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Profitable Bioresource Management: Basis for Circular Bioeconomy

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Abstract: *Organic waste (OW) can be profitably managed through recycling and reuse under the concept of circular bioeconomy. The objectives of this study were to design an in-vessel composter for transforming OW to compost and to raise community awareness about the value-added and profitable management of OW. A design of an in-vessel composter for the small-scale recycling of OW is presented. Based on available data about solid waste (SW) produced from eight major cities of Pakistan, a model (OW = 0.1989×SW1.0577; R2 = 0.997) was developed to calculate the profit of OW recycling. This model was used to make a 5-year business plan for eight major businesses of Faisalabad – an economic hub and the third-largest city of Pakistan. The businesses were convinced by helping them make a 5-year business plan based on their individual needs for reaching a break-even point of returns for their investments. The businesses that did not produce enough OW to run the composter at its full capacity were advised to think about the composter's commercial use. The small businesses in the town may be interested in selling their waste to those involved in compost produ5ction. Farmers can recycle their byproducts, businesses can make a profit from waste recycling, and cities can benefit from a circular resource economy.*

Keywords: *Circular economy, Compost, Environmental stewardship, Faisalabad, Solid waste, Value addi-tion*

1. INTRODUCTION

Bioresources including municipal solid waste (SW) are a valuable component of the ecosystem. An economic system for the reuse of resources putting an end to the concept of waste is termed as the circular economy. Economic activity in such a system does not need synthetic ways of resource production but anthropogenic activities of agriculture and food production that provide bioresources as replacements for non-renewables [1]. The concept of circular economy has a contrast with the linear economy as the economic actors of a circular economy are environmentally safe. It aims at redesigning the life cycle of a product, having minimal input of resources, and minimal production of waste materials thus promising sustainability [2]. Thus, the circular economy transforms wastes of numerous industries including food and agriculture into a resource for another industry enabling circulation of bioresources, sustainability, and environmental stewardship [3]. The principles of reducing, reusing, and recycling lead towards a circular economy [4] which is completely in line with several targets of the United Nations' Sustainable Development Goals (SDGs).

According to the definition adopted by the German Bioeconomy Council [5] "circular bioeconomy is the production, utilization, and conservation of biological resources, including related knowledge, science, technology, and innovation, to provide information, products, processes, and services across all economic sectors aiming toward a sustainable economy". European Commission [6] defines circular bioeconomy as "the generation of renewable biological resources and the transformation of these resources into value-added merchandise including food, animal feed, bio-based products, and bioenergy". Circular bioeconomy benefits from enhanced circularity or bioresources by integrating the huge volumes of organic processes and waste from agriculture, forestry, fishery, food and animal feed, and organic processing wastes. It is an economic system meant for the persistent use of bioresources putting an end to the concept of waste. Economic activity in such a system does not need synthetic but bioresource as replacements for non-renewables. In the domain of agricultural and food production, the circular bioeconomy concept suggests that greater sustainability is achievable through this paradigm that is based on golden principles of reusing and recycling wastes.

A variety of organic waste materials are used as input for circular bioeconomy. Waste material is any by-product, deposit, or maybe stuff that is unable to be used further along the way that it had been shaped for. Waste materials may occur in many sorts, say for example as a solid material, like sludge, as a liquid, or even a combination of the two. There are many varieties of wastes as well as waste channels each along with their unique chemical makeup as well as actual traits. Waste products can vary from normal back garden reject as well as domestic waste, through to health-related, chemical, mining, and industrial waste. The actual make-up of each waste is unique which is determined by the functions as well as activities from which the waste was generated. Mismanagement of waste materials, whether that be solid or liquid, ends up posing environmental risks.

Most South Asian countries encounter serious environmental problems due to poor management of waste materials. The rapid growth of population and poor growth of gross domestic product (GDP) put massive pressure on the country's pure resource base and result in significantly increased pollution risks. The South Asian countries have yet to address the downsides of sustainable development as well as environmental protection within their national decision-making practices. Unregulated use of forests, terrain, water, urbanization, and population demand-driven expansion of agriculture has led to producing huge quantities of waste materials. This is due to in-sensitivities to poverty-environment nexus as well as flaws with current national policies of most of the developing countries [7]. The SDG target 11.6 aims at sustainable urbanization and reducing the environmental impact of the cities. The targets 12.2 and 12.4 necessitate the efficient use of natural resources and their sustainable management, especially environmentally sound waste management.

