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ORIGINAL RESEARCH

Smart vermicomposting bin for rapid transformation of Dal lake aquatic weed into fortified vermicompost

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Abstract

Purpose The study was conducted to develop and assess the feasibility of the low-cost mechanical interface as an alternative to the conventional land-based bin type vermicomposting process. The idea was to reduce the drudgery, enrich the nutrient status and reduce the cost of preparation of vermicompost.

Method A smart vermicomposting bin comprising of Arduino, feeding hopper, shredding rollers, spiral mixing unit, degradation bin and harvesting gate was fabricated for the preparation of vermicompost from Dal Lake aquatic weed in Kashmir valley. *Eisenia fetida* earthworm facilitated the degradation process.

Results The Dal lake aquatic weed was degraded in the smart vermicomposting bin. The turning frequency was set as 10 days and 20 days. The performance parameters at 10 days turning interval were pH 7.05, electrical conductivity 0.837 dSm^{-1}, available nitrogen 1.15%, available phosphorus 0.06%, available potassium 1.91%, organic carbon 26.2% and C:N ratio 16.3:1 after 60 days degradation period. The comparative evaluation revealed that increase in available nitrogen, phosphorus and potassium at 10 days turning interval was higher by 4.01%, 6.06%, 4.94% than 20 days turning interval. The benefit – cost ratio was 0.45 in first year and 1.78 in second year with a pay-back period of 19 months. The unit cost of vermicompost production was Rs. 13 per kilogram.

Conclusion The involvement of mechanical intervention in vermicomposting can help in reducing the dependence on scarce land and addressing the issue of peak labour shortage. Moreover, the automation of the system can reduce the human errors.

Keywords Arduino, Vermicompost, *Eisenia fetida*, Dal lake aquatic weed, Waste management

Introduction

Modern production technologies have resulted in generation of large quantities of organic waste (Muzamil 2012) with an opportunity to recycle (Hiloidhari et al. 2014). The conventional methods of unscientific disposal at land sites, dumping, sanitary land filling and incineration is unsustainable (Atiyeh et al. 2000) and often culminates in the pollution of entire terrestrial ecosystem (Sehar et al. 2016; Mishra et al. 2017). Vermi-composting is perceived as viable, cost-effective (Asha et al.

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2008) eco-friendly technique (Yadav 2015) for transformation of organic waste (Garg et al. 2006) using earthworm as bioagent (Blouin et al. 2013; Alidadi et al. 2007). Vermicomposting utilizes the service of *Eisenia fetida, Eudrilu seugeniae, Lampito mauritii, Lumbricus rubellus, L. terrestris, Perionyx excavatus* for enhancing the degradation rate of organic wastes. *Eisenia fetida*, also called as red earthworm possesses maximum conversion efficiency (Barik et al. 2011) of organic waste into nutrient and soil conditioner (Pathma and Sakthivel 2012; Wani et al. 2013; Ramnarain et al. 2018). Although, vermicomposting is a sustainable technological solution for degradation of organic waste, however, the technique relies heavily on land, labour and capital (Devkota et al. 2014). The shrinkage of agricultural land owing to fragmentation, diversion, construction and orchard cultivation and heavy requirement of labour has reduced the adoption of this technology among the farmers. In Jammu and Kashmir, the problem is mainly restricted to availability of large quantities of aquatic flora manifested mainly in Dal lake of Srinagar city (Najar and Khan 2010). The aquatic weeds usually serve as a food for aquatic animals and complete at least a part of their lifecycle in water (Varshney et al. 2008). However, the anthropogenic addition of about 18.1 tons of phosphorus and 25 tons of inorganic nitrogen annually to sustain agriculture productivity system (Masoodi 2017) has resulted in the rapid growth of these aquatic weeds, which in turn, induced nuisance in terms of invasion of water bodies, choking of drainage channels, reduction in penetration of sunlight, thereby, affecting aquatic production system and human health (Kumar 2011). The aquatic weeds are also responsible for damaging pumps and turbines of thermal and hydroelectric power stations, resulting in an increase of maintenance cost (Lancar and Krake 2002). A number of physical, chemical, biological and technological methodologies are present to manage and control organic waste invasion system; however, most of them are manifested with low degradation rate, labour intensive, costly and abysmal for environment (Najar 2011). Lack of viable cost-effective technology for the economic nutrient recycling has rendered the system unsustainable (Jeyabal and Kuppuswamy 2001).

