The Potential of Ascophyllum Nodosum to Accelerate Green Waste Composting

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Abstract

Millions of tonnes of green waste are produced annually in the UK. The process of composting usually extends to more than two months as well producing greenhouse gases which affect the environment. We proposed a potential approach to use algal extract from *Ascophyllum nodosum* as a compost accelerator. Seaweed-based treatments offer an economical and effective biological solution which activates and stabilises the decomposition of organic matter. Reducing both the cost and time associated with widely used composting approaches. The seaweed was collected from Scottish coastline, extracted, and formulated to enhance application. Its effects on the timeline of the composting process was systematically investigated through physical, biological, and observational quantification. The emission of gases, the pH, temperature, humidity, consistency, and microbial growth of the compost were studied.

Interestingly, the results showed that the compost reached a stability status within 6 weeks, less ammonia and lower carbon dioxide produced. The use of this formulation has the potential to minimise expense, reduce resources used, and lower the levels of harmful volatile organics. This approach is economically beneficial and environmentally crucial in compost formulation, the control of contamination, and reduction of greenhouse gases.

Introduction

Daily consumption of food materials and agricultural industries produce large amounts of waste materials (Barthod et al. 2018). In 2018, around 179 certified compost makers distributed throughout the UK have dealt with around 3.5-5 million metric tonnes of waste materials and produced approximately 1.86 million metric tonnes of compost. About 76% of these processes were accomplished in England, 13% in Scotland, 7% in Wales, and 4% in Northern Ireland. Approximately 68% of all these processes were accomplished in the open air, turned windrows and more than 75% of the centres processed green waste (Hasznos 2019). These amounts of waste impose pressure on the environment and may cause water and air contamination. The gases like NO_2, CH_4, CO_2, sulphur compounds, and volatile organic compounds (VOCs) produced from the metabolism of these materials are an additional challenges (Cerda et al. 2018).

Composting of the waste organic materials is one of the approaches used to convert the organic materials into useful biomass to achieve a carbon sequestration (Calabi-Floody et al. 2018). The target of all recycling centres is to produce a safe compost free from or has undetectable levels of pathogenic microorganisms like *Bacillus anthraces* which causes anthrax and *Bacillus cereus* which causes gastroenteritis, and other examples as mentioned Wichuk (Wichuk and McCartney 2007). Usually the immature compost is not suitable for plant fertilisation, also it is a source of harmful odours (Bernal et al. 2009).

Generally the compost is produced by windrow and aerated pile techniques (Hobson et al. 2005), however, homebased composters who process small amount of waste, is still of value in the composting of organic matter (Andersen et al. 2011). The aeration pumps are used instead of the pile turning process, even though it is more expensive, as it gives the compost producer more control on the dynamics of the composting process. With a good control to the temperature and aeration of the pile, the aerated static pile produced the compost within 3–4 months (Mussari et al. 2013). Other researchers showed that usually composting process took around 2–8 months according to the type of waste, size of the pile, sizes of shredded waste, temperature, humidity percentage, aeration mechanisms, and addition of compost accelerator, (AyanfeOluwa et al. 2017). Under normal conditions and without the addition of any compost accelerator, the compost needs 3.5-6 months to mature (El Hayany et al. 2018) while composting time under aerated environment often extends to more than 6 months (González et al. 2016).

The ideal temperature of composting is between 40–65°C (de Bertoldi et al. 1983). The stages of the composting process start by the sanitisation step, this step is usually accomplished within 3 days and some recycling companies run that process for two times for 6 days. The pile in the vessel is activated using air current to blow the pile to destroy any anaerobic spots. The temperatures reach up to 70°C ensure that many pathogenic microorganisms are eradicated. However, higher temperatures eliminate the microorganisms used in the compost formation (Gajalakshmi and Abbasi 2008) thus relief of the pile's temperature is also recommended. Adaptation of the routine composting techniques is followed to increase the air flow through the pile by the addition of inert materials or "bulking agent" (Villasenor et al. 2011). Aeration in the pile ensures more aerobic microbiota activities, less odour, and a shorter time for compost formation. At the start of the composting process the simple molecules are metabolised and organic acids like; 3-hydroxypropionic acid, acetic acid, citric acid, gluconic acid, lactic acid, and succinic acid are produced (Singh et al. 2017).

