Review

Innovative Processes and Technologies for Nutrients Recovery from Wastes: a Comprehensive Review

Running Title: **NUTRIENTS RECOVERY FROM WASTES**

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Abstract: Nutrients management is a mainspring in agricultural systems for sustained productivity, economy sustainability and environmental quality. Excessive and lesser nutrient application caused environmental pollution and reduced production, respectively impacting socio-economics of the entire ecosystems. Sustainable agricultural production thus demands supplementation of nutrients either through natural processes, application of animal by-products, and mineral fertilizers to crop fields. Technology application for treating useless agricultural wastes into useful source is a management strategy that prevents environment pollution. Crude animal manures triggered soil degradation, attenuation air and water quality, and resulted in higher concentrations of heavy metals. Primary nutrients, i.e., nitrogen, phosphorus and potassium are used globally and are non-renewable. Augmented upsurge in prices of inorganic fertilizers and required discharge restrictions on nutrient has stimulated the technological developments including biochar, composting, vermicomposting, composting with biochar, pyrolysis, forward osmosis, and electro-dialysis to recover nutrients. Therefore, outlining the research gaps considering the present and imminent potential of these technologies for adaptation of nutrient recycling is of great importance. Thus, it's need of an hour to fix our environment and for that scientists are trying to introduce and renovate the technologies which have immense potential to mitigate the negative effects of technology adversities on our environment.

Key words: Environmental pollution; wastes; nutrient recovery; biochar; composting

Introduction

In the era of modern technology and globalization, mankind has reached at its peak in terms of progress in everyday life activities such as urbanization, industries implantation, space technology, agriculture etc. left the massive amount of solid waste in return. Advancement in lifestyle has facilitates us at best but has taken away the sense of responsibility for our environment, animals, soils and water bodies. Unfortunately, with every invention there is no way to go back or cut down its negative effects on us for example, heavy machinery usage in agriculture, intensive usage of insecticides, pesticides, fungicides etc. If we only take agriculture as an example, we can easily assess the exploitation of natural resources, poor soil health and untreated as well as bad quality water with tons of solid waste either in form of organic, industrial, sewage sludge etc. There is generation of million tons of soil waste and management of such wastes is very difficult and uneconomical to use

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at broad level. Thus, it becomes extremely difficult to keep our surrounding environment clean and healthy. In United States of America, 6% municipal solid wastes was recycled (Troschinetz & Mihelcic, 2009). Vietnam produces 27.87 million tons of solid waste annually from different sources and in it municipal solid waste (MSW) accounts at largest i.e. 45.94% (Thanh & Matsui). In China, MSW production increases at the level of 3-10% annually (Wang & Nie, 2001). Waste management depends upon socioeconomic, political and environmental factors. Thus, it varies from countries to countries. European countries are shifting toward recycling as compared to landfilling. Zero waste concept was presented by different researchers considering the importance of sustainability. This concept involves reutilization of organic waste produced from agriculture, municipal and industrial waste as resource rather than its disposal as waste directly. Sweden have best example of resource recovery from waste and they are using waste to energy technology (incineration) as well as biological treatment to manage municipal waste. Solid waste management is now environmental as well as political concern. The potential emerging technology for waste management includes Dry composting, Sanitary landfill, Anaerobic digestion (AD), Gasification, Pyrolysis thermal processes, Plasma arc, Bio-chemical conversion, anaerobic process, Pyrolysis-Gasification, Plasma arc-gasification, Bioreactor technology, Hydrolysis, Conversion of solid wastes to protein and Hydro-pulping (Zaman,2013). W*aste* management to organic resource utilization and to recover nutrients is key way to have sustainable and ecofriendly agricultural production. Since food demand of population is increasing day by day therefore, to reduce the environmental impact of food production sustainable intensification have been suggested (Godfray et al., 2010). Nutrients recovery from waste would be good option to meet the demand of increasing population as fertilizer availability is decreasing day by day. Similarly, excessive use of inorganic fertilizer is main cause of climate change.

Nutrient is any substance which is required for nourishment. With reference to plant nutrition, nutrients are substances that are needed by the plants for growth and development. Number of nutrients exist which are required by the crop plants. Some (16) of them are considered essential based on concentration range in dry tissue. Macro nutrient comprises group of carbon (CO_2), oxygen (O_2, CO_2), hydrogen (H_2O), nitrogen (NO_3^-, NH_4^+), phosphorus ($H_2PO_4^-$ and HPO_4^{2-}), potassium (K^+), calcium (Ca^+), magnesium (Mg^{2+}) and sulfur (SO_4^{2-}) while micro nutrient consist of Iron (Fe^{2+}, Fe^{3+}), Chlorine (Cl^-), Manganese (Mn^{2+}), Zinc (Zn^{2+}),Copper (Cu^+, Cu^{2+}), Boron (BO_3^{3-}, H_3BO_3) and Molybdenum (MoO_4^{2-}). Without proper nutrition, plants undergo stunted growth and no nutrient can be replaced by other. Concentration of nutrients in plant dry tissue i.e. carbon di oxide is (45%), oxygen (45%), hydrogen (6%), nitrogen (0.5-6%), phosphorus (0.15-0.05%), Potassium (0.8-8%), calcium (0.1-6%), sulfur (0.1-1.5%), magnesium (0.05-1%), iron (20-600ppm), chlorine (10-80000 ppm), manganese (10-600 ppm), zinc (10-250 ppm), copper (2-50 ppm), boron (0.2-800 ppm) and molybdenum (0.1-10ppm). Most of plant systems require nutrients to function properly; nitrogen is vital component of amino acids which are building blocks of protein. Adenosine Triphosphate (ATP) is energy currency needed for anabolic and catabolic processes which contain phosphorus. Potassium play vital role in opening and closing of leaf stomata's regulating transpiration. It also induces resistance in plants against disease. Calcium metabolizes nitrogen and reduced plant respiration. Magnesium enhances mobility, utilization of phosphorus and iron. Sulfur helps in seed production, nodulation and also a part of amino acids. Certain micro nutrients like zinc is necessary for seed, starch formation and work as co-enzyme. Iron transport oxygen throughout plant and involve in cell division, and also helps in chlorophyll formation. Manganese improves availability of phosphorus and calcium. Molybdenum is needed for the formation of nitrate reductase which converts nitrate to ammonium in plant and help in nodule formation as well. Cupper act as catalyst in several processes of plant and play major role in photosynthesis. Cell wall and seed formation requires boron as essential element; furthermore, it promotes maturity and carries out sugar translocation.

Variation in rainfall pattern, intensity and frequency under climate changing scenario will alter nutrients cycle and utilization. Nutrients will tend to accumulate in dry soils, which will further be not available to crop plants and consequently will leach down or lost through erosion, resulting in nutrient losses (Matias et al., 2011). Plants depend on soil fauna for mineralization of mineral nutrients which is needed for plant growth and development (Chen et al., 2003). Terrestrial carbon cycle is highly influenced by climate extremes and onset of drought (Frank et al., 2015). Nutrient

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cycles have changed due to variation in precipitation and temperature. This accelerated change resulted to the unavailability of nutrients to crop plants. Plants community will suffer due to differential availability of Carbon (C), Nitrogen (N) and specifically Phosphorus (P) which is closely interconnected with water use efficiency that will make the crop plants susceptible to drought stress (Matias et el., 2011).