The fertility status of the vermicompost can help to cater to the needs of crop plants in order to promote the growth activity and serve as a sustainable alternative to chemical fertilizers (Chauhan and Singh 2015). It plays an essential role in the accretion of essential nutrients (Gandhi and Sundari 2012), enhancement of physio-chemical and biological properties (Ansari and Jaikishun 2011; Chauhan and Singh 2013), improvement in porosity, aeration, drainage, solubility of the nutrients, water holding capacity (Ismail 2005; Edwards et al. 2011) and bioaccumulation of heavy metals in the soil (Hemalatha 2012). In fact, the utilization of vermicompost based organic agriculture can usher a revolution in terms of consumer's health and environmental protection (Kaplan 2016).

The mechanical interface in the vermicomposting is critical as mixing of the materials at regular intervals is cumbersome and laborious. The mixing of materials regulates the temperature, distributes the moisture and rearranges the position of earthworms, thereby, contributing to the augmentation of degradation of organic wastes in less duration (Hande and Padole 2015). The variation in mechanical properties of organic waste in terms of moisture content and stem thickness demands an efficient shredding unit for particle size reduction (Muzamil et al. 2016). The particle size reduction provides more surface area for the earthworms to multiply and increase the degradation rate (Muzamil et al. 2015). However, size reduction and mixing of the materials at regular intervals is not possible in conventional bin-based vermicomposting system. The size reduction can help to increase the degradation rate (Muzamil et al. 2014) for preparation of vermicompost in shortest possible time (Hande and Padole 2015). The mechanical intervention can also help to maintain the optimum temperature essential for the growth of *Eisenia fetida* in Chilly weather and prepare the vermicompost throughout the year (Edwards 1998).

Materials and methods

Collection of organic waste

The research activity initiated with the collection of aquatic weed from the interiors of the Dal Lake. The initial preliminary experiments were conducted to understand the dynamics of shredding and degradation process in order to finalize the design parameters of smart vermicomposting bin. It was followed by the conceptualization and design of the smart vermicomposting bin using AutoCAD, Fig. 1. The fabrication was carried out in 2018-2019 in the workshop of College of Agricultural Engineering and Technology (CoAE&T), SKUAST, Shalimar, J&K.