During the thermophilic stage of the composting process, the temperature builds up again and the microorganisms that thrive in the high temperatures resurge again. Complex molecules like polysaccharides and polyphenolic materials are metabolised into simpler entities (Bernal et al. 2009). In the final stage or mesophilic phase, the temperatures start to decline due to a decrease in the microbial activities; this phase is called the maturation stage or mesophilic stage.

There is a tireless effort to shorten the time required for compost formation and to reduce the release of the harmful gases and volatile organic compounds (VOCs) to the environment. This can be achieved to some extent by the addition of organic or inorganic additives or microbial cultures (Barthod et al. 2018; Bernal et al. 2009; Onwosi et al. 2017). The addition of microbial colonies contain several Gram positive genera like *Bacillus*, *Clostridium*, *Enterococcus* and *Lactobacillus*, and Gram negative *Alcaligenes* lead to enhance the composting process of the compost from cattle manure and decrease the ammonia and nitrate concentrations (Wakase et al. 2008).

The following fungi; *Plectosphaerella cucumerina*, *Fusarium oxysporum*, *Fusarium domesticum*, *Fusarium delphinoides*, and *Pyrenochaeta unguis-hominis* are able to metabolise all kinds of carbohydrates (Jurado et al. 2014). Hydrolysis of lignin is achieved by the *Streptomyces albus*, *Bacillus smithii*, and *Brevibacillus borstelensis*, and the fungus *Conioscypha lignicola*. Lipase producer microorganisms such as the bacterial genera *Bacillus*, *Pseudomonas* and *Streptomyces* and the fungal genera *Fusarium*, *Alternaria*, *Penicillium*, *Scopulariopsis*, *Acremonium* and *Pyrenochaeta* are also of importance in compost formation (Hasan et al. 2006; Jurado et al. 2014).

Researchers investigated the composting process of seaweed as a process to limit their negative interferences with the tourism on the beaches and reduce their impact on trading at seaports as excessive growth limited the movement of ships, etc. (Eyras et al. 2008; Wosnitza and Barrantes 2006).

The addition of oven dried manually shredded sea lettuce (*Ulva sp.*) powder to the compost pile formed of green waste and manure produces higher temperature and longer thermophilic stage. The composting process stabilised within 4 months (Wosnitza and Barrantes 2006). Other researches revealed that the effect of the phosphorus and potassium provided by seaweed, the slightly alkaline effect of algae, and better aeration of the soil improved the production of tomato *Licopersicon esculentum* (Eyras et al. 2008).

Having noted the potential of algal natural products to enhance composting, here in we aim to produce seaweed extract-based formulation to enhance green waste composting. The effect of a natural extract from Scottish *Ascophyllum nodosum* is investigated for the first time taking into account the influence of temperature, moisture, microbiota, O_2 and CO_2 levels and the release of VOCs on the composting process.

Materials And Methods

Collection of algae

A. nodosum shown in Fig. 1 was collected manually from the intertidal zone of Irvine Rd, Ardrossan KA22 8PH, UK Lat: 55.669307794062966, Lng: -4.845159785066649 on the 11th of March 2019 and a voucher specimen code AN-Ardrossan01 was kept in natural products chemistry lab., Institute of Biomedical and Environmental Health Research (IBEHR), School of Computing Engineering & Physical Sciences, University of the West of Scotland, UK. The whole parts of the algae were completely dried by lyophilisation using Modulyo freeze dryer from Edwards.

Preparation & Application of algal extract

The lyophilised material was pulverised using mechanical mill. A 100 g of the powdered material was subjected to several steps of extraction leading to the final formulated product in 1 L of 3% Na_2CO_3 aq. Sol. A 1 L sample of the extract was diluted to 50 L using tap water. The mixture was dispensed and mixed with 5 metric tonnes of green waste after processing *via* two stages sanitisation phase in vessel where temperatures must be held at 60°C or more for 48 hrs each stage at a local commercial waste recycling facility. The study started on the 4th of February 2020 and ran for six weeks. A control sample separated from the same pile was running in parallel.

