved to be key elements for composting since they lead the proper conditions for microbial growth and development and organic matter decomposition [80].

6.1. Moisture

Various groups of microbial populations can decompose organic material. Depending on the temperature of the composting mass, different groups of microbes are involved in the composting process and these clearly indicate the different steps of the process [65]. Bacteria prevail early stage of composting, fungi are present during the entire process but can highly active when moisture levels fall below 35% and are inactive at temperatures greater than 60°C [66]. During the maturation phase Actinomycetes predominate, and together with fungi are capable of degrading highly resistant polymers. The particle size of the feedstock affects microbial activities. Smaller particles have more surface area per unit volume and, therefore, microbes have more surfaces to work. However, if particles are too small, porosity will decrease and airflow within the compost pile will be restricted or lowered [67].

Moisture contents of between 45-60% by weight are ideal for composting processes [66]. Low moisture contents slow down the process. Moisture also governs temperature. Drier composting piles tend to heat up and cool down more quickly than wetter piles, and excessive dryness makes piles more susceptible to spontaneous combustion [68]. Moisture contents exceeding 60% lead the compost pile to anaerobic conditions [69]. To regulate temperature during composting a large amount of water is lost by evaporation, and as water content reduces, the rate of substrate degradation decreases. Thereby, in order to maintain moisture content suitable for microbial activities, remoistening is required [70].

6.2. Temperature

Proper temperature control is an important factor in aerobic composting process. During the process, the temperature condition is considered to be a reflection of the metabolic status of the microbial population involved in the process [71].

Iglesias Jiménez and Perez Garcia [72], state that the temperature pattern observed in compost piles demonstrates the microbial activity and has an impact on the composting process. They concluded that the ideal temperature range for composting during the thermophilic phase is 40-65°C [73], and temperatures above 55oC are necessary to kill pathogens, while Plat et al. [74] states that the temperature should range from 52-60°C during the thermophilic phase. However, if the temperature goes beyond the tolerance range of the thermophilic microbes, the effect is detrimental for the composting process. Plat et al. [74] suggests that removal of excess heat can be achieved in several ways: (a) controlling the size and shape of the composting mass; (b) improving cooling and favorable temperature redistribution; (c) mechanical turning operation, which leads to heat removal by evaporation cooling, and (d) achieving superior temperature control in systems that actively remove heat by temperature feedback-controlled ventilation (Rutgers strategy) [75].

6.3. pH

The pH value indicates the acidity or alkalinity of the organic materials, and affects microorganism growth. A pH ranging between 6.0 and 7.5 is preferred by bacterial decomposers while a pH ranging from 5.5 to 8.0 is a good working environment for fungal decomposers [67]. When pH values exceed 7.5, gaseous losses of ammonia are more likely to occur during composting. Some specific materials such as dairy manure, paper processing wastes, olive mill wastes and cement kiln dust can increase pH, while food processing wastes or pine needles can reduce pH [76].

6.4. Physical and Chemical Nature of Substrates

The chemical and physical properties of the substrate affect the composting process and the quality of the finished product [77]. The waste which contains high content of organic matter, domestic wastes, sewage sludge and agricultural biomass are suitable for composting [78].

Nutrient quality and quantity are the terms which may be considered for the chemical characteristic of the wastes. The relative quantity of carbon, nitrogen, phosphorus, sulphur and other nutrients is important, but it is also the quality of the substrate that decides the rate of decomposition [70]. Cellulose and lignin have similar content of carbon but lignin undergoes decomposition much more slowly than cellulose [79]. Microbial and enzymatic access to the substrates accelerates decomposition of wastes [80].

Substrates Porosity plays a vital role on composting performance since a suitable physical environment for aeration must be maintained during the composting process. If porosity exceeds 50% then the pile may remain at a low temperature due to energy loss. Low porosity leads to anaerobic conditions and hence bad odours. Ideally, the air-filled pore space of the compost pile should be 35–50% [77].