Matias et al. (2011) projected different climate set-ups (dry summers with 30% reduction in rainfall, wet summer with simulated storms and current climate) with three habitats i. e. forest, shrub land and open areas on C, N and P fractions in soils. Results described that nutrients in litter layer was not influenced by climate effects however, microbial and soil nutrients showed variation to seasonal differences, habitat and climate variance. Nutrients in soil increased with dry scenario and summer while microbial nutrients showed increase to wet summer and spring. Holm oak seedlings (control) with water availability under spring and wet summer, resulted increase in nitrogen and phosphorus content. Results justify the idea that plant nutrient uptake can be accelerated by high rainfall and ultimately recycling of nutrients. Furthermore, climate change projection will have direct impact on nutrients cycle, reflect functioning of ecosystem.

Soils enriched with organic matter have higher N concentrations as compared to barren soils. Heavy rainfall causes nitrate leaching triggering soil acidification. Lower nitrogen rates are thus required to be applied for efficient utilization or application of organic manures could be helpful in mitigating nitrate leaching to prevent soil pollution (Rebecca, 1992). An investigation to water quality of area under agricultural practices (2007-09) unveiled that nitrate and chlortoluron concentrations exceeded beyond MAC (minimum alveolar concentration) values resulted to water pollution hindering its usage in future (Šimunić et al., 2011). Fertilizer application in agricultural practices release greenhouse gases contribute to climate change and air pollution. About 12% of emissions are reported, emitting from agro related activities (USEPA, 2012).

Nutrients management is driving force for sustained crop production accompanied by economic sustainability and environmental quality. Both excessive and less amount of application have considerable impact on socio-economics of ecosystem. Decreased quantity may result in reduced crop production failing to feed the projected population of world while incremental nutrient application will pollute the surrounding. Crops till maturity exhaust almost all nutrients leaving the soil infertile. Sustainable agricultural production thus necessitates supplementation of those nutrients either through natural processes (nitrogen fixation) or application through animal by-products or mineral fertilizers to crop fields (Vitousek et al., 2014).

Undesirable wastes are useful tools if managed properly instead allowing it to contaminate soil, air and water resources which create hazardous environment. Application of technology in this regard can help in agricultural waste management. Untreated animal manures left in field trigger soil degradation and diminishing air and water quality (Obi et al., 2016). Soil amended with untreated municipal solid waste resulted in higher concentrations of Cu, Zn, Cd and Pb as compared to soil without solid waste application (Adjia et al., 2008). Nitrogen, phosphorus and potassium fertilizers are used globally and it is non-renewable. Once applied to the soil, will be taken up by crop plants exhausting the soil of nutrients and some fraction of it may leach down the soil. Furthermore, accelerated increase in prices of fertilizers and required discharge restrictions on nutrient has stimulated the technological development to recover nutrients such as nitrogen, phosphorus and potassium. Therefore, outlining the research gaps considering the present and imminent potential of these technologies for adaptation of nutrient recycling is thus of great importance (Mehta et al., 2015).

Nitrogen (N), phosphorus (P), and potassium (K) are critical nutrients for intensive agricultural production but their long-term availability and cost of extraction (P and K) is big concern in future. P, main source is nonrenewable phosphate rock which will be depleted in future as 90% phosphate rock reserves is found in just five countries (Morocco, Iraq, China, Algeria, and Syria). Mined P will be exhausted by the end of this century therefore it is essential to move to the alternative sources such as organic wastes. N is a renewable resource but its conversion to ammonia is energy intensive and cost dependent process. K availability is also big concern as most of potash ores are in Canada and Europe which resulted to its limited distribution globally particularly for developing world. Alternative sources of nutrients recovery are required to fulfill the ever-increasing demand of global

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population. Since humans and animals consumes nutrients from crops and produces nutrients rich waste. This waste from human can fulfill the 22% of the demand of P while animal derived waste particularly manure is widely used as fertilizer. However, the value of nutrient recovery from these wastes is very low and they also contained heavy metals, pathogenic microorganisms, and odor (Mehta et al., 2015). Inefficient nutrient management and limited recycling of wastes resulted to be a big environmental concern. Oxide of N and CH_4 are largely being generated by manure management and excessive use of N fertilizers. It has been reported that 30-32% of GHG emissions were contributed by agricultural activities and livestock production. The other strong concern is eutrophication due to excess nutrients in waterways. Recovery of nutrients from wastes has largely focused on exploiting nutrient cycling reactions and sequestration of nutrients. Recycling nutrients is emerging as economically sustainable method to solve the issues mentioned above. Nutrient recovery technologies have been used in the past to show the importance of use of wastes (Mehta et al., 2015). This review focuses on the use of different processes and techniques to recover nutrients from wastes so that issue of nutrients depletion and climate change can be solved by use of these technologies.

Bioenergy byproducts (anaerobic digestate, rapeseed meal, bioethanol residue, biochar) and organic amendments (sewage sludge and two composts) were used to see impacts on C and N dynamics and soil functioning. The results depicted that bioenergy by-products should be taken into account to minimize the impact of GHG emissions and improve the quality and nutrient balance of amended soil (Galvez et al., 2012).

Nutrients Recovery Processes (NRP)

Nutrients Recovery Processes (NRP) includes use of composting and vermicomposting as nutrient shortage will be one of the most common problems of the coming years. Since prices of inorganic fertilizers will increase therefore, there is dire need to use waste as source of nutrient recovery. Furthermore, mixture of organic and inorganic fertilizer could be an efficient alternative to meet the rising demands of nutrients and solve the issue of food security and climate change. One example of such mixer is Comlizer (mixture of ammonium sulphate and composted municipal waste). Recycled human excreta (fertilizer cum-soil conditioner) and urine (well balanced NPK source of nutrients) could be used as rich source of organic matter and essential nutrients for agricultural crop production. Accumulated domestic wastes are often burnt or disposed of in landfills which results in production of huge quantity of greenhouse gases. This way of waste disposal occupies cultivable land; thus, composting provides a road map to utilize this waste for nutrient recovery complemented with reduced risk of environmental vulnerabilities (Zhang and Sun, 2014). Composting is useful in recycling nutrients and managing organic wastes in a sustainable way (Raut et al., 2008). It is natural rotting or decomposition process of organic matter (crop residues, animal wastes, food garbage, municipal wastes and suitable industrial wastes) by microorganism under controlled conditions. The compost is rich source of organic matter and it can play an important role in sustaining soil fertility and crop productivity (Fig 1). The physiochemical and biological properties of the soil could be improved due to the application of compost. Composting types includes aerobic and anaerobic. Aerobic composting gives more stable organic product which is used dominantly in agricultural production. Horrocks et al. (2016) stated that organically certified compost contains 2 - 2.5% N. New techniques of waste management has the potential of nutrient recovery if managed properly. In a study carried out by Mia et al. (2018) indicated that placement of municipal organic waste in landfills will result in emissions of gases causing environmental deterioration. Hence composting with biochar can be proven better in utilizing the huge amount of waste (15507-15888 t day^{-1}) including 75% of organic waste as recorded in Bangladesh (Mia et al., 2018). The process of composting can be elaborated by following chemical equation.