Monitoring temperature, moisture, O_2 and CO_2 levels of the compost piles

The temperature, moisture %, O_2% v/v and CO_2% *v/v* were recorded using a generic monitoring device (Compost Manager, Freeland Scientific, Hextable, Kent, UK). The tool provides advisory information for the optimisation of the aerobic composting process, with data logging over time. Using relative values of variables, the monitor provided guidance on turning, irrigation, or maintain compost piles. The balance between O_2 and CO_2 is important to avoid the anaerobic digestion and hence production of airborne harmful gases like CO_2, ammonia, some phenolic materials, and H_2S. The monitor recorded the O_2 and CO_2 from zero to 20% and 40% *v/v* respectively with ± 0.5% accuracy. Temperature can be recorded up to 90°C with a ± 2°C accuracy and moisture can be recorded at levels from 25–65% w/w with ± 10% accuracy (FreelandScientificLtd 2020).

Sampling techniques and studying the microorganisms from compost samples

Samples were collected in triplicate from the test and control piles in 50 mL sterile falcon tubes to culture the microorganisms and measure the pH. The sampling times were labelled as T0 (the day of application), T1 (7 Days), T2 (14 Days), T3 (21 Days), T4 (28 days), T5 (after 5 weeks) and T6 (after 6 weeks) of application. The microbial isolates were extracted and cultured on separate agar plates for non-selective growth, for selective bacterial growth, and for selective fungal growth. Several microorganisms were isolated and preserved in 50% glycerine stock for further studies. About 5 g of the sample was suspended in 20 mL of DW for 2 min. Only seven samples were collected due to the outbreak of COVID-19. About 100 µL was cultured in different growth agar plates and incubated at 30°C for several days to check the results.

Checking ammonia levels

Ammonia levels were checked on different times during the composting process. Using the Dräger™ Short-Term Detector Tubes 2–30 ppm to adsorb ammonia molecules.

HPLC analysis and quantification of sodium alginate in the formulation

Chemicals

Sigma-Aldrich UK supplied sodium alginate produced by Merck. Calcium chloride, hydrochloric acid, phosphoric acid, sodium hydroxide pellets, and sodium carbonate supplied by Fisher Scientific UK Ltd. Ultra-pure water was prepared using a Milli-Q water purification system from Merck.

Instrumentation and chromatographic conditions

Agilent series system consists of 1100 quaternary pump 1, Agilent 1100 diode array detector 1, Agilent 1100 auto sampler 1, Agilent 1100 column thermostat 1, and enhanced integrator. Hypersil™ Phenyl-BDS HPLC Columns from ThermoFisher Scientific analytical column (150 x 4.6 mm i.d., 5 µm) used in this assay. The elution system was isocratic composed of 100% Aqueous H_3PO_4/NaOH buffer pH 7. The system was operated at the rate of 0.7 mL/min at thermostatic 25°C temperature. UV detector was operated at λ 200nm. The system was allowed to equilibrate for 90 min before injection of the first sample, the injection volume was 50 µL.

Preparation of the solvent system

Phosphoric acid 0.5 mL was added to 1 Liter of ultra-pure water. The pH was adjusted to 7 by the addition of enough quantity of 1 M NaOH. The NaOH solution was prepared by the addition of 39.997 g of NaOH pellets to 1 L of ultra-pure water. Finally the buffered solution was filtered by a suitable kind of filter using a vacuum to remove all air bubbles.

Preparation of the standard solutions

A set of different concentrations of sodium alginate standard solutions were prepared by solubilisation of 50 mg of sodium alginate in a 50 mL aqueous buffer in 50 mL volumetric flask to produce 1 mg/ mL standard solution, then by a double dilution method, the following concentrations were produced; 0.5, 0.25, 0.125, 0.0625, 0.03125, and 0.015625 mg/ mL.

Sample preparation

5 mL of the formulation diluted to 25 mL by Ultra-pure water then the final suspension filtered using 0.43 µm filter disk. The filtrate was neutralised to pH 7 by the addition of enough quantity of phosphoric acid.