Bulking agents are used to increase porosity, decrease phytotoxic materials and maintain optimum level of C/N ratio. During composting different type of bulking materials are used such as poultry manure, sheep manure, olive tree pruning, cereal straw, waste wool, olive leaves, sheep litter, wheat straw, bean straw, grape stalks, cow manure, horse manure, turkey manure, pre-composting material, wood chips and grass from municipal pruning, wood chips, rice by-products, straw trimming, agricultural by-products, sesame bark, sewage sludge, cotton gin waste, fresh cow bedding, yard trimmings, maize wastes, etc. Some authors also utilized different types of chemical additives such as urea, P, Fe, and S to reduce the pH and electrical conductivity, and biological agents like fungi and earth worms [70].

6.5. C: N Ratio

The carbon to nitrogen ratio affects the speed of the composting process and the volume of materials finished. In other words, the rate at which organic matter decomposes during composting is principally dependent upon the C: N ratio of the materials. During composting, microorganisms utilize the carbon as a source of energy and the nitrogen for building cell structure. But, if the C is excessive, decomposition decreases. When the availability of C is less than that required for converting available N into protein, microorganisms use most of the available C and there may be loss of N through NH_3 volatilization [81].

Ganbahi and Hanafi [82] reported that the optimum C:N ratio as 20-25 to 1. However, the C:N ratio of 50:1 is well within optimum range and excellent results are also obtained with even higher ratios as demonstrated by successful composting of leaves, sugarcane bagasse, saw dust, alder chips and cotton waste. Demirbas [83] observed that when there is a severe nitrogen deficiency in the waste, addition of small amount of urea or other nitrogen sources may be required to overcome to complete.

6.6. Aeration/Turning

Aeration is one of the key factors for successful aerobic composting. An aerobic composting pile should contain at least 5% oxygen during the bio-oxidative phase of composting (optimally closer to 10%). Composts must be aerated either passively or actively as aeration is a key element to successful composting. As microbial activity increases with time in the composting pile, more oxygen will be consumed with time. If this oxygen demand is not supplied decomposition can become anaerobic, slowing down, the composting process and producing foul odors [84].

6.7. Odor and Color of the Compost

The unpleasant odor emitted from composting heaps decreased during the first stages of bio oxidation phase and practically disappears by the end of the composting process [85]. Puyuelo et al. [86] stated that lower fatty acids are one of the major components causing the very unpleasant odor in the compost. During the composting of waste, a gradual darkening or melanization of the material takes place and the final product was dark brown in color.

7. Characteristics and Application of the Compost in Agriculture

Compost produced by super thermophilic bacteria was well characterized by Kanazawa et al. [87] for its application as fertilizer to cultivate plants. Soil fertilized by the compost keeps nutrient ions in forms easily accessible for uptake by plant roots. Nitrogen in organic compounds is converted to ammonium ion through hyper-thermophilic aerobic fermentation. The oxidative process producing nitrate ion does not take place during composting because Nitrosomonas or Nitrobactor cannot survive or be active under temperatures higher than 80°C. For the same reason, the denitrification process might not be activated. Organic nitrogen, typically amino or heterocyclic group in biochemicals, is either converted to ammonium or remains in an undigested form in the compost, thus reducing any losses of nitrogen. One explanation of the advantages of applying the compost in agricultural fields is that the chemical and micro-morphological features of compost produced by the hyper-thermophilic aerobic bacteria effectively control the ecology of bacteria and other organisms, even though the hyper-thermophilic bacteria themselves are inactive [88].

Lim et al. [89] conducted the preliminary studies on wheat straw to test the technical viability of an integrated system of composting, with bioinoculants and subsequent vermicomposting. Wheat straw was pre-decomposed for 40days by inoculating it with Pleurotus sajor-caju, *Trichoderma harzianum*, *Aspergillus niger* and *Azotobacter chroococcum* in different combinations. This was followed by vermicomposting for 30 days. Chemical analysis of the samples showed a significant decrease in cellulose, hemicellulose and lignin contents during pre-decomposition and vermicomposting. The N, P, K content increased significantly during pre-decomposition with bioinoculants. The best quality compost, based on chemical analysis, was prepared where the substrate was treated with all the four bioinoculants together followed by vermicomposting. Results indicated that the combination of both the systems reduced the overall time required for composting and accelerated the composting of lignocellulosic waste during the winter season besides producing a nutrient-enriched compost product.