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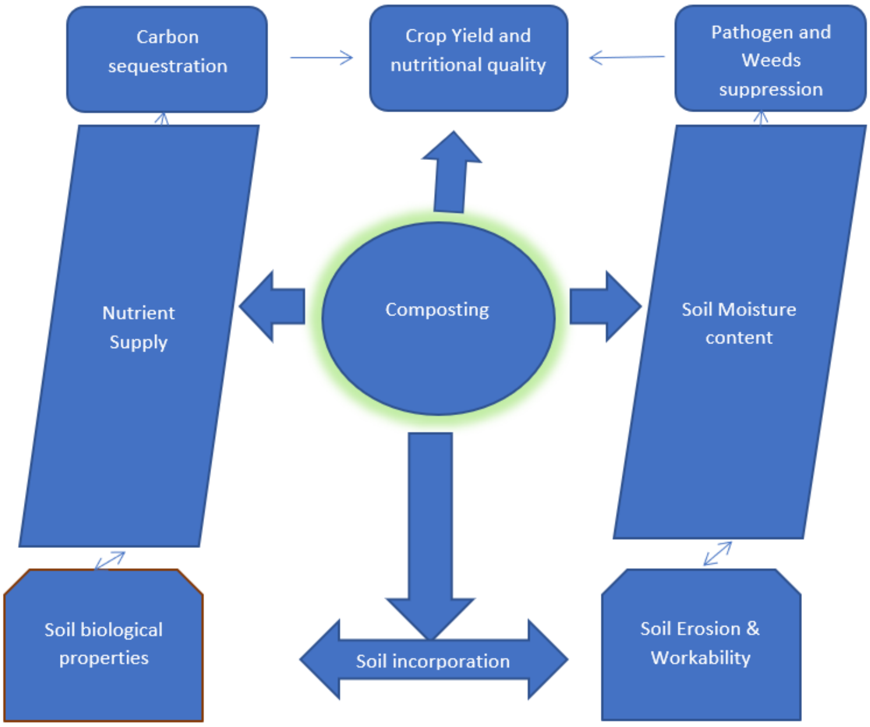

Figure 1. Beneficial aspects of Composting

$$Organic\ waste + O_2 \xrightarrow{\text{Microorganism}} CO_2 + H_2O + \text{Compost} + \text{Heat}$$

Vermicomposting is a method that utilizes the microbes as well as earthworms for decomposition of solid organic wastes into useful organic manure. It's an ecofriendly and very viable method yet economical to use. It's a bioconversion process and in this method of treating of solid waste earthworms feed on the organic wastes to enhance their population growth rate & synthesis of vermicompost. Vermicomposting can be done for the wastes coming from different sources such as food, plants, animals, pharmaceutical and sewage. Its time duration is very important and usually it takes 28-125 days approximately. As its operational system involves living organisms thus for survival of them and for good quality of vermicompost several conditions are needed. These conditions are temperature, pH and moisture content. Generally it takes 18-67^{o}C temperature range, basic pH ranging from 5.9-8.3 and moisture contents at 10.68% (Manyuchi & Phiri, 2013). Research proves that cow dung is a best substrate as it provides organic nutrients and faster the process of vermicomposting (Gupta & Garg, 2008; Sen & Chandra, 2007; Garg et al., 2006). When cow dung is mixed with plant residues and waste it significantly maximizes the rate of vermicomposting but decreases the C: N about 87.6%. Horticultural wastes i.e. vegetables waste provides the good quality vermicompost and cow dung is added into this waste as a substrate primarily consumed about 40% (Garg & Gupta, 2011). Leather industry waste has been proved fully toxic substance for earthworms thus cow dung is added to mitigate the effect of toxicity and rich organic matter source. The resulting vermicompost is rich in nutrients, low value of C: N and can be used as manure later on (Vig et al., 2011). Improved quality of vermicompost is obtained when cow dung is added in proportion of 30% in food waste (Yadav & Garg, 2009). Kitchen waste is enriching source of nutrients and when it is subjected to the vermicomposting, the resulting matter recovers the nutrients from it. Amendments in biodegradable waste improve the quality and nutrient content of resulting product as well as become the good source of feed for earthworm. Wood chips and paper is added into the subjecting vermicompost material. Efficiency of kitchen waste can be enhanced when its pre-composting is done for the period of 2 weeks at temperature <25^{o}C. The resulting pre-compost has higher value of nutrients like N, P & K i.e. 12, 66 and 40% respectively while the end product vermicompost has range values of N, P & K 2.2-3, 0.4-2.9 and 1.7-2.5 on % dry basis (Hanc & Pliva, 2013).

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Vermicomposting is a combinable process in which earthworms and other microbes produce useful manures (vermicompost) by reducing wastes harmful effects (Fig 2). The procedure involves earthworms and microorganisms, as mentioned, which shows mutualistic relationship between each other and it's better for good biodegradation of waste maintaining the quality of vermicompost and nutritional level (Singh et al., 2011). In vermicomposting, earthworm plays vital role in decomposition of organic matter into small pieces. This resulted to increase in total surface area of organic matter thus providing more exposed open area to the microbe to show their activity. This activity increases the biodegradation of waste and enhances the overall activity of the microorganisms (Lim et al., 2016). The vermicompost made dominantly by the earthworms have low value of carbon to nitrogen ratio i.e. C: N, maximum nutrients availability and water holding capacity and increased porosity (Lim, 2015). Once vermicompost has been made, the chamber is untaken from earthworms through separation i.e. upside or horizontal separation. Their excess amount of earthworms can be reused by biodegradation of waste for synthesis of protein source for animals (Edwards et al., 2010). To survive and continuing the progeny, earthworms & microorganisms needs nutrients enrich solid waste for efficiently conversion of waste into useful organic matter, but industrial wastes lacks those nutrients reason why amendments are required. These amendments can be anything from waste category but should be a good source of nutrients & shall release them during the vermicomposting process. The nutrient rich waste can be saw dust, crop residues, wood chips, poultry wastes, animal dung, grass residues, kitchen waste etc. (Garg et al., 2005).

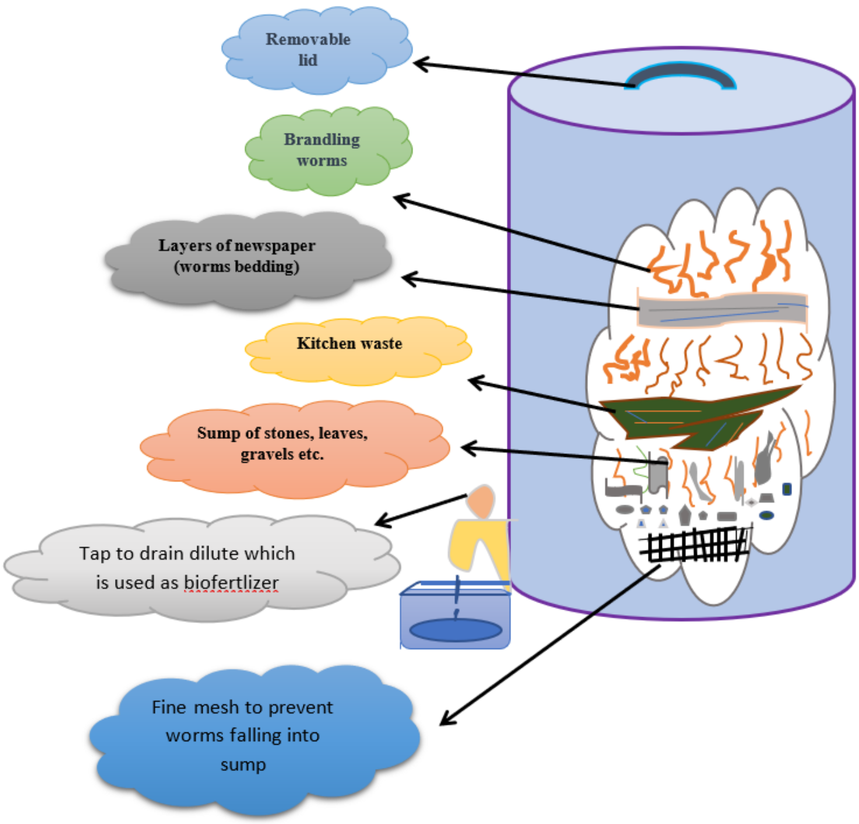

Figure 2. Components and procedure of vermicomposting

Vermicomposting efficiently utilizes the earthworms, so there is certain criterion for earthworm to be used on process for maintaining the efficiency & quality up to the mark at the end i.e.

i) Maximum utilization, decomposition & assimilation of organic waste.
ii) High moderation to environmental stress.
iii) High reproduction rate
iv) Fast growth & maturation of off springs (Singh et al., 2011).