Linearity

To determine the linearity of the chromatographic method several concentrations of sodium alginate (0.5, 0.25, 0.125, 0.0625, 0.03125, and 0.015625 mg/ mL) were injected as a duplicate. A calibration curve was sketched using Microsoft Office Professional Plus 2016. Regression analysis and straight line equation were produced.

Precision and specificity

To check the precision of our method we ran several standard solutions on different days under the same conditions to ensure repeatability which was expressed statistically by the standard deviation. The specificity of the test was determined by comparing the chromatographic profile of sodium alginate standard and its profile in the formulation.

Calculate the percentage of water in our formulation

The percentage of water in formulation was calculated using two methods; the first method using moisture analyser HB 43-S Halogen from Mettler Toledo. The moisture content also calculated after serial lyophilisation cycles using Modulyo freeze dryer from Edwards. The weight of the lyophilised mass was calculated several times until a stability of weight was achieved.

Elemental analysis

We used Thermo Scientific iCAP 6000 Series ICP-OES standard operating procedure, to 2 mL of the sample in a 50 mL Eppendorf 50 mL centrifuge tube we added 2 mL of H_2O_2 and 5 ml HNO_3. The tube has been placed in a hot block for 30 minutes. Made to 50 mL using UHP and filtered by 0.2 µm filter disk. We used a multi-element standard with stock concentration 100 mg/L and do serial dilutions for a working calibration, the dilutions were all made up to 50 mL with 10% nitric acid. 0.1 ppm – 0.05 mL, 0.2 ppm – 0.1 mL, 0.5 ppm – 0.25 mL, 1 ppm – 0.5 mL, 2 ppm – 1mL, and 10 ppm – 5 mL. The standards to make 25 and 50 ppm were made from single element standards of 1000 mg/ L stock concentration, again as before made to 50 mL with 10% nitric acid. Other parameters to note for the run are; plasma 8 L/ min, aux 0.2 L/ min, nebuliser 0.7 L/ min, power: 1500Watts, and sample flow rate 1.5 ml/ min.

Compost analysis

The compost samples were analysed by NRM, a division of Cawood Scientific Ltd. Coopers Bridge, Braziers Lane, Bracknell, Berkshire RG42 6NS. The results were supplied by Enva Organics Recycling Ltd, Glasgow, UK.

Statistical analysis

The results reported in this study were means of several replicates with standard deviation values. The temperature, moisture %, O_2% *v/v* and CO_2% *v/v* were recorded from eight different spots around the test and control piles, average values were calculated with the standard deviation of these values. Samples for pH studies were collected from three different spots around the pile.

Results And Discussion

The data was collected for two months from the date of application on the 4th Feb 2020 until 2nd of April 2020. The test pile was turned five times on days 9, 16, 29, 34, and 56 of the test, while the control pile was turned only three times on days 9, 16, and 34 of the test as advised by the compost monitor.

Analysis of the phases of the composition process

The waste mass was subjected to a sanitisation process which was expected to kill the pathogenic microorganisms as temperatures between 50–70°C eliminate all the enteric bacteria (de Bertoldi et al. 1983; Tønner-Klank et al. 2007). Other researches stated that temperatures above 55°C for three days was enough to meet the Class A, alternative 5 requirements under 40 CFR Part 503 regulations (Mussari et al. 2013). The best temperature for the microbiota responsible for composting process to thrive within compost has been reported to be between 40–65°C (de Bertoldi et al. 1983). Higher temperatures of the compost for long time decreased the activity of microbiota responsible for composting of the organic matter (Mussari et al. 2013). The declined temperatures during the course of composting indicated a depletion in the organic matter that worked as a food source for the microorganisms which dwell in the compost and the development of unfavourable condition for the microorganisms. Figure 2 shows that the temperatures of the control at all stages of the composting process were almost above 60°C indicated weaker composting process compared to the one at the test pile.