Solid waste assortment by government-owned and by operated companies in Pakistan's metropolitan areas currently averages solely 50% of waste materials produced; however, for cities being relatively clean, at the lowest 75% of waste materials must be collected. To do this level, large capital investment is needed for waste management services. Demand for services may grow since urban populations grow resulting in to increase in per capita waste generation. The latter is estimated to be 3% per year. The increased quantity of waste places greater demands on disposal companies, thereby exacerbating the already inadequate situation because present disposal methods for solid waste management are inadequate. Fingertips of poor waste management are simply by open throwing, primarily on flood plains and in ponds, creating significant ecological damage.

Unfortunately, not many cities of South Asia have a proper strong waste managing system right from the collection of solid waste to its proper disposal. High of the uncollected squander poses a significant risk to public wellbeing through clogging of drains, the creation of flat ponds, as well as providing mating ground for mosquitoes and flies leading to the consequential hazards of malaria, cholera, and other bacterial infections. Moreover, because of the possible lack of adequate removal sites, most of the gathered waste locates its technique in throwing grounds, start pits, ponds, rivers as well as agricultural territories in the suburb of cities. Environmental degradation is not new in most of the countries of this region. It is getting progressively worse since the human population, urbanization, and industrialization is boosting without caring for environmental stewardship.

Developing countries face serious environmental problems regarding waste management worse than those of many other developing countries. People and to some extent governments of these countries take natural resources as a base for the achievement of their basic needs of life such as food, fuel, fiber, fodder, minerals, water, and air, etc. The growth of the population has put great pressure on the natural resources of these countries with a great effect on the level of governance. The management of SW materials remains a big challenge. The basic reason for this challenge is increasing waste generation; it has resulted in the burden on a municipal budget as a result of the larger cost of management of waste. The management of SW materials absorbs a big part of the municipal economic budget. Municipal solid waste management is an extensively neglected area for the overall management of most developing nations.

Nowadays, developing countries are seriously concerned with the consequences of improper management of municipal SW [8]. The present methods of municipal SW management include incineration, landfilling, source reduction, and reuse, recycling, and composting [9]. Composting mostly deals with organic waste (OW) materials including food waste, leaf, and yard, and other green wastes, food-soiled paper, and other paper products. Composts are valuable alternative components for soilless substrates [10], which are generally considered as environment-friendly and sustainable management processes to recycle OW [11]. This aligns with the concept of circular bioeconomy.

The best practicable environmental option is defined as "the option that provides the most benefit or causes the least damage to the environment as a whole, at a cost that is acceptable to society in the long term as well as the short term" [12]. Finding out essentially the best practicable environmental option for organic waste management is adopting a circular bioeconomy to be able to optimally shield the environment at the most logical price tag. Sustainable recycling and reusing of organic waste through circular bioeconomy can be environmentally tolerable when accomplished correctly. Therefore, the objectives of this study were to design an in-vessel composter that uses OW segregated from SW for compost production and to raise community awareness about the value-added and profitable management of SW as a step toward the promotion of circular bioeconomy.

2. Materials and Methods

The study reported here was conducted during 2017-2018 in Faisalabad for a Master's research thesis at the Government College University Faisalabad – Pakistan [13]. The city of Faisalabad is considered a hub of textile and agriculture industries. This is the third-largest city of Pakistan located in the east-central and the most populous province of Pakistan –Punjab. The city generates 337,370 Mg of waste per year [14]. Non-technical composting of OW is common in Faisalabad because of the availability of OW and the potential needs of compost in this agriculture-based city of Pakistan [15].

2.1 The Compost Mechanism

The compost production mechanism with the use of an in-vessel composting procedure has three main steps including i) mixing of raw material, ii) active composting inside a vessel, and iii) curing. The OW can be used as a raw material feedstock for mixing porosity, particle size, moisture carbon to nitrogen ratio, substrate complexity, and quality of the feedstock.