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There are three types of earthworms i.e. epigeic, endogeic & anecic. Epigeic earthworms are considered as most suitable for vermicomposting. This type is very efficient in degradation of organic waste and releases maximum nutrients in the soil (Yadav & Garg, 2011). Vermicompost fertilizers are enriched with higher concentrations of highly decomposed organic matter improving soil fertility and crop productivity and can replace synthetic fertilizers. In this way, nutrients can be recycled and detoxified improving environment health (Bhat et al., 2018). Vermicomposting technique comes with total benefit i.e. its residual matter can be used as bio fertilizer and can be applied on plants such maize, cow peas, soybeans etc. as vermiwash (Suthar, 2010). The procedure involves earthworms and microorganisms, as mentioned, which shows mutualistic relationship between each other and it's better for good biodegradation of waste maintaining the quality of vermicompost and nutritional level (Singh., 2011). Vermicomposting method is considered better in comparison to composting in order to kill the pathogens, but some research studies showed that composting utilizes the high temperature of up to 70^{o}C unlike former reason why it has more ability to kill the pathogens. As vermicomposting method includes earthworms so its operating temperature ranges between 30-35^{o}C, temperature above this level may prove lethal to earthworms that may stop the bioconversion process (Neklyudov et al., 2008). Organic solid waste on which earthworms acted upon should have moderate pH of 5-8, 45-55% moisture content and C: N ratio of 30 at initial this will also give the good quality vermicompost at the end. The former mentioned conditions are somewhat ideal to have thus many organic wastes don't meet these criteria. Hence, to make the solid organic waste suitable for biodegradation through vermicomposting should be; undergone from pre-vermicomposting treatments and mixed with bulking agents (Edwards, 2004). Besides all above mentioned details of earthworm activity & microorganisms, vermicomposting needs amendments for increasing the bulking capacity, substrates and co-substrates. These substrates and co-substrates changes the physical & chemical state of the solid waste thus directly effects the processing of vermicompost. These substrates carry lot of importance in whole process as they speed up the chemical reaction, decreases the surface area, significantly reduces the waste matter and enhances the organic matter in the resulting vermicompost. It also faster the rate of production of earthworms (Vig et al., 2011).

When animal dung specifically of cow get mixed with the saw dust and guar residues the resulting mixture release the essential nutrients providing favorable growth conditions for the life involve in biodegrading process (Suthar, 2007). But sometimes even the addition in waste matter failed to increase the growth and ultimately the quality of vermicompost. This manly happens in liquid waste thus efficiency of biodegradation reduced (Suthar, 2008). When sewerage waste is mixed with paper waste in 2:3 increases the efficiency of earthworms and reduce the mortality rate but scenario reversed with the addition of pig dung (Elvira et al., 1997). The good quality vermicompost has been obtained when sewage sludge is used as initial substrate for earthworms and also biodegraded the aromatic hydrocarbons present in the waste (Contreras-Ramos et al., 2009). When apple pomace waste is mixed with straw and used as vermicomposting material and substrate respectively, it recovers the nutrients from the waste and minerals. It enhances the value of EC from 1.6-4.4 mS/cm, slightly increases the pH from 5.9 to 6.9 and C: N from 13-14 less than 20% (Table 1). This vermicomposting material does not increase the surface area for the activity of earthworms. Resulting vermicompost constitutes N, P, K & Mg on average about 2.8%, 0.85%, 2.3% and 0.38% respectively(Hanc & Chadimova, 2014).

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Table 1. Review of vermicomposting aspects as affected by various factors.

S. No.	Factors effecting vermicomposting	Characteristics of vermicomposting
1)	Degradation rate	Rapid
2)	Temperature	25-40°C
3)	PH	Neutral
4)	Humidity	High
5)	Carbon to Nitrogen Ratio (C: N)	<20°C
6)	Mode of Action	It involves microbes and earthworms.
7)	End product	Stable homogenous fine peat like material and vermiwash which is a liquid portion contains humic acid.
8)	Nutritional status	High due to N, P, K, S and traces of other elements but this mainly depends on what one is feeding to its catalytic agents i.e. worms.
9)	Usage	Not adopted at fullest on industrial level yet.
10)	Capital	High
11)	Shortcomings	It's difficult to maintain its parameters' range such as T, pH and humidity level.

Paper cup can be recycled and turns into value added manure through vermicomposting. This process involves the use of some bacterial groups *(B. endophyticus, Acinetobacter baumanni, Lactobacillus pantheries, Virigibacillus chiquenigi, Bacillus anthracis, B. funiculus, B. thuringiensis, B. cereus & B. toyonensis)* and earthworm specie *Eudrillus eugeinea* thus time duration of biodegradation reduces. Two treatments were used, one is combination of bacteria with waste of paper cup, cow dung and earthworm *Eudrillus eugeinea* and the second involves cow dung, waste of paper cup and bacterial groups. The resulting vermicompost have C: N value of 15.03 & 11.92%, pH value 8.01 & 7.56 and values of K, Ca, Mg & P are 1.75 & 1.86%, 50 & 64%, 50.52 & 64.3% and 46.1 & 51% (Arumugam et al., 2017).

A comparative study has been conducted to assess the quality of vermicompost produced by paper waste using an earthworm specie *Eisenia fetida* and rice straw. The resulting vermicompost was finer in texture and have high N, P and K values. There is low rate of activity reported for earthworms in a treatment of 50% rice straw rest all shows the significant activity of earthworm. The value of C: N and total organic carbon decreases in vermicompost by 19-102% and 17.38-58.04% respectively (Sharma & Garg, 2018) Better quality of vermicompost is attained when 25% cattle manure is added to sheep bedding and the progeny of *Eisenia fetida* grows and develops at rapid rate (Cestonaro et al., 2017). A study is conducted on the quality of vermicompost using liquid waste and tea leaves by utilizing *Eisenia fetida* specie of earthworm. The resulting vermicompost shows declined values for C: N, EC and total organic matter but increasing trend has been showed for N, P & K (Mahaly., 2018). The vermicompost made from vegetable waste is proved to be nutrients enriched and very effective. This vermicompost is rich in nutrients like Na, Ca, K, Mg, Fe, Zn, Mn and Cu (Jadia & Fulekar, 2008). Wine by product waste can be used as vermicomposting material and provides essential nutrients to the vermicompost which ultimately affect production of various crops (Table 2). The progeny of