The temperatures in the test compost pile continued to increase until day 23 of the test to record 67.35°C as the first thermophilic phase then declined to record 33.5°C on day 30 of the test. That revealed a six-day first mesophilic phase then increased again reaching the maximum temperature at 58°C on day 37 of the test as a second thermophilic phase. It then decreased again after that indicating the initiation of the maturation stage or the second mesophilic phase. The compost stabilised at 26.3°C. The composting profile was comparable with the data recorded in several research articles (Zhang and Sun 2018; Zhang et al. 2013).

This composting profile revealed two building stages with one concave point as shown in Fig. 3. The temperatures range between 26–45°C is the ideal environmental temperature to nourish the *Actinomycetes* and other thermophilic microbiota (Insam et al. 2010). This explained what happened in the test pile where this ideal temperature range led to rejuvenation of the microbial activities which increased the temperature again. We noticed that turning of the test pile (t3) led to increasing the temperature from 33°C on day 29 of the test to 50°C on day 34 of the test (t4), the fourth turning point of the test pile. The maximum temperature 58°C of the second thermophilic phase has been reached on day 38 of the test. This indicated that turning of the test pile led to activation of the aerobic digestion as shown in Fig. 3.

The profile of composting using the algal extract formulation agreed with the results of composting using other means of compost accelerator like GORE ® cover membrane and a ventilation system (Al-Alawi et al. 2020). Figure 3 illustrates the stages of the composting process at the test pile. The figure showed that the two thermophilic phases were identified at the ideal temperature composting temperature range 40–65°C.

Studying the aerobic vs. anaerobic metabolism conditions in the compost piles

The levels of CO2 and O2 shown in Fig. 4 and Fig. 5 respectively. The CO2 production decreased with time for both the test and control piles, however, the control pile produced more CO2 compared with the test pile as shown in Fig. 4. The reduction of release of CO2 may be attributed to the effect of the algal extract which contains high concentrations of sodium alginate. Sodium alginate restricted the release of CO2 after formation of a nitrogen coated surface due to reaction with ammonia molecules.

This assumption is supported by the results which were revealed from several research articles stated that the molecules of sodium alginate contain many hydroxyls and carboxylic acid moieties which upon treatment with ammonia produced by the composting process accelerated the interaction with CO_2 due to the formation of the

basic environment (Hosseini et al. 2017; Zhu et al. 2014). The composting process in the test pile appeared to occur under aerobic conditions compared with a relatively anaerobic conditions at the control pile as shown in Fig. 5 which is the unfavourable scenario in the composting process.

Analysis of the pH levels and effects of pH on the production of greenhouse gases

The pH results for the test and control piles are shown in Fig. 6. The pH of the compost decreased from 8.9 to 6.5 during the first 13 days of the composting process due to the production of small organic acid like acetic and butyric acids that were produced due to the microbial activities (Huang et al. 2004). Then the pH started to increase to reach a neutral pH value of around 7.2. The buffering capacity of the composting media is important to the final quality of the compost produced.

The large amount of ammonia that leaves the compost leads to the production of compost with poor agricultural value and more noxious odour during the composting process. The evaporation of ammonia played a critical role in reduction of the pH (Eklind and Kirchmann 2000). This clearly indicated that the algal formulation saves a considerable amount of nitrogen and increase the pH in the compost compared with the control pile. The ordinary composting process wasted up to 70% of the total nitrogen contents (Barrington et al. 2002). It is apparent that sodium alginate in the formulation adsorb a major part of the ammonia produced by the composting process. This revealed by Dräger sampling tubes which detected lower ammonia level around 50% in the vicinity of the test pile compared with higher levels of ammonia that reached around 20 ppm in the vicinity of the control pile. Sodium alginate could efficiently immobilise the ammonia-oxidising bacteria which have an important function in the transformation of ammonia to nitrite (Dong et al. 2017); a property that would facilitate the use of our extract in further applications like the remediation of the waste water as well as in agriculture as a soil bioremediation product.

Effect of moisture levels on the production of methane

Methane usually produced due to the effect of high moisture and lower oxygen contents of the compost (Amlinger et al. 2008) these conditions were apparently noted in the control pile. Figure 7 shows the moisture levels in the test and control piles.