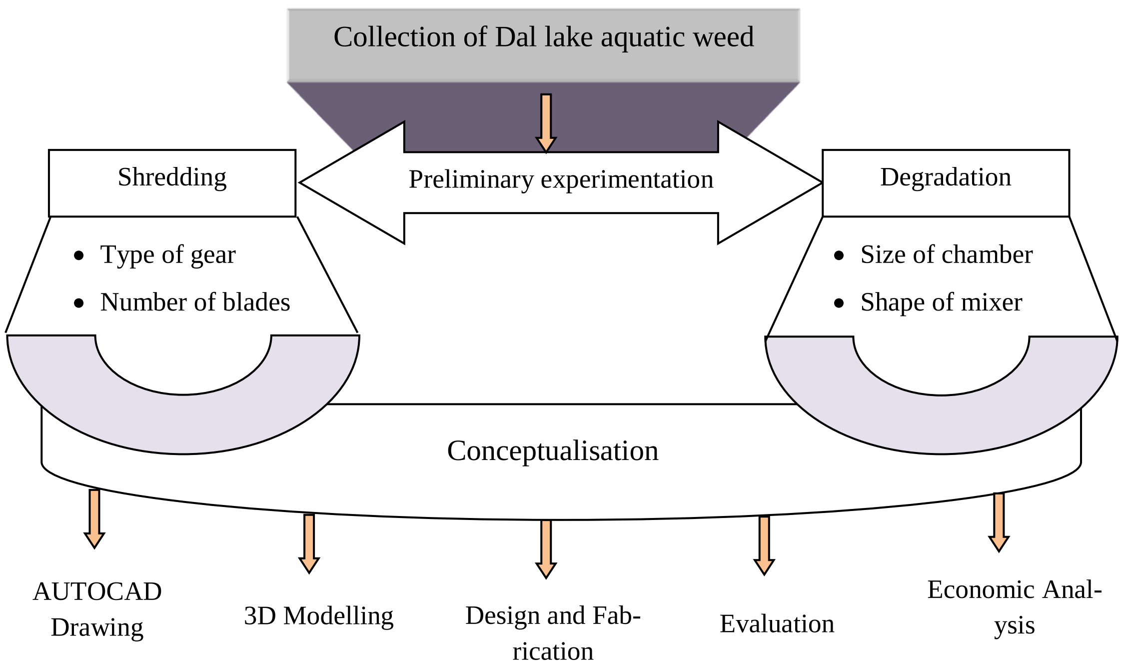


Fig. 1 Protocol of the study

Fabrication of smart vermicomposting bin

The vermicomposting unit comprised of feeding hopper, shredding rollers, rectangular bin, spiral mixer and harvesting gate, Fig. 2a. The feeding hopper was provided with trapezoidal shape (volumetric capacity 0.021 m^3) to converge the material towards the blades of the shredding rollers. The convergence ensured that the biomass covers the entire cutting surface of the shredding section for uniform size reduction. The shredding section was provided with cutting blades mounted on two rollers of (Φ 0.02 m) equidistant from each other. Each roller contains 22 blades with a set of gears mounted at the periphery. One of the rollers was attached with a handle to impart rotary motion to it. The gear on the periphery transmits the motion of one roller to the other. Each blade on the roller was installed in such a way that it covers the space between two adjacent blades on other roller, leaving a small space for the biomass to pass. The motion generates differential speed, shear and impact force for biomass size reduction. The arrangement was made to chop the materials into size lower than 5 cm. The rectangular chamber (0.80 m x 0.50 m x 0.90 m) was designed to serve as storage bin for the degradation of the biomass, Table 1. The box has the maximum capacity of about 80 kilograms. The sides of the rectangular chamber were covered with double layered carbon fiber to maintain the temperature inside the chamber. A spiral shaped mixer was installed inside the rectangular chamber to mix the materials at regular intervals. The spiral mixer was operated manually. The mixer aerates the materials, distributes the moisture, temperature and earthworms to enhance the rate of degradation. The harvesting gate was installed at the bottom to harvest the prepared vermicompost from rectangular degradation chamber. The harvesting gate was provided with a latch to keep it closed during the degradation phase, Fig. 2b.