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earthworm rapidly increases due to this substrate eventually faster the rate of biodegradation. The resulting material is alike peat and contains polyphenol enrich extracts in it (Domínguez., 2017). As mentioned earlier, kitchen waste is enriching source of nutrients and when it is subjected to the vermicomposting, the resulting matter recovers the nutrients from it. Amendments in biodegradable waste improve the quality and nutrient content of resulting product as well as become the good source of feed for earthworm. Thus, wood chips and paper is added into the subjecting vermicompost material. Efficiency of kitchen waste can be enhanced when its pre-composting is done for the period of 2 weeks at temperature <25°C. The resulting pre-compost has higher value of nutrients like N, P & K i.e. 12, 66 and 40% respectively while the end product vermicompost has range values of N, P & K 2.2-3, 0.4-2.9 and 1.7-2.5 on % dry basis respectively (Hanc & Pliva, 2013). Food industry meets the nutritional demands but also produces the tons of solid waste which badly pollutes the soil health and water reservoirs. For management of sewage sludge produced by this industry vermi-technology with *Eisenia fetida* is employed. After 03 and half months the resulting vermicompost has higher value of N_{total}, P_{avail} & K_{total} i.e. 60-214%, 35-69% and 43-74% respectively. The observed C: N value was 61-77% (Garg et al., 2012). Likewise, food industry, industrial waste was also subjected to vermicomposting for nutrient recovery. In this process *Eisenia fetida* is utilized for good quality vermicompost. Total 09 vermi-reactors were utilized in which different concentration of industrial waste has been used. Among 09, earthworm failed to survive in vermi-reactor which has 100% concentration of waste. The resulting vermicompost has more heavy metals concentration than before due to mineralization and fragmentation. Low pH and C: N has been reported but increasing trend wa observed for EC, N, P & K contents. Contents of total kjeldhal nitrogen i.e. TKN has also been increased (12-28 g kg^{-1}) (Yadav & Garg, 2009). Vermicompost generated from duck manure with reeds straws and zeolite as additives can adds up to 236 and 233 mgg^{-1} carbon into soil. Even after the period of 100 years, carbon potentially remain in the soil with minimum 4.72 and 4.66 mg g^{-1} and maximum with 23.6 and 23.3 mg g^{-1} derived from previously mentioned resources (Wang et al., 2014).

Table 2 Crop production as affected by various vermicomposting treatments.

S No.	Crops	Treatments	Parameters affected by the addition of vermiwash and vermicompost	Literature cited
01	*Triticum aestivum*	Goat dung and vegetable wastes as additives with the qty. of 10 g m^{-2}.	Plants shows vigorous growth when vermiwash which is rich in humic acid is applied through foliar spray. Zinc and copper also becomes available to the plant by the activity of worms and microbes supplied by vermicomposting.	(Nath & Singh, 2016)
02	*Zea mays*	Three levels of vermicomposting i.e. 0%, 50% and 100% respectively with same 03 levels of NPK as former.	Crop is more responsive to at 100% of NPK and vermicomposting. This treatment shows maximum height i.e. 158.22 cm, more leaves per plant i.e. 11, cob length 17-18 cm, highest yield of 42.70qha^{-1} and maximum net return.	(Prajapati, Swaroop, Masih, & Lakra, 2018)
03	Cicer arietinum	Use of vermicompost as fertilizer.	Increased photosynthetic activity reported in gram when subjected to drought. As vermicompost is rich in hormone alike substance humic	(Hosseinzadeh, Amiri, & Ismaili, 2018) and (Hosseinzadeh,

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			acid which is known for mitigating the effect of water stress, alleviates the effect of drought on the crop	Amiri, & Ismaili, 2017)
04	*Brassica compestris*	03 levels of vermicompost i.e. control, 2.5 and 05 t ha^{-1} has been used along with 05 levels of different nutrients i.e. Fe, Zn and S.	Increasing level of vermicompost tends to enhance plant height, no. of siliqua per plant and no. of seeds per siliqua, grain weight, biological and grain yield of this crop. Whereas, the application of mentioned nutrients increases the available nitrogen, phosphorus, potassium, sulphur, zinc, iron, manganese and copper. It is also influential on the oil content, availability of organic carbon, EC & pH of soil. Combination of both treatments proves to be more beneficial as compared to separate application.	(Amiri, Ismaili, & Hosseinzadeh, 2017)
05	*Arachis hypogea*	Application of phosphorus enriched vermicompost.	When crop is treated with vermicompost which is enriched in P at the rate of 150% with water sufficient conditions resulted in more yield as compared to the treatment utilizing P at 100% with inorganic fertilizer.	(Das, Debnath, Satpute, & Bandyopadhyay, 2015)
06	*Oryza sativa*	Priming of seeds with vermicomposting	Better seed emergence rate and development of early and healthy seedlings.	(Khan, Narayan, Bhat, & Maqbool, 2016)
07	*Vigna radiata*	Cow dung with *Eisenia foetida*	When vermiwash applied at the concentration of 10, 20 and 30% it increases the plant growth. It also stimulates the length of hypocotyl and radical. It is responsible for early seedling establishment as well.	(Jaybhaye & Bhalerao, 2015)
08	*Vigna mungo*	Vermicompost made up with cattle litter, equine litter and poultry litter.	Addition of vermicomposting to the soil during the life cycle of this crop resulted in enhanced growth, better combating with water stress, more pods, increase accumulation of protein content and more biological and grain yield.	(Mahmoudi, Nasri, & Azizi, 2016)

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09	*Helianthus annuus*	Application of vermicompost with inorganic fertilizer.	In water deficit conditions, vermicompost tends to increase the water holding capacity and availability of nutrients lead to improvement of plant growth, more source to sink accumulation of assimilates in Sunflower.	(Ahmadvand & Sanjani, 2016)
10	*Pennisetum glaucum*	Four levels of vermicompost with RDF i.e. 60kg N and 30kg of P (recommended dose of fertilizer) levels	Addition of vermicompost with 100% RDF shows better result than control and 50%RDF. Crop shows more height, number of effective tillers and grain weight.	(Choudhary, Yadav, & Parihar, 2015)

Vermicomposting method is considered better in comparison to composting in order to kill the pathogens, but some research studies showed that composting utilizes the high temperature of up to 70°C as it has more ability to kill the pathogens. As vermicomposting method includes earthworms so its operating temperature ranges between 30-35°C, temperature above this level may prove lethal to earthworms that may stop the bioconversion process (Neklyudov et al., 2008).

Nutrients Recovery Technologies (NRT)

The pathway for nutrient recovery from wastes includes three steps i.e. nutrient accumulation, release and extraction. Pyrolysis, chemical precipitation, Adsorption/Ion exchange, Algae, Liquid-Liquid extraction, Plants, Membrane filtration and Magnetic separation could be used for nutrient accumulation. However, for nutrient release, biological, thermochemical and bioleaching processes could be used. Furthermore, for nutrient extraction, chemical precipitation/Crystalisation, Gas permeable membrane, Liquid-gas stripping and Electrodialysis are very effective techniques (Fig 3). Some of the nutrient recovery technologies are discussed below.