Lower levels of moisture were recorded from the test pile after 4 weeks of the experiment compared to the moisture levels of the control pile. This could be attributed either to more microbial activities and metabolism, drying effect of the wind affecting the test pile at the windrow, or to more frequent turning times compared with the control. Considering that more moisture and less oxygen in the pile produced more methane (Amlinger et al. 2008), we proposed that algal extract reduced methane levels released by the composting process. However, the concentration of the methane produced by the composting process need to be checked and analysed thoroughly.

There are several approaches adapted by the researchers to decrease the greenhouse gases like CO_2, CH_4, N_2O, and NH_3 using a semipermeable cover (Sun et al. 2018) or by the addition of methanotophic microorganisms to consume the produced methane in their oxidation metabolism (Luo et al. 2014). Aeration of the pile by the addition of bulk materials like the spent mushroom and mulch decrease the anaerobic spots in the pile and so reduce the ultimate methane produced (Maulini-Duran et al. 2014). Absorption of the gas produced was also used as an adaptive measurement to decrease the release of methane to the environment, and the surface area was also crucial in the absorption process as more surface area absorb more methane. Example of this is the use of small particles of biochar to adsorb more methane (Awasthi et al. 2016).

The microbiota in the test and control piles

Clear difference between the control and the compost piles was recognised during the test, comparison of these piles revealed that the algal extract altered the physical appearance of the compost pile markedly. The fungus-like bacterium, Actinomycetes or fungal populations were distributed more throughout the test pile while the control pile showed less white filaments as shown in Fig. 8. This indicates more decomposition of complex fibrous tissues in the test pile (Grant 2020). Isolation and cultivation of the compost's microbiota on T1 revealed that the microorganisms were more abundant in the test pile compared with the control. Generally, until week 6 (T6) of the experiment the microbiota in the test pile was more abundant than that in the control pile. Several endophytes were isolated from *A. nodosum*, around 800 bacterial isolates isolated from this seaweed some of them have polysaccharides hydrolytic activities (Ihua et al. 2019). This indicated that the bacterial cells present in *A. nodosum* might play a positive role in the digestion of the waste material and enhancing or accelerating the composting process.

Stabilisation of the compost

Algae have a relatively low C/N contents so the ideal composting process can be achieved by mixing a material with high carbon content like trees, shrubs, etc. to reach the required 30 C/N mixture and to kick off the composting process. Aerobic metabolism consumes the carbon of the biomass, the stabilisation stage of the compost is achieved at 15 C/N mixture. Higher carbon contents in the waste biomass extends the time of composting, hence the stabilisation process and achievement of higher fungal contents in the compost takes longer time (Eiland et al. 2001). This means the high fungal contents of the compost is one of the signs indicating the compost stabilisation. The oxygen levels in the test piles was almost 20 and carbon dioxide approached zero levels suggesting the achievement of maximum aeration and aerobic metabolism led to complete decomposition of the organic materials. The pH of the test pile was just above 7 in contrast to the acidic pH of the control pile, which is further evidence that the algal extract accelerated the composting process toward formation of favourable neutral compost. Further details of compost analysis are shown in Tab. S1-S7 in the supporting information.

Chemical analysis of the formulation

HPLC analysis and moisture content of the formulation

The calibration curve of the sodium alginate is shown in Fig. S1 in the supporting information. The equation of the straight line was as followed

$Y = 0.0003x - 0.01$ ($R^2 = 0.9996$)…….. Eq. 1.

This equation is for the calibration curve of sodium alginate, y is the concentration of sodium alginate in mg/ mL and x is the AUC (Area Under the Curve) in mAU*s.

Sodium alginate is a polymeric hydrophilic polysaccharide composed of glucuronic and mannuronic acid residues. It is the sodium salt of alginic acid, a compound synthesised naturally in algae (Kovalenko et al. 2011). Analysis of alginic acid and its derivatives is documented in the BP (British Pharmacopoeia) and USP (United States Pharmacopeia), the methods prescribed in the pharmacopeia are not specific enough, as they depend on either the titration of alginic acid moieties with equivalent concentrations of a base or the quantification of the CO_2 released after hydrolysis of alginate polymer. Hence it missed the exact quantification of alginic acid's derivatives. Colourimetric analysis using a Beckman Model DU-68 single-beam spectrophotometer is another method used to identify the concentration of alginates in a solution. This process needs enzymatic or chemical hydrolysis to release

the moieties from the polymers and made them available for the reaction with the detector to establish the identification and quantification purposes (Filisetti-Cozzi and Carpita 1991).