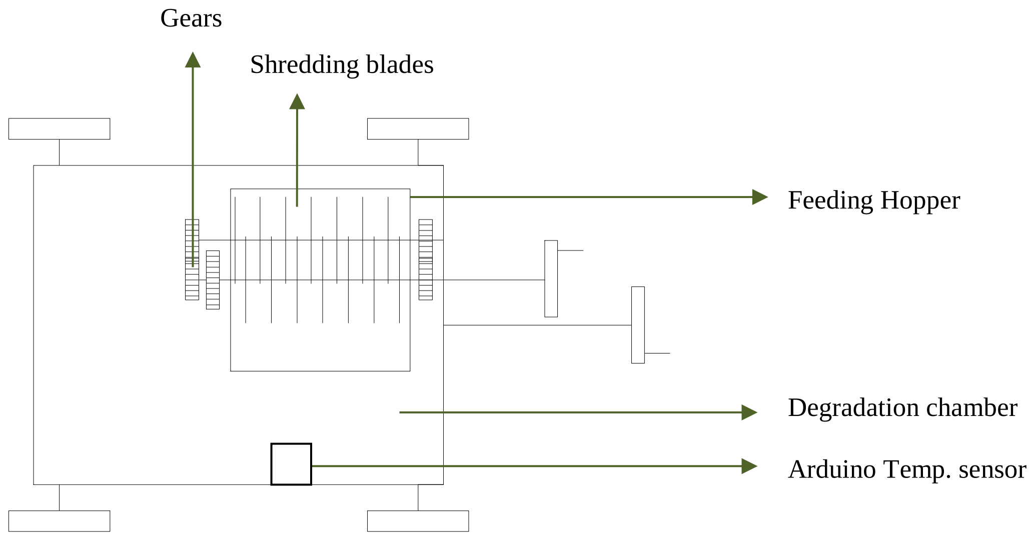


Fig. 2a Conceptual design of smart vermicomposting bin

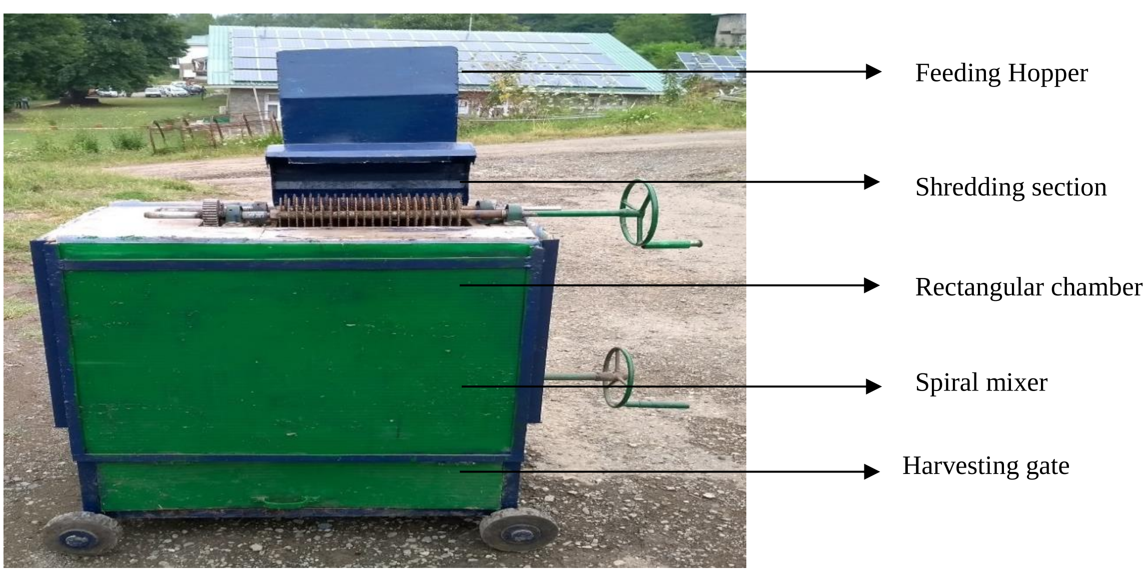


Fig. 2b Developed prototype of smart vermicomposting bin

Table 1 Design values of individual components of smart vermicomposting bin

Components	Design parameters	Shape	Dimensions	Values
Dimension	-	-	Height, m Length, m Width, m	1.35 0.87 0.56
Feeding Hopper	Density of biomass, kg m^{-3} = 100	Trapezoidal	Volumetric capacity, m^3	0.021 m^3
Degradation bin	Density of cow dung, kg m^{-3} = 400 Unit weight of earthworms	Rectangular	Size, m	0.80 m x 0.50 m x 0.90 m
Shredding section	Speed of the smaller roller = 45 rpm	Circular	Rotor diameter, m No. of blades Diameter of blades, m Type of gear	0.02 m 42 0.1 m Spur
Mixer	Total load, kg = 20	Spiral	Diameter, m Rotor diameter, m Speed, rpm No. of bars	0.025 m 0.4 m 10 8
Harvesting gate	-	Rectangular	Size, m	0.74 x 0.19 m

Arduino based watering and temperature sensor

An Arduino based automatic watering system was provided to maintain sufficient moisture for sustaining metabolic growth of earthworms, Fig. 3. The sensor was attached with the motor to spray water at the time of turning of materials. A temperature sensor was also placed inside the rectangular bin to monitor the temperature throughout the degradation process. It was intended to cater to the needs of cold temperature climatic regions. The system comprised of Arduino UNO board, water pump motor, motor driver, soil moisture sensor, temperature sensor (LM-35) and analog to digital convertor.

Experimental procedure

The experiment was laid by feeding the Dal lake aquatic weed to the feeding section of the smart vermicomposting bin to chop it below 5 cm size, Fig. 4.

It was followed by mixing 3-4 old pre-digested cow dung in the ratio of 1:1. The initial nutrient content of the Dal lake aquatic weed and cow dung was measured in terms of organic carbon, nitrogen, phosphorus, potassium and C:N ratio for comparative evaluation, Table 2. About 1 kilogram of *Eistenia fetida* was also added as bio-agent. Two set of experiments were laid with 10 days and 20 days turning frequency and samples were collected after each turning to witness the change in 20 days, 40 days and 60 days degradation period, Fig. 5. The samples were grinded and passed through 2 mm sieve for analytical procedure (Muzamil et al. 2020).