The OW materials of a range of type and source are mixed in the rotary drum of the composter. In the phase of active composting in the vessel, pathogens and weed seeds are killed with high temperature, rapid decomposition, and high order potential. This process is generally 2-3 weeks long but could be shorter or longer depending upon the nature of OW and the size of the vessel. In this process, water may be introduced for leachate collection and air supply is mandatory for the removal of moisture content. After the microbial activity, the compost begins to stabilize and pile cools (mesophilic) in its ending stage. The curing process can be carried out inside the composting vessel, in a separate vessel, or outside in windrow or aerated static piles. Odorous compounds are not usually produced but are generally cured for at least 30 days.

2.2 Desing of the Composter

A rotary drum composter is an efficient technology for small-scale compost production operations. A rotating drum provides agitation, aeration, and mixing of the compost, to produce a consistent and uniform product without any odor or leachate related problems. The drum can be made from an iron sheet and the inner side of the drum may be painted with anti-corrosive coating. The motor needed to rotate the drum at 2 rpm needs a power of 7.46 kW. For the appropriate mixing, this longitudinal drum is welded angularly in which the feedstock (i.e; OW) moves through the drum because of the drum's tumbling action. An air pump or air blower is used to extract air from its outlet toward the inlet of the drum for aeration and escaping the foul gases from the drum. Its basic purpose is the maintenance of aerobic conditions inside the drum. Compost temperature needs to be monitored after every 24h intervals through thermocouples. Moisture reduction is possible by the installation of the air blowers. An efficient design must have a digital pH meter installed to continuously monitor the pH of the product (i.e; compost). Ideal values of the compost pH may range from 6 to 8; i.e; the limit of pH of the product being beyond acidic or alkaline nature. Composting proceeds most efficiently at the thermopile temperature when pH = 8.

The assumptions made for the design of the in-vessel rotary drum composter needed a maximum mass flow rate (maximum production of waste) of 3750 kg per week, an average density (ϱ) of food that composes most of the OW to be 540 kg m^{-3} [16-17]. The exterior of the drum was covered in insulation to reduce heat loss by conduction and convection. The calculating factors included i) dimensions of the cylinder, ii) shear strength and moment distributions across the cylinder, iii) heat transfer, and iv) surrounding environment with and without installation. Dimensions of the cylinder were volume, length, shear strength, and moment distribution. The volume of the vessel was chosen based on half the maximum potential production. Equation 1 was used to calculate the original value of the maximum potential load of compost; Q_{max} [18].

$$Q_{max} = m \times SRT \tag{1}$$

where Q_{max} has the units of kg, m is the mass flow rate (i.e.; = 3750 kg /week), SRT is the solid retention time (i.e. = 7 days). Putting all these values in equation 1 results in Q_{max} = 3780 kg. The volume of the cylindrical drum (V) was calculated in m^3 using a load of compost (Q) as:

$$V = \frac{Q}{\rho} \quad (2)$$

where Q is that half of the maximum potential of compost generation and density (ρ) of the compost (540 kg/m^3) as:

Load of compost, $Q = \frac{Q_{max}}{2} = \frac{3780}{2} = 1890$ kg

Putting all the value of Q_{max} in equation 2, V becomes 3.5 m^3 = 3500 L. A low surface area to volume ratio was required to reduce heat loss by convection thus by using a trial-and-error approach using various values of the radii of the cylindrical drum. The following equation was used to calculate the length of the cylindrical drum (m) using equation 3:

$$L = \frac{(V \times 4)}{(\pi \times d^2)} \quad (3)$$

where and V is the volume of a cylinder (3.5 m^3), π is 3.14. Taking the values of the diameter of the cylinder (d) exactly as 1.001 m, equation 3 results in L for the cylinder equal to 4.70 m.

2.3 Composter's Operating Cost

The designed in-vessel rotary drum composter needed a 10 Hp (10×746W = 7.46 kW) electric motor to rotate its drum of 1.00l m diameter and 4.70 m length. Considering the 85% efficiency of the motor, the electric input was calculated to be 8.78 kW (7.46 kW / 0.85). Energy cost requirements were based on charges of PKR13.5 per kWh resulted in the per hour operational cost of PKR119 for the motor. Therefore, one week of operational cost, to process 320 Mg of OW was calculated to be PKR1 9,905. Adding PKR7,557, as an operational cost for air pump (2.50 kW; 75% efficiency) to blow through composter for one week of 320 Mg of OW processing, to the motor operational cost, the total operating cost was calculated to be PKR27,462 per week. Therefore, the annual operating cost of the designed composter becomes PKR 1,428,024.