Sodium alginate concentration in our formulation was calculated as 12.1 g/ L ± 0.18 (n = 6). The retention time ± SD of the sodium alginates standard was 1.45 ± 0.02 min (n = 32) and in formulation was 4.36 ± 0.05 (n = 3). The results showed a linear relationship between the concentrations of sodium alginate and their AUCs with R^2 = 0.9996 which meets the pharmaceutical analysis criteria. The results indicated that the method is repeatable and specifically quantify sodium alginate. We found that the use of methanol in the solvent system blocked the HPLC system and led to build up the pressure in the system indicated a precipitation of sodium alginates. The alkaline condition of the sample analysed by our method yielded a shift in the peaks. After neutralisation of the sample to pH 7 which was the pH of the solvent, we noticed better separation of the compounds and this might be attributed to the effect of the pH on the conformational structure of sodium alginate. The conformational structure of the molecule govern the interaction of the molecule with the stationary phase of the column. Quantification of water quantity in the formulation revealed that this formulation contains high percentage of water reached 90%, this was confirmed by the two methods used.

Elemental analysis

Table 1 shows the concentration of the elements detected in the formulation in mg per 1 L of the formulation using ICP-OES. Mainly the alkali group I & II metals were of high concentrations but as expected sodium concentration was the highest concentration compared to other elements.

Table 1
shows the concentration of the elements in mg detected in 1 L of formulation

Wave length in nm	Al 396.153 nm	As 188.979 nm	B 249.677 nm	Ca 317.933 nm	Fe 238.204 nm	K 766.490 nm	Mg 285.213 nm	Na 589.592 nm	Sr 407.771 nm
Average con.	10.5	0.8	5.06	396.1	9.9	2422	178.7	8946	16.4
SD (n = 2)	± 0.04	± 0.18	± 0.04	± 3.47	± 0.18	± 21.72	± 1.69	± 358.21	± 0.07

Conclusion

In conclusion, the algal extract formulation has shown to influence the composting process of green waste leading to shorter time of attainment of final compost. The results indicated that this formulation accelerated the compost production by 25% and altered the classical course of this operation. The effects of *A. nodosum* extract were clear because it reduced the normal time line of the composting process to around 6 weeks and diminished the release of harmful gases to the environment. This formulation is environmentally friendly as it is composed ultimately of phytochemicals extracted from *A. nodosum*, and the endophytes naturally available in this alga. This algal extract produced higher class compost, almost neutral which is of higher benefits to the agricultural applications. The aerobic metabolism facilitated by the algal extract led to the concentration of nitrogen instead of loss it in the form of ammonia. Lower moisture of the test pile which was mixed with this formulation with more oxygen in the pile promoted the production of less methane into environment.

Declarations

Ethics approval and consent to participate;

“Not applicable”

Consent for publication

“Not applicable”

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Author contributions

All authors contributed to conception and design of study. Material preparation, data collection and analysis were performed by Omar Al-Dulaimi. The first draft of the manuscript was written by Omar Al-Dulaimi and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. All authors are contributed to the conceptualization of the manuscript. Omar Al-Dulaimi was responsible for data curation. Omar Al-Dulaimi and Mohammed Yaseen did the formal analysis. Funding acquisition was accomplished by Mostafa E. Rateb, Andrew S Hursthouse, Gary Thomson, and Mohammed Yaseen. Investigation by Omar Al-Dulaimi, Gary Thomson, and Mohammed Yaseen. Methodology was designed by Omar Al-Dulaimi, and Mohammed Yaseen. Omar Al-Dulaimi was responsible for project administration. Mohammed Yaseen, and Gary Thomson were responsible for the supervision role. Visualization of data, and writing the original draft by Omar Al-Dulaimi. Mostafa E. Rateb, Andrew S Hursthouse, Gary Thomson, and Mohammed Yaseen were reviewed the draft.