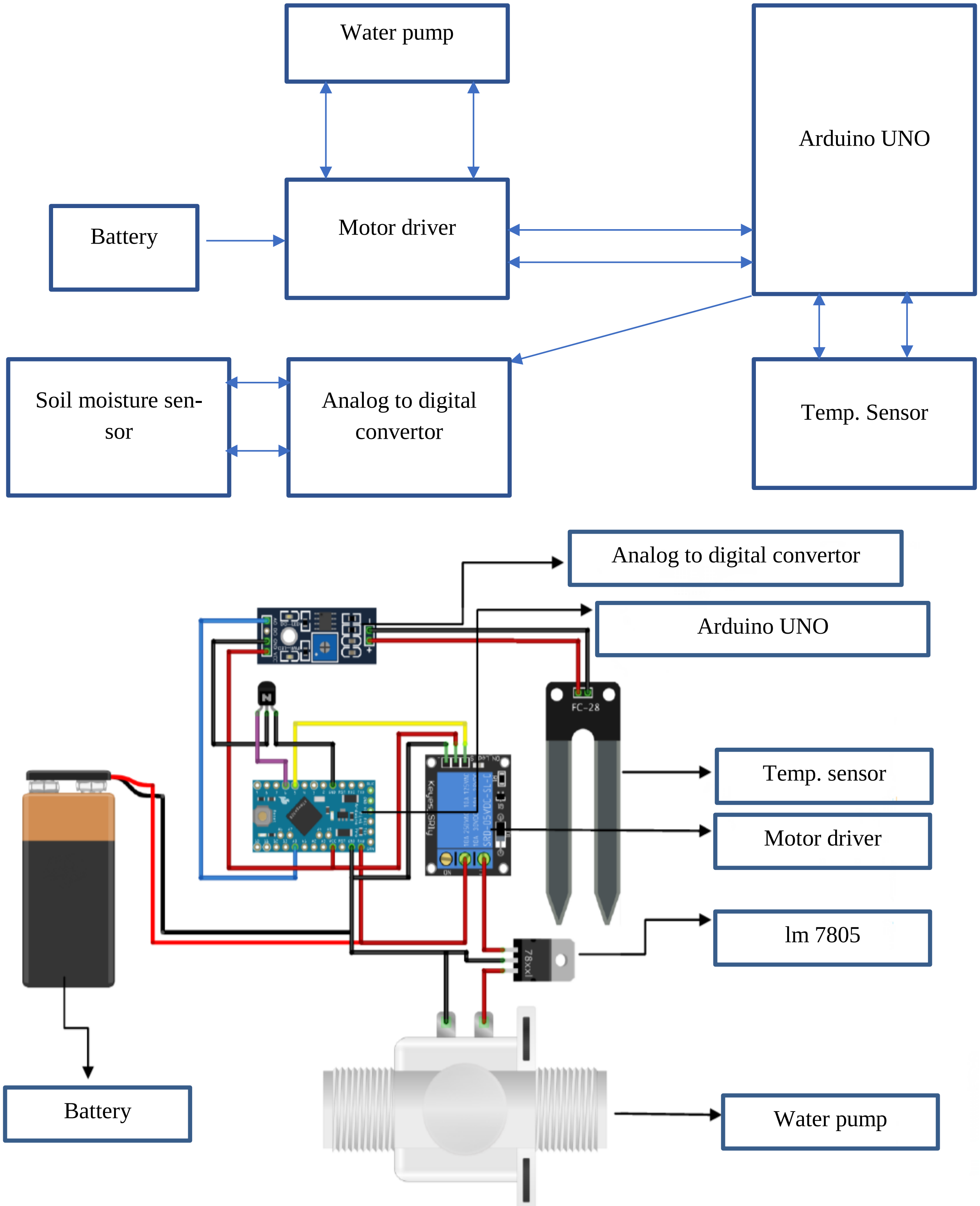


Fig. 3 Arduino based watering system and temperature sensor

Fig. 4 Size reduction of the Dal lake aquatic weed

Fig. 5 Collection of samples and preparation for analysis (S: sample; T: Turning frequency; D: Degradation period)

Table 2 Initial nutrient status of the mixing materials

Parameters	Organic carbon (%)	Nitrogen (gkg^{-1})	Phosphorus (gkg^{-1})	Potassium (gkg^{-1})	C:N ratio
Dal lake aquatic weed	36.70 ± 1.2	7.50 ± 0.47	5.10 ± 0.2	7.20 ± 0.31	48.93 ± 1.1
Cow dung	41.70 ± 1.7	8.20 ± 0.35	5.80 ± 0.1	3.60 ± 0.1	50.85 ± 3.1

Evaluation of developed smart vermicomposting bin

The developed prototype of smart vermicomposting bin was evaluated in terms of turning frequency and degradation period. The responses were measured in terms of pH, electrical conductivity, available nitrogen, available phosphorus, available potassium, organic carbon and C:N ratio, Table 3.

Statistical analysis

The experiments were organized as per the plan of the experiment and statistically analyzed by CRD (completely randomized design) to determine main, interaction effect and significant differences between treatment means at 5% level of significance.

Table 3 Plan of experiment for accessing performance of smart vermicomposting bin

Parameters	Levels	Responses
Turning frequency	10 days (T10) 20 days (T20)	• pH (Jackson 1973) • Electrical conductivity (Jackson 1973) • Available Nitrogen (Subbiah and Asija 1956) • Available Phosphorus (Olsen et al. 1954) • Available Potassium (Jackson 1967) • Organic carbon (Walkley and Black 1934) • C:N ratio
Degradation period	20 days (D20) 40 days (D40) 60 days (D60)	

Results and discussion

pH

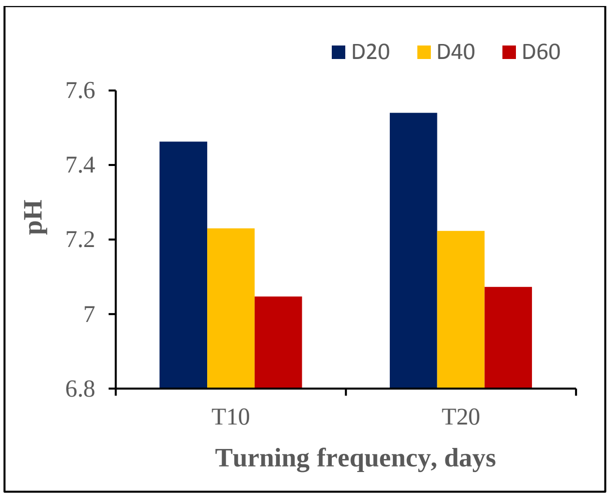
The neutrality of vermicompost is essential for accessibility of the critical nutrients (nitrogen, phosphorus and potassium) and survivability of earthworms (Edwards and Arancon 2004). The hydrogen ion concentration of Dal lake aquatic weed in terms of pH decreased from 7.46 to 7.04 with a mean value of 7.24 turned at 10 days frequency after 60 days degradation period. The turning frequency of 20 days resulted in reduction in pH from 7.54 to 7.07 with a mean value of 7.27 in same period, Fig. 6. The statistical analysis revealed that turning frequency and degradation period was significantly influencing the pH of the vermicompost at 5% level of significance.