2.4 Data Collection and Analysis

The dataset (columns 3 and 4 of Table 1) of the solid waste used in this study was taken from the published report by Engineering Planning and Management Consultants Lahore [35] for eight major cities of Pakistan namely, Gujranwala, Faisalabad, Karachi, Hyderabad, Peshawar, Bannu, Quetta, and Sibi. Two cities from each of the four provinces were selected to have representative information about the life-style/eating habits of the people across Pakistan. This gave information of varying percentages of OW in the SW from different eating/consuming habits. The relationships used to calculate the values of the remaining columns (5-7) of Table 1 are given in the header of the columns.

Table1. *Calculations for the compost produced per year from the data of solid waste (SW) and the relevant percent by weight values of organic waste (OW) for eight cities of Pakistan [19].*

Cities	Province	SW (Mg) produced by the city per year	OW (% by weight of the SW)	OW (Mg) (SW[col3]×%OW[col2])/100	Compost produced (Mg) = (OW[col5]	Cost (Income) of compost produced per year (PKR) Compost[col6]

					× 0.07)*	×150**
Karachi	Sindh	2,354,250	49.8	1,172,417	82,069	12,310,373
Hyderabad	Sindh	356,131	47.1	167,738	11,742	1,761,246
Faisalabad	Punjab	337,370	41.0	138,322	9,683	1,452,378
Gujranwala	Punjab	300,770	36.8	110,683	7,748	1,162,175
Peshawar	KP[1]	295,395	41.2	121,703	8,519	1,277,879
Quetta	Balochistan	137,970	33.2	45,806	3,206	480,963
Bannu	KP	13,140	39.0	5,125	359	53,808
Sibi	Balochistan	6,205	32.1	1,992	139	20,914

[1] KP: Khyber Pakhtunkhwa; * OW has 7% of compost contents; ** based on PKR150 per kg of compost price in the local market

2.4.1 Organic waste - solid waste relationship

Data of columns 3 (SW produced by the selected cities in Mg) and 5 (OW calculated from %SW values of each city in Mg) were regressed against each other to generate a model relating SW and OW (Figure 1). The resulting power function relationship between OW and SW ($OW = 0.1989 \times SW^{1.0577}$; $R^2 = 0.997$) is a useful model that can be considered as a representative model to convert OW from SW generated by people of Pakistan resembled lifestyle in South Asia as most of this region has almost similar food, fruits, and eating habits.

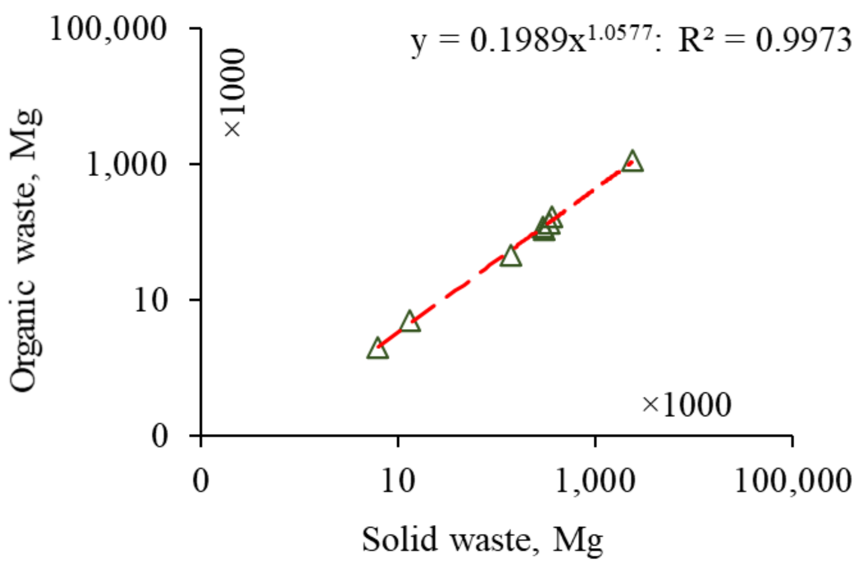

Figure1. *Organic wastes of the eight major cities of Pakistan plotted against the solid waste on log-log scales. The values at the horizontal and vertical axes are in thousands (×1000). The solid waste is the collected data, and the organic waste is the calculated data based on percent organic waste values given in Table 1 [19].*