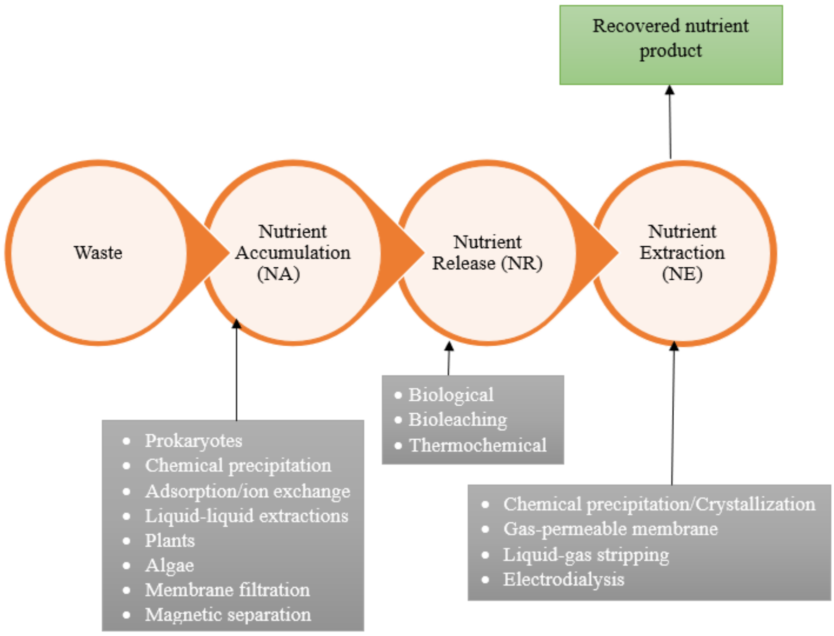

Figure 3. Nutrient recovery pathway from wastes

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Pyrolysis

During the heating process in pyrolysis most of elements are lost to atmosphere, became soluble oxide or fixed into recalcitrant form (Fig. 4). Biochar produced from wood under natural condition the Carbon, Nitrogen, Sulfur, Potassium and Phosphorus volatilize around 100ºC, 200°C, 375ºC, 700ºC and 800ºC respectively while above 1000ºC the volatilization of Magnesium, Calcium and manganese occur (Neary et al., 1999; Knoepp et al., 2005). Biochar produced from sewage sludge's at 450°C contain all of P and 50% N (Bridle and Pritchard, 2004). Using organic wastes as such for agricultural practices leads to serious environmental pollution (Carpenter et al., 1998; Matteson and Jenkins, 2007). These wastes can be used as by product for the charring process, weight and volume of waste also reduces after this process (pyrolysis) which is very important in mostly managing livestock waste (Bridgwater, 2003; Cantrell et al., 2007). Biochar is stable form of carbon which can be produced by the controlled heating of animal or plant materials at temperature 350-600 °C under the limited supply of oxygen (Jenkin and Jenkinson, 2009). Almost any materials which are organic can be used to prepare biochar. The benefits of Biochar on agriculture and environment have been presented in Fig. 5. Its quality depends upon method of its production and feedstock used to produce it. Old traditional technologies of producing biochar are energy consuming and prone to environmental pollution. Biochar can be prepared by pyrolysis, gasification and hydrothermal carbonization. Pyrolysis (fast and slow) is primary method for making biochar. Slow pyrolysis occurred at temperature 400 °C under the absence of oxygen (Kammer *et al.*, 2005) where as in fast pyrolysis, heating of biomass can be done at 400-700 ºC under anaerobic environment (Cummer and Brown, 2002). Modern biochar producing technologies has been develop in which drum pyrolysers, rotary kilns, screw pyrolysers, the Flash Carbonizer, fast pyrolysis reactors, gasifiers, hydrothermal processing reactors, and wood-gas stoves, all of which produce varying quantities of gas and liquids along with biochar. Biochar application can increase the carbon content in soil and help in carbon sequestration to improve soil and environment quality (Fig. 5). Moreover, biochar could also enrich soil with nutrients by improved recycling (Kammman et al., 2015; Mia et al., 2017a, 2017b). About more than half nitrogen, phosphorus and potassium can also be recovered (Mia et al., 2018).

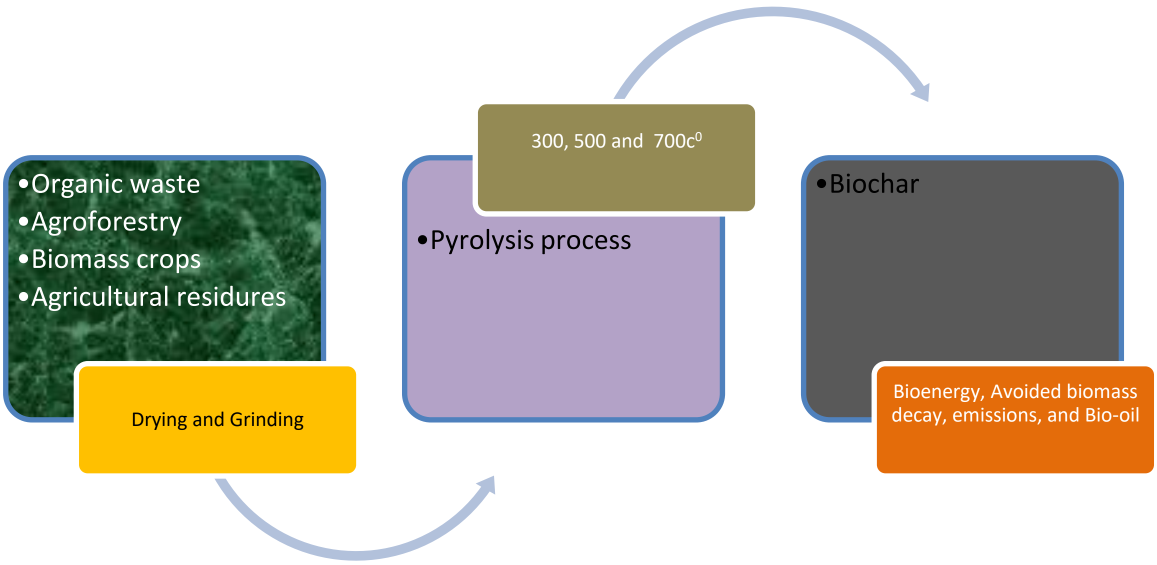

Figure 4. Biochar production process

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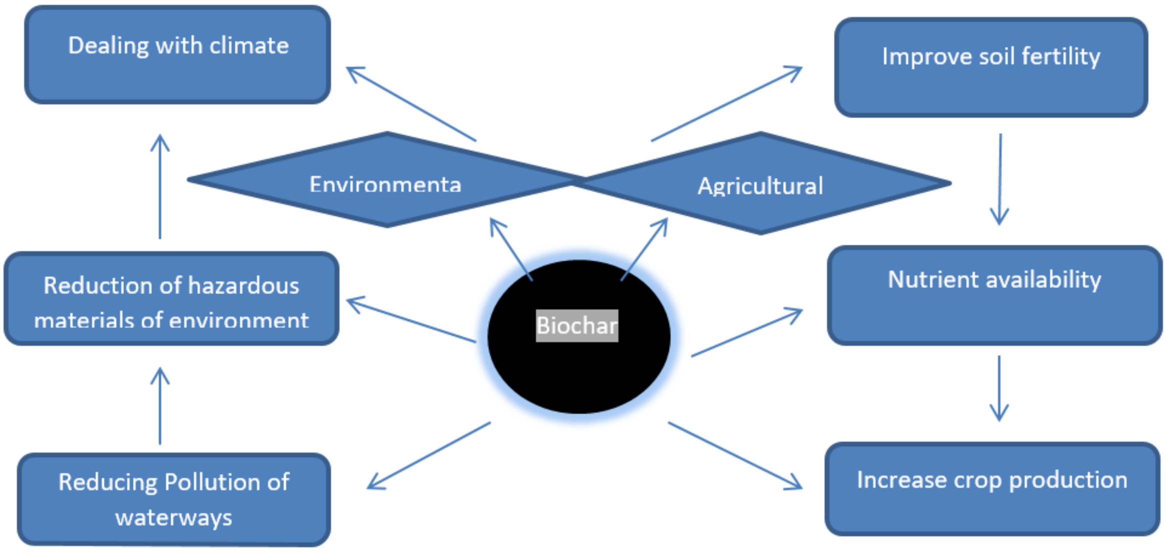

Figure 5 Impact of biochar on agriculture and environment.