Electrical conductivity (dS m^{-1})

The electrical conductivity signifies the availability of the nutrients in ionic form to the plant roots. The electrical conductivity of the Dal lake aquatic weed increased with the increase in microbial activity of the earthworm *Eisenia fetida*. When the materials were stirred at 10 days turning frequency, the electrical conductivity increased from 0.68 to 0.83 dSm^{-1}, which was comparatively higher than 0.67 to 0.78 dSm^{-1} increase with 20 days turning frequency, Fig. 6. The increase in electrical conductivity is attributed to the release of mineral salts and mineralization of organic matter (Kaviraj and Sharma 2003; Najar and Khan 2010). The parameters of turning frequency, degradation period along with their interaction was found to be significantly influencing the bolstering of electrical conductivity at 5% level of significance.

Available nitrogen, phosphorus and potassium (gkg^{-1})

The availability of nitrogen governs the growth of plants as it ensures the synthesis of chlorophyll. An increase in available nitrogen from 9.96 to 11.47 gkg^{-1} with 10 days turning frequency and 9.9 to 11.01 gkg^{-1} with 20 days turning frequency was observed in 60 days degradation period, Fig 7. The increase in nitrogen content was mainly due to the metabolic activities of the earthworms as their excretory products contain high amount of ammonia (Ansari and Rajpersaud 2012), rich nitrogen mixture of cow dung and aquatic weeds (Patil et al. 2012; Ansari and Rajpersaund 2012) and mineralization of nitrogen organic matter in the substrate (Najar and Khan 2010). The interactive effect at 5% level of significance between turning frequency degradation period was significantly governing the nitrogen content in vermicompost prepared from Dal lake aquatic weed. The increase in available phosphorus content with 10 days turning frequency increased from 0.5 to 0.66 gkg^{-1}, comparatively higher than 0.49 to 0.61 gkg^{-1} with 20 days degradation period in 60 days degradation period. The mean value at 10 days turning frequency of available phosphorus content (0.59) was higher than 20 days turning frequency (0.56), Fig. 7. The suitability of the environment and individual capacity of the earthworm *Eisenia fetida* may be the reason for the increase in phosphorus content (Patil et al. 2012). The activity of the phosphorus solubilizing bacteria present in the aquatic biomass can also be accredited to the rise in phosphorus content (Ankaram et al. 2012). The potassium content followed similar trend as that of nitrogen and phosphorus, owing to presence of sufficient moisture and biomass for sustaining earthworm load. The available potassium content increased from 17.36 to 19.12 gkg^{-1} when the materials were turned with 10 days turning frequency in 60 days degradation period. The uniform mixing of the materials by spiral mixer can be the rationale behind mineralization of the substrate materials by the earthworm *Eisenia fetida* (Manna et al. 2003; Suthar 2007 and Najar and Khan 2010).



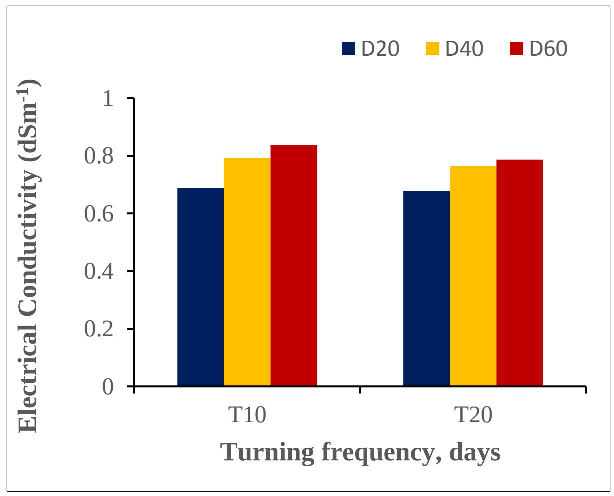


Fig. 6 Variation in pH and electrical conductivity with turning frequency and degradation period

Change in organic carbon (%)

Organic carbon is responsible for acting as a barrier against destructive substances and supplements the water holding capacity of the soil. The organic carbon decreased continuously due to release of carbon dioxide owing to the respiration of earthworm *Estenia fetida* and microorganisms (Kannadasan et al. 2013; Sridevi et al. 2016; Najar 2011 and Yuvaraj et al. 2018). Consequently, a continuous decrease in organic carbon was witnessed with both turning frequency of 10 and 20 days. At 10 days turning frequency, the organic carbon decreased from 30.8 to 26. 2%, Fig. 8. In general, the decrease was more prominent with 10 days turning frequency in 60 days degradation period.