The effect of composts prepared from various organic waste were examined by several workers through glass house and field experiments. It is evident that increased yield and nutrient uptake were related mainly to the improved physical condition or the nutrient contents of organic wastes [39] and a significant increase in crop yield and nutrient uptake was reported due to the application of enriched compost. The results of field experiments indicated that application of 3202 kg of pressmud compost was equivalent to 502 kg of triple super phosphate. They also demonstrated that dry matter yield, phosphorus uptake, grain and straw yield of rice were comparable for pressmud compost and triple super phosphate.

Gaind [90] observed that the compost application increased the phosphorus use efficiency by wheat (20.48%) and greengram (12-90%) as compared to single super phosphate. It was also reported that the compost increased the quality of grains by increasing the protein and Ca contents.

Gaur [83] observed that the addition of compost to the top layer at a soil favoured the penetration of water and air. Organic matter has greater influence of water retention through soil structural changes viz., change in pore size between soil aggregates. The results of the three year field trials conducted by Srinivasan et al. [41] have shown that application of pressmud significantly increased infiltration rate as well as water stable aggregates and found to be superior compared to fly ash and gypsum.

Pressmud applied to sugarcane along with N, P and K fertilizers significantly increased the yield of cane and also quality of rice [48]. On the contrary, Singh et al. [91] observed that application of pressmud and nitrogen alone or in combination did not affect the sucrose and purity of cane juice. However, they found that the yield of cane increased by 12.9 to 65.6% over that of control. Application of pressmud increased the maize and wheat yield by 129.4 and 62.2% respectively. Continuous application of pressmud and nitrogenous fertilizer also significantly increased the cane and sugar yield of sugarcane. Fantaye et al. [92] found that combined application of 5 tonnes of pressmud and 5 tonnes of FYM significantly increased sunflower seed yield, seed protein and oil contents as compared to control without pressmud.

Dotaniya et al. [39] observed that addition of pressmud obtained from carbonation process increased the pH and decreased the available phosphorus; whereas sulphitation pressmud caused no change in the pH and available P, both types of pressmud increased the organic carbon and available K content of soil. Addition of organic manure in conjunction with fertilizers to maize-soybean cropping system significantly increased available N, P, K, Fe, Cu, Mn and Zn in soil.

Babu et al. [93] reported that addition of sugarcane trash enriched with rock phosphate, phosphorus solubilizers, cellulolytic fungi and Azotobacter increased the number of nodules, nitrogen activity of nodules and grain and straw yields of greengram. In sugarcane cultivation, nitrogen uptake and dry matter production was increased by incorporation of pressmud (normal or enriched with Pleurotus or Trichoderma viride) in to soil for sugarcane. Continuous application of pressmud and nitrogenous fertilizer also increased significantly cane and sugar yield of sugar cane.

López-González et al. [75] conducted the compost studies to determine the conversion of sugar mill wastes into a stable product that may be useful in crop production and to characterize the N transformations. Two kinds of sugar mill by-products were composted, filter cake and filter cake mixed with bagasse, at a 2:1 ratio to reduce the C:N ratio in an attempt to reduce N loss during composting. Materials were mixed manually at 3-5 day intervals during the composting process. Both composts were analyzed at least weekly to measure temperature, pH, NH, NO, total N content, C loss and germination index. For both mixtures, the thermophilic stage lasted 15-20 days and was higher than ambient for nearly 80 days. The degradation of organic matter was rapid in both mixtures to approximately 40 days after which it began to stabilize. Both mixtures achieved maturity at approximately 90 days as indicated by a stable C: N, low NH /NO, lack of heat production and a germination index was higher than 80%.

Oviedo-Ocaña et al. [64] studied the changes in temperature and physico-chemical parameters of sugar industry wastes during windrow composting. The rise in temperature which occurred as composting progressed was accompanied by an increase in NH–N and the passage of the thermophilic phase to mesophilic took place between 90 and 105 days. This overall pattern was observed in all composting mixes, whereby the concentrations of NH–N increased rapidly and then declined gradually over the course of monitoring with increase in NO–N. The C:N ratios of the composting mixes decreased substantially by the 90^{th} day in full thermophilic phase and became comparatively stable later on. Addition of additives showed potential in improving the C: N ratios.