2.4.2 Organic waste - solid waste relationship

Eight businesses of varying operations and services were contacted in Faisalabad to hold awareness sessions individually with each of the participating businesses. The outcomes of this effort were i) to design a composter for the businesses' needs, depending upon the volume of SW produced, and ii) to convince the participants for adopting circular bioeconomy through demonstrating basic calculations for the benefit-cost ratio of their intended investments.

3. Results

A WASTE-to-PROFIT (WAStPRO) model was prepared and financial analysis for a five-year business plan was prepared to promote the concept of circular bioeconomy in the study area. The WAStPRO tool (Figure 2) is for a layman's use to easily demonstrate and precisely calculate earnings from compost production. The idea was not to confuse the users with background modeling. This Excel sheet tool calculates the profit of users from the proposed SW management. The users are asked to enter the data of SW generated from their businesses and the market price of compost in their neighborhood. The profit is calculated using the formula Income = $0.1989 \times SW^{1.0577} * 0.07 * 150$.

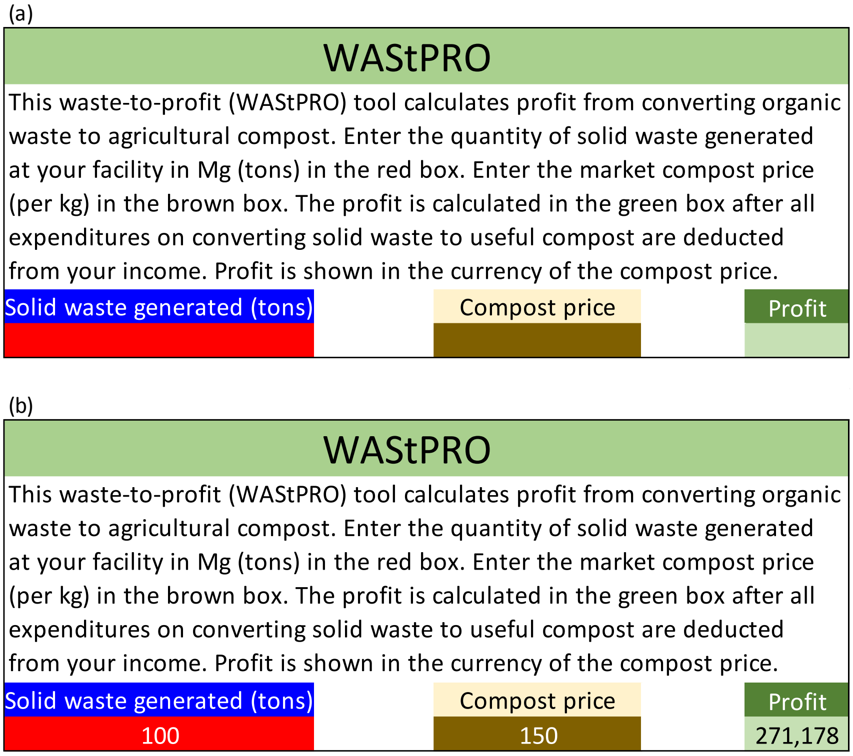

Figure2. *WAStPRO (WASTE-to-PROFIT) tool used during the community awareness drive to convince people for adopting circular bioeconomy: (a) the original tool without entries of the information and (b) the tool showing income in Pakistani rupees as the market price of compost was entered as PKR150 per kg.*

Eight businesses operating in Faisalabad city (Table 2) were targeted for awareness about circular bioeconomy. The business managers were convinced to participate in the awareness sessions. Data about the amount of waste generated by these businesses were collected. Necessary calculations included the Faisalabad businesses dataset and the model developed in Figure 1 ($OW = 0.1989 \times SW^{1.0577}$; $R^2 = 0.997$). Calculations in Table 2 give the expected per week income of the participating businesses through adopting a circular bioeconomy. This income is expected to increase after incorporating charges paid by these businesses for disposing of their solid wastes. These charges varied for each business with the quality of services, and season; summer versus winter and/or dry versus wet.