C:N ratio

C:N ratio of 20:1 or lower depicts the availability of nutrients, quality of vermicompost and stabilization of biomass to a level equalizing to that of fertilizer (Hussain et al. 2016). A reduction in the C:N ratio was obtained with both turning frequency of 10 days and 20 days. This lends support of involving mechanical interface for the production of vermicompost as C:N of the vermicompost prepared in vermi-beds failed to reach that mark.

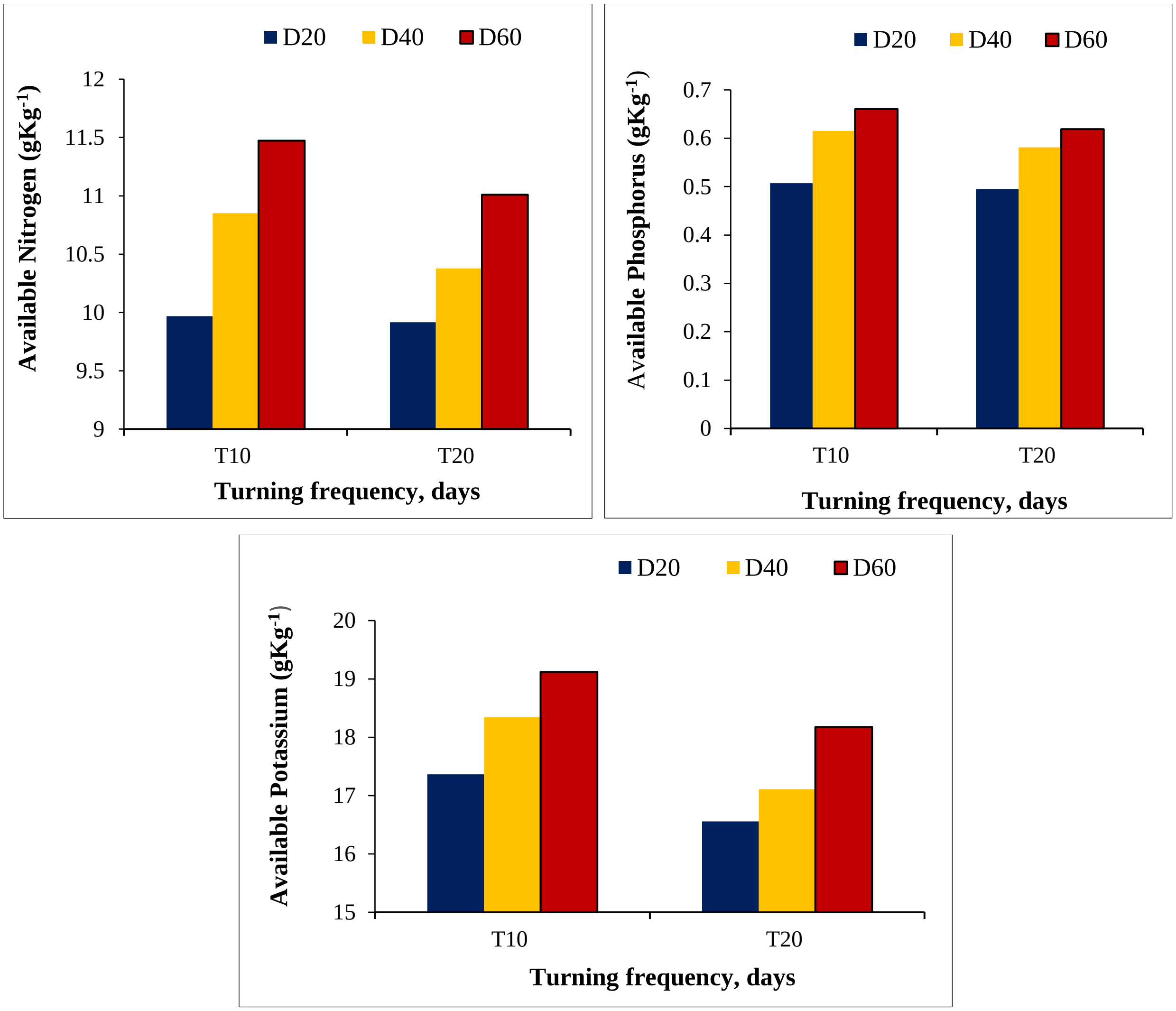


Fig. 7 Change in available nitrogen, phosphorus and potassium content with turning frequency