Mehta et al., (2015) evaluated various technologies (electrodialysis and crystallization) for nutrient recycling or recovery based on various aspects as nutrient accumulation (plant microorganisms), extraction (chemical methods) and release of nutrients through bio and thermochemical treatment using waste stream. It was concluded that air and water pollution can be reduced by recovering nutrients without exposure to pathogen risks. Furthermore, application of these nutrients products in agriculture is needed to be developed. Further advancements in innovative technologies for nutrient recovery will help to tackle nutrient losses and combat surge prices of fertilizers needed for sustainability. Various aspects of environment like plant nutrient productivity, induced emission factor, global warming potential and greenhouse gas emissions related to nutrient uptake and release can be computed through below given formulae to get insight into their impact on ecosystem.

Plant nutrient productivity (PNUP)

$$\text{PNUP (kg grain/grain)} = \frac{Y}{F}$$

Here Y shows grain yield while F represents total N (Kg ha^{-1}) and P applied.

Nitrogen fertilizer induced emission factor N_2O

$$EF(N_2O - \frac{N(g)}{kg}N = EN_2O/N$$

N_2O describes total nitrous oxide and nitrogen emissions per season in life cycle of maize. Global warming potential (GWP) is the product of methane and nitrous oxide emissions released during single maize life cycle.

$$GWP\left(\frac{CO_2}{ha}\right) = 28 \times ECH_4 \times 265 \times EN_2O$$

Greenhouse gas emissions (GHGI)

$$GHGI\ (kg\ Co_2 - e/t) = \frac{GWP}{Y}$$

In the above equation, GWP depicts total sum of methane and nitrous oxide emissions while Y is the grain yield.

Net carbon budget in life cycle of crop can be calculated by given equation which includes direct, indirect carbon emissions and organic soil carbon addition.

Net carbon emission $(MgCO_2) = \sum(Ai\ \times fi)GWP_t + C_{seq}$

In the above equation, *Ai* represents agricultural inputs, *fi* shows emission factor, GWPt divulge total emissions in two life cycles of maize (Zhang et al., 2015). Effect of different waste management treatments on nutrient uptake have been presented in Table 3.

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Table 3. Effect of different waste management treatments on nutrient uptake.

Treatment	Nitrogen (N)	Phosphorus (P)	Potassium (K)	References
Composting of poultry litter with sugarcane and cabbage waste (20-100 days)	N decreased from 26 to 22 g kg^{-1} with increase in composting days	Extractable P decreased with composting time which was higher at early stages	K Increased from 725-775 mg kg^{-1} with increase in composting days	Saleem et al. (2018)
Biochar	No effect	Increased (above ground productivity)	incresead	Biederman and Harpole, (2013)
Only composting	50% of initial N was found in final compost	86.4% P was retained at final stage of composting	-	Pongani et al. (2012)
Vermicomposting (plant and animal wastes)	Highest N uptake (168-188 kg ha^{-1}) was recorded with 10-20 t ha^{-1} compost application	P uptake was not influenced with direct application. However, rate of (10 tha^{-1}) gave highest nutrient uptake (29-37 kg ha^{-1})	Uptake of K was increased	Nurhidayati et al. (2018)
Vermi composting(vegetable waste, mixture of spent mushroom waste, cow dung and leaf litter)	Uptake increased (160 kg ha^{-1})	Increase up to 33 kg ha^{-1}	K uptake (102 kg ha^{-1}) decreased as compared to N but was higher than P.	Nurhidayati et al. (2018)
Vermicomposting (mixture of coconut, vegetable waste, leaf litter and cow dung)	Increased up to 168 kg ha^{-1}	Relatively decreased (increased up to 32 kg ha^{-1}) as compared to N uptake.	Increased (109 kg ha^{-1})	Nurhidayati et al. (2018)
Vermicomposting (cow dung, leaf litter, vegetable waste and sugarcane)	142 kg ha^{-1} uptake was recorded	Decreased uptake of P (31 kg ha^{-1})	Decreased (91 kg ha^{-1})	Nurhidayati et al. (2018)
Biochar (Rice Straw) with nitrogen and phosphorus fertilizers	Increased total uptake by	Increase up to 40 kg ha^{-1}	-	Si et al. (2018)

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	plants up to (166.6 kg ha^{-1})	

Forward osmosis

Nutrient recovery from various raw materials including waste water can be enhanced through forward osmosis (Fig 6). This is semi permeable membrane-based technique used for solutions having different concentration i. e. dilute and concentrated (Fig. 6). In forward osmosis, water across the membrane is allowed by osmotic pressure (Xie et al., 2016). By using marine water draw solution Xue et al. (2015) recovered 93% water in FO process resulting in ten times more recovery of ammonium and phosphates. This high recovery of nutrient is also accompanied by using FO filtration (solution diffusion model) producing 50-80% rejection of ammonium and higher than 90% rejection of phosphate (Zhang et al., 2014). Higher strength of nutrient enrichment can be obtained through using membrane with high solute selectivity specifically ammonium and phosphate (Xie et al., 2016).

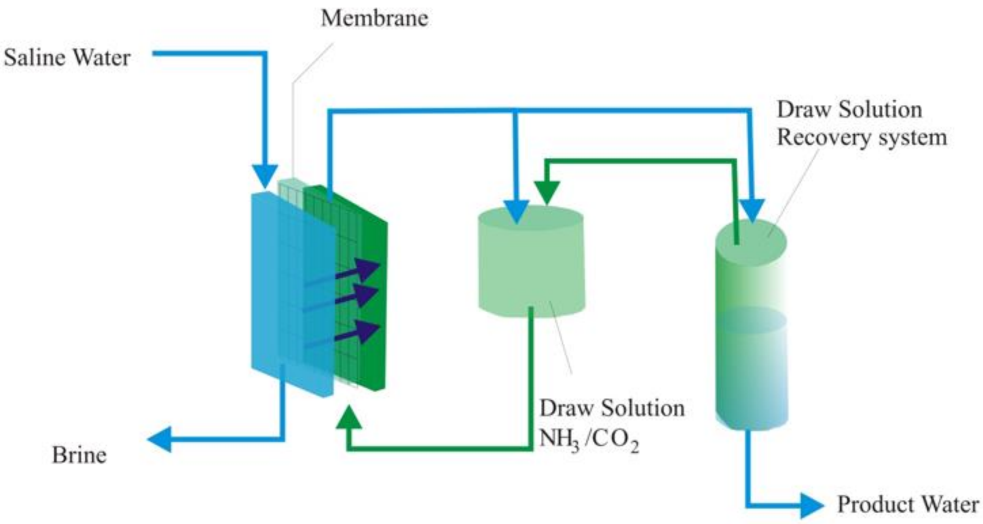

Figure 6 Nutrient recovery procedure of forward osmosis.