Table2. *Amount of reported solid waste generated per week from various businesses operating in Faisalabad city. For confidentiality, the exact business names have been omitted.*

Businesses	Industry	Store	Club	Restaurant	Pizza shop 1	Hotel	Pizza shop	Café

							2	
Waste generated, kg/week	186680	133484	18200	728	1040	1040	728	520
Income from composting (PKR)*	785352	550796	66942	2224	3243	3243	2224	1558

* calculated using the relationship 0.1989 × $SW^{1.0577}$ × 0.07 × 150 (Figure 1)

A 5-Year business plan and a budget 2018–2022 was worked out as a roadmap for the future direction and actions of city waste and resource recovery services to achieve operational performance, capital replacements, and preventive maintenance for the benefit of the community/industry over the next five years. The plan covered the first five years (2018-2022) of the investments and operations by providing calculations for the profitable reuse of SW of small-scale business. A careful cost and benefit analysis of composting presented a real picture of the beneficial use of solid waste. The analysis included calculating the operational cost of the composter of variable size based on the business needs (amount of SW to be processed for composting). Initial cost (i.e.; the cost of purchasing/manufacturing a small size composter; PKR200,000) plus the operational cost gave the total investments needed to be a part of circular bioeconomy. This helped in i) the provision of the state-of-the-art of compost production opportunity at a commercial level to industry and businesses, ii) understanding of the economic analysis of compost production from SW at small scale, and iii) availability of design of modern in-vessel composter producible at local workshops.

The 5-year business plan was based on the initial input cost on the purchase of a composter, its operating costs, the total cost on compost production, the market price of the produced compost, and annual income from the activity of circular bioeconomy (Table 3). As shown in Figure 3, the business is expected to start earning right during the second year. The income generated during the years onward may be partially utilized for up-gradation of the system as well as profitable SW management. An idea was floated from one of the participants that the businesses which do not produce enough OW to run the composter at its full capacity may think of its commercial use. The small businesses in the town may be interested in selling their waste to those involved in compost production.

Table3. *Expected income from the composter to produce compost from organic wastes calculated over the five-year business plan (2018-2022).*

Year	**Input capital (the price of a composter of the proposed design quoted by a local industry of Faisalabad)**	**Operating cost (from Section 3.1 plus annual maintenance cost of 10% of the operating cost from year 2 onwards)**	**Total expenditure on compost production (input capital plus the operating costs)**	**Income from compost production (from the relationship 0.1989 × $SW^{1.0577}$ × 0.07 × 150 for a composter to process 320 Mg)**	**Profit (total income [col5] minus total expenditure [col4])**
2018	-200,000	1,428,024	1,370,826	0	-200,000
2019	-200,000	1,570,826	1,370,826	1,388,741	1,188,741
2020	1,188,741	1,570,826	2,759,567	1,388,741	2,577,482
2021	2,577,482	1,570,826	4,148,308	1,388,741	3,966,223
2022	3,966,223	1,570,826	5,537,049	1,388,741	5,354,963