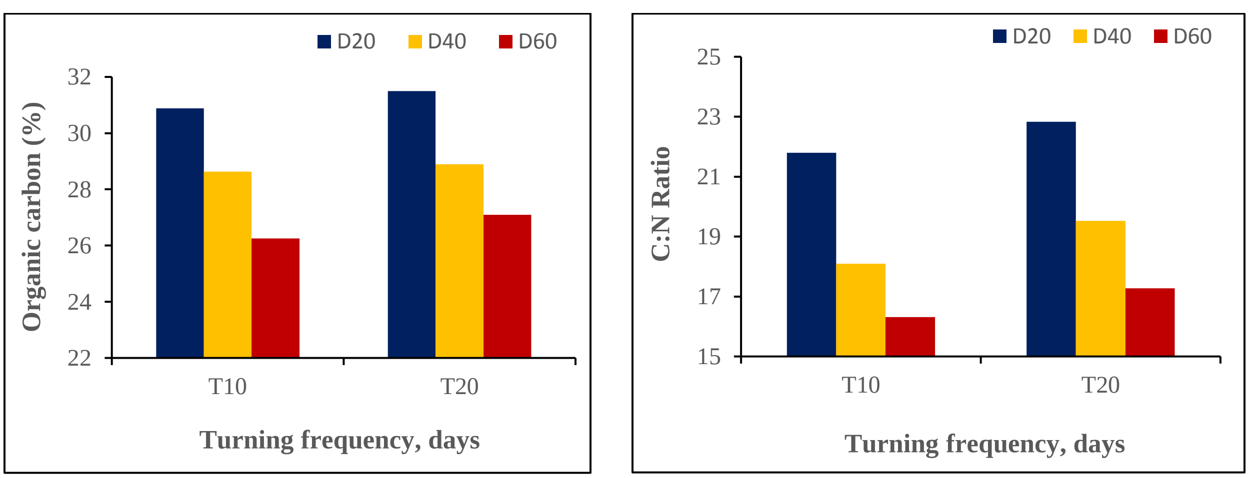


Fig. 8 Variation in organic carbon and C:N ratio during vermicomposting process

Table 4 Economical parameters of smart vermicomposting bin

S. No.	Parameters	Value, Rs.
1.	Cost of operation per hour	117.4
2.	Breakeven point, kg	140
3.	Payback period, months	19
4.	Benefit cost ratio	0.45 – First year 1.78 – Second year
5.	Annual Utility (Kg)	320
6.	Cost of production per kg	13

The C:N ratio decreased from 21.79 from 16.31 with 10 days turning frequency in 60 days degradation period. The decrease was more evident with 10 days turning frequency than 20 days, Fig. 8. The reduction in C:N ratio was mainly due to combustion of organic matter resulting in release of gases and mineraliza tion of organic nitrogen from the mucus and excreta of earthworms (Hussain et al. 2018). The statistical analysis revealed that both turning frequency and duration was having profound effect on the reduction in C:N ratio during vermicomposting at 5% level of significance.

Economical assessment of the vermicomposting process

The techno-economic feasibility of the smart vermicomposting bin was accessed in terms of function, cost, availability and characteristics of materials, to determine the adoption rate among the farmers, Table 4. The economic feasibility was evaluated in terms of benefit cost-ratio, break-even point, annual utility and payback period. The total cost of the smart vermicomposting bin was calculated to be Rs. 10, 625 with unit cost of production of vermicompost as Rs. 13.

Conclusion

Dal lake aquatic weed was selected as a substrate to evaluate the performance of the developed prototype of smart vermicomposting bin (0.87 x 0.56 x 1.35 m) with feeding hopper, shredding section, rectangular chamber, spiral mixer and harvesting gate. The results revealed a reduction of 5.57% in pH level, 15% organic carbon and 25.19% C: N ratio along with an increase 15.1% electrical conductivity, 15.1% available nitrogen, 30.17% available phosphorus and 10.12% available potassium at 10 days turning frequency and 60 days degradation period. The cost of the smart vermicomposting bin was Rs. 10,625 with operational cost 117.4 rupees per hour. The annual utility of the vermicomposting bin was 320 kilogram per annum with benefit-cost ratio of 0.45 and 1.78 in the first and second year. The break-even point and pay-back period of the smart vermicomposting bin was calculated as 140 kilogram and 19 months, respectively. The involvement of mechanical system to prepare vermicomposting can help to find the sustainable solution in terms of scarce land, peak labour shortage, high drudgery and low degradation time.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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