Electrodialysis

In an electro dialysis (ED), fraction of nutrients from waste water to high quality nutrients can be done through arrangement of ion-exchange membranes (Fig. 7). Migration of cations and anions towards their respective cathode is driven by direct current field (Xie et al., 2016). Applying ED process using bipolar membrane to convert phosphate and nitrogen present in sludge to pure phosphoric acid and nitrate or ammonia recovering quantity of (0.075mol L^{-1}) could provide an approach for nutrients recycling Wang et al. (2013) with higher recovery efficiency (Fig. 8 and 9).

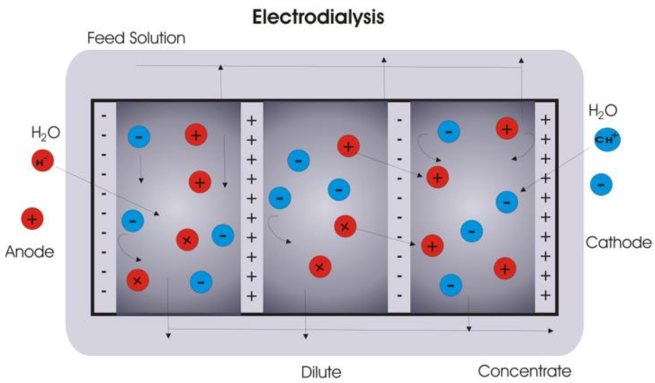

Figure 7. Illustration of electro dialysis unit mechanism.

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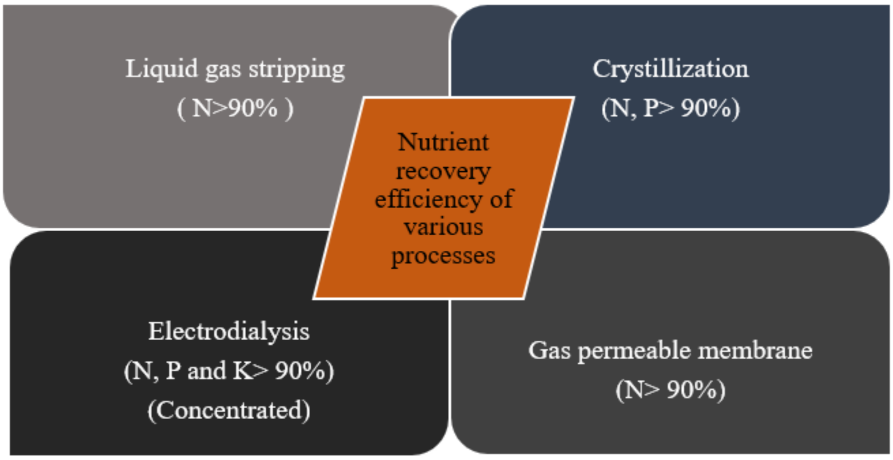

Figure 8 Nutrient use efficiency of various techniques

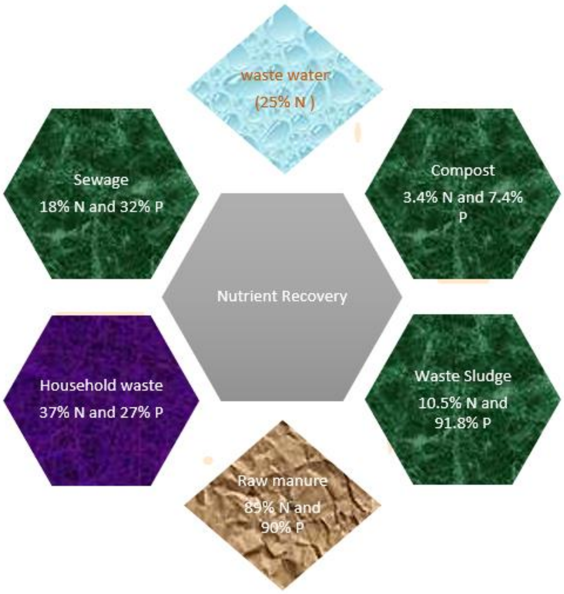

Figure 9. Nutrient recovery from various raw materials

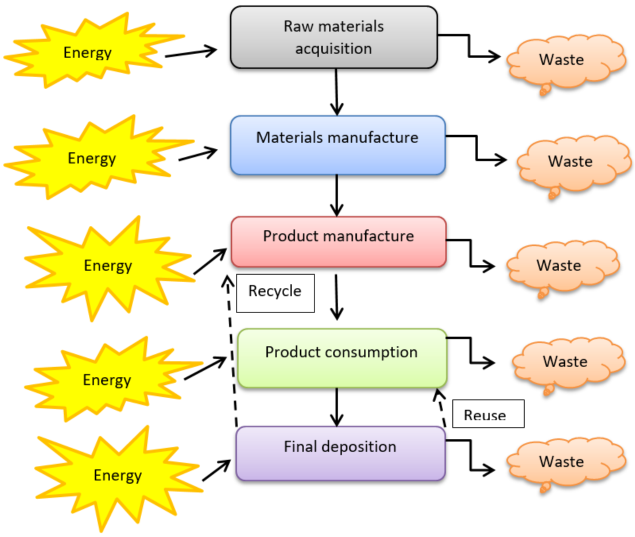

Figure 10. LCA Flow chart showing energy utilization and resulting by product.

Quantification of environmental impact using LCA

The impact of product, activity or process on environment can be evaluated by life cycle assessment (LCA). Nowadays, masses are employing diverse expertise to carry out evaluation of their products for energy gain and environment impacts (Fig. 10). Recent LCA studies on various agro-industrial products revealed that agriculture play key role in the life cycle of various products which can be assisted by the LCA for exploring sustainable development in future. LCA in combination with other approaches may prove helpful in development of strategies and policies for selection of dynamic products and processes (Roy et al., 2009). Moreover, number of products and by-products either dissipates energy to environment through release of nutrients or is wasted (Fig. 10).

Biochar contained pyrolysis life cycle assessment was conceded by Dutta and Raghavan (2014) to quantify the magnitude of carbon cycling and profitability of biochar obtained from various agro sources. Regarding emission, reduction was observed with corn fodder showing great economics as compared to forest residue and hence exhibiting the potential for soil carbon sequestration. Greenhouse gas (GHG) emissions observed was reduced due to stable carbon in biochar. This analysis can be used as tool for calculation of biochar environmental pollution and its applications.

Composting was evaluated using life cycle assessment (LCA) for possible impacts on environment. Critical insight to analysis disclosed that compost (processing stage) play crucial role, with largest impact on the environment by emerging emissions to induce eutrophication, acidification and global warming phenomenon. Inference divulged compost as useful for reduction of emissions as compared to peat system. This assessment provides a pathway to explore global impact of emissions on ecosystem and possible minimization co-related with methane, nitrate and nitrous oxides release (Saer et al., 2013). This review suggested that wastes management could be used to reduce the alarming threats to environment. Thus, these techniques should be implemented on ground level complemented with economic analysis to have real picture of these beneficial technologies.

Author Contributions: MA designed project conception and supervision, draft manuscript, manuscript writing and collection of data; SA, manuscript revision, FUK, manuscript writing and collection of data; AJ, manuscript writing and collection of data.

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