Lim et al. [3] composted the waste by-products of the sugar cane industry, bagasse, pressmud and trash using bioinoculation followed by vermicomposting to shorten stabilization time and improve product quality. Pressmud alone and in combination with other by-products of sugar processing industries was pre-decomposed for 30 days by inoculation with combination of Pleurotus sajor-caju, Trichoderma viride, Aspergillus niger and Pseudomonas striatum. This treatment was followed by vermicomposting for 40 days with the native earthworm, Drawida willsi. The combination of both treatments reduced the overall time required for composting to 20 days and accelerated the degradation process of waste by-products of sugar processing industry, thereby producing a nutrient enriched compost product useful for sustaining high crop yield, minimizing soil depletion and value added disposal of waste materials.

Kästner and Miltner [45] monitored the microbiological and physicochemical parameters during composting of five piles containing mainly rice straw, soybean residue and enriched with rock phosphate. Physico-chemical changes confirmed the succession of microbial populations depending on the temperature of each phase in all treatments. Intense microbial activities led to organic matter mineralization and simultaneously narrow C/N ratios. Inoculation of composting mixtures enhanced the biodegradation of recalcitrant substances. The duration of exposure to a temperature above 55°C for at least 16 consecutive days was quite enough to sanitize the produced composts. After 84 days, all composts reached maturity as indicated by various parameters.

Liang et al. [94] tested the microbial populations and their relationship to bioconversion during lignocellulosic waste composting quinone profiling. Nine quinones were observed in the initial composting materials and 15 quinones were found in compost after 50 days of composting. The quinone species which are indicative of certain fungi appeared at the thermophilic stage but disappeared at the cooling stage. Q-10, indicative of certain fungi and characteristic of certain bacteria, were the predominant quinones during the thermophilic stage and were correlated with lignin degradation at the thermophilic stage. The highest lignin degradation ratio (26%) and good cellulose degradation were found at the cooling stage and were correlated with quinones and long-chain menaquinones attributed to mesophilic fungi, bacteria and actinomycetes, respectively.

Zayed et Abdel-Motaal al. [95] investigated the compost production by using Trichoderma fungus, different acidities of the used water in moistening organic wastes and nitrogen in a factorial completely randomized design. Treatments included different levels of water pH for moistening organic matter and urea. Each treatment contained a mixture of bagasse, filter cake, manure and fresh alfalfa; that the microorganism's suspension was sprayed on the raw materials amounted 2.5 mg/kg^{-1} dry organic matters. Results indicated that the C/N ratio reduced to less than 16% in produced compost. Treatment having pH=5.5 of the used water with 0.5% urea was suitable for providing compost from the cane organic wastes.

Awasthi et al. [96] conducted the experiment on disposal of spent wash by composting with pressmud cake (PMC) through microbial consortium treatment by pit and windrow system. The compost prepared by windrow and pit methods from PMC and spent wash using microbial culture within 45 days ranged C: N ratio from 10.19:1 to 13.88:1 and 14.32:1 to 22.34:1, respectively. The compost obtained in various treatments by windrow method contained 1.52-3.7% N, 0.9-3.54% P_2O_5, 1.95-3.45% K_2O and had pH range from 7.02-7.82. Similarly, the compost obtained in various treatments by pit method contained 1.34-2.85% N, 0.30-0.72% P_2O_5, 2.20-4.72% K_2O and had pH range from 7.40-8.16. Microbial consortium used in their investigation included phosphate solubilizing fungi and *Burkholderia* species isolated from the sugarcane and sugar beet rhizosphere.

8. Conclusion

Sugarcane industry are age-old industrial practices in Morocco which contribute a significant amount of by-products as waste. Handling and management of these by-products are huge task, because those require lot of space for storage. However, it provides opportunity to utilize these by-products in agricultural crop production as organic nutrient source. Therefore, it is attempted to review the potential of sugar industries by-products, their availability, and use in agricultural production.

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