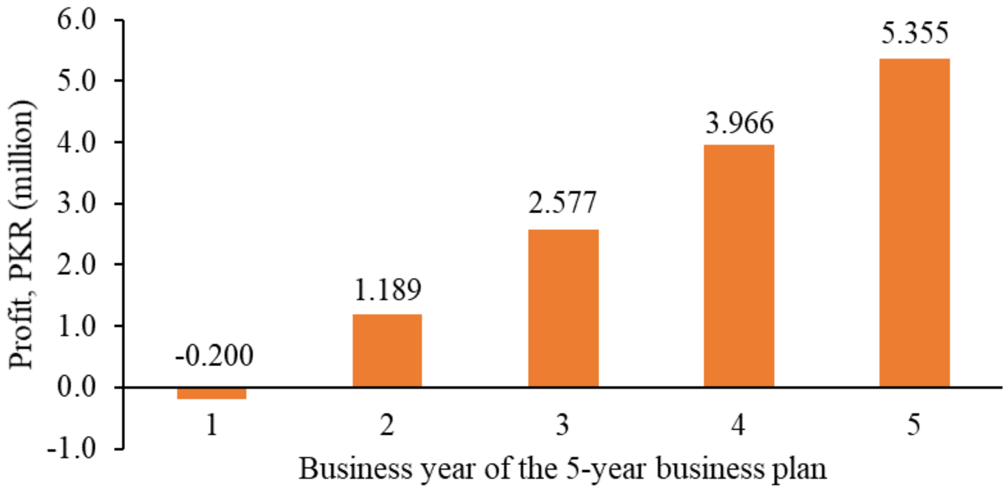

Figure3. *A 5-year business plan for reaching a break-even point of returns for investments and the further profitable adoption of composting from the business organic wastes.*

4. Discussion

Compost is a humus-rich product that is achieved from the conversion or stabilization of degradable OW by the action of microorganisms. Compost is produced from many different methods by using different types of OW materials. In-vessel composting is an anaerobic, heat-producing, and controlled process in which microorganisms convert a mixed organic substrate into CO_2, water, inorganic nutrients, and stabilized organic matter. The organic fraction of municipal SW is commonly treated through anaerobic digestion and/or composting as the best available techniques [20].

The final product of compost is of high quality, i.e; stable, mature, and free of health hazards and environmental risks [21-22]. It is considered beneficial for soil fertility and plants disease suppressive activity [23-24]. Aerobic composting and/or anaerobic digestion are biological treatments, which are the most environmental ways to process domestic wastes that are liable to decay [25]. It has been shown from earlier studies that both techniques can make the most of the re-processing of waste elements [26]. However, the most cost-effective method for the management of OW and the practice for concurrently generating a beneficial end product is through composting [27], which is the biochemical degradation of OW materials to hygienic and nuisance-free humus like substance. The process of composting occurs naturally; however, it can be accelerated through various methods such as the introduction of effective microorganisms [28], chemical nitrogen activators [29], frequent turnings, and shredding or natural additives and minerals [30].

Compost amendment in agricultural soils energizes the activity of microorganisms which upgrades the availability of plant nutrients and manufactures hormone-like substances with property to stimulate crop growth [31]. Compost is applied as a mixed soil amendment with biochar and studies have been conducted to analyze the effect of the combined use of biochar with compost on greenhouse gas emissions from soil application, to measure any positive effect on this parameter [32]. A compost production system constitutes a stunning technology that substitutes for municipal SW management in various socio-economic and technological contexts [33]. Besides, the biogas enhancement could improve the economic and social benefits for all the plants which perform biomethane upgrading for injection into the natural gas network, as stated in the study by Martìn-Pascual et al. [34].

Compost was reportedly preferred over organic fertilizer due to the positive response of farmers [35]. In a semi-arid environment of Pakistan, the combined use of compost and nitrogen fertilizer was analyzed by Iqbal et al. [36] for its effect on maize quality, productivity, and profitability. They reported that compost increased nitrogen use efficiency, crop nitrogen uptake, and reduced nitrogen losses. Nawaz et al. [37] reported that the imbalanced fertilizer application was a major cause of low sugarcane yield and deterioration of soil as compared to the field with compost amendment. The generation of compost from waste materials ensures sustainability and environmental stewardship [38]. A careful cost and benefit analysis of composting can present a real picture of the beneficial recycling of SW.

Circular bioeconomy presents a conceptual framework that leads to the use of renewable natural capital to transform and manage the land, food, health, and industrial systems, to achieve sustainability in coherence with nature. Encouraging participation of the Faisalabad business community revealed the interest of the community in circular bioeconomy. Such concepts must be introduced to the developing countries where the use of synthetic products is expensive and unaffordable for many. The approach introduced in this study can be used for convincing people to adopt the circular bioeconomy practices. Such ways of reusing or recycling bioresources are better than landfilling the food wastes because it does not only reduce negative environmental impacts but improves user's ability of profitable waste management. It is concluded that the circular bioeconomy seems one of the solutions to sustainability as it is a closed-loop sustainability framework involving biomass. It has the attributes of success at small and large scales. Farmers can recycle their byproducts, businesses can make a profit from waste recycling, and cities can benefit from a circular resource economy.

Author Contributions

The authors list is produced based on their contribution. All authors have read and agreed to the published version of the manuscript.

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