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Figures

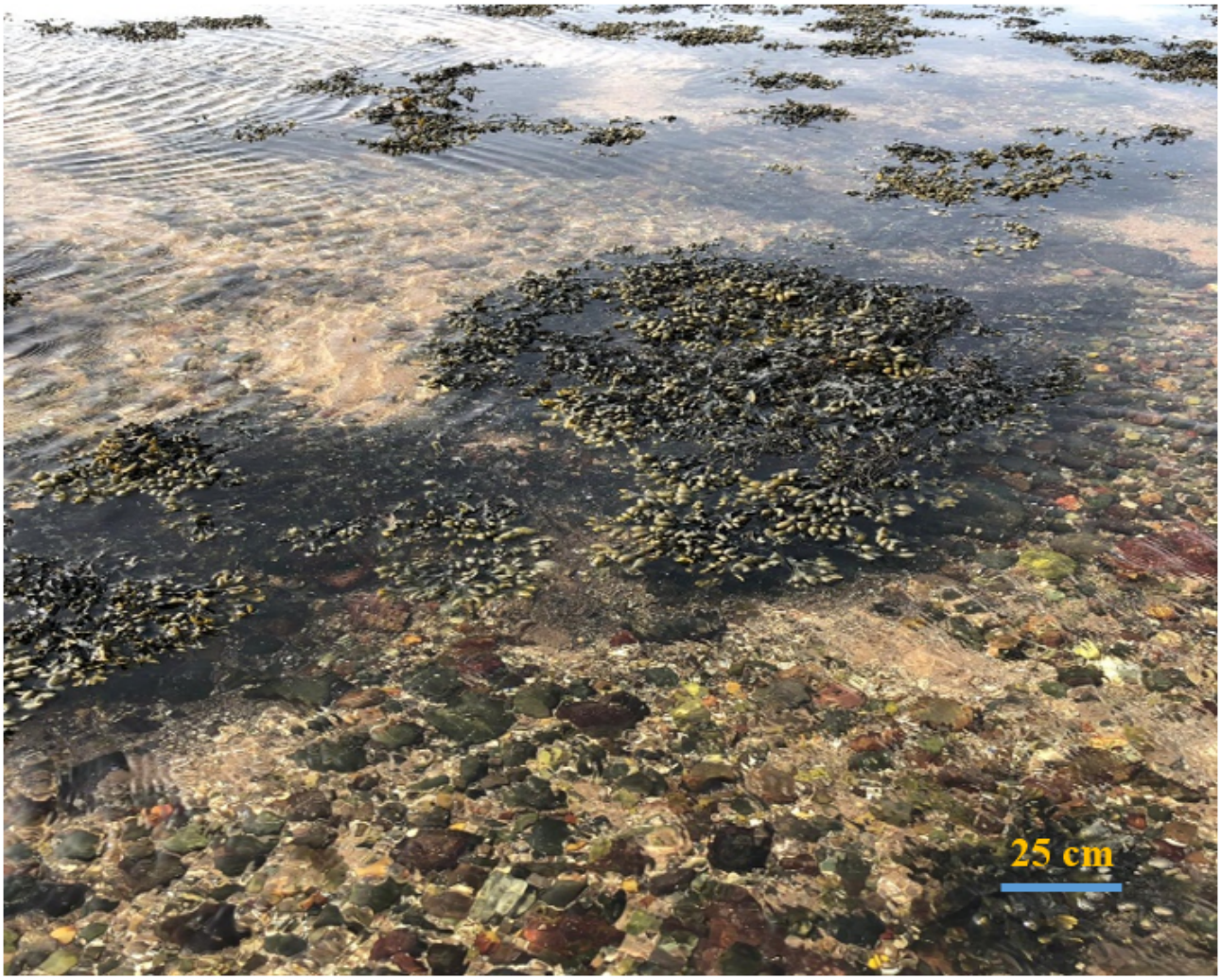

Figure 1

Ascophyllum nodosum from the intertidal zone of Ardrossan, Scotland (Image scale 1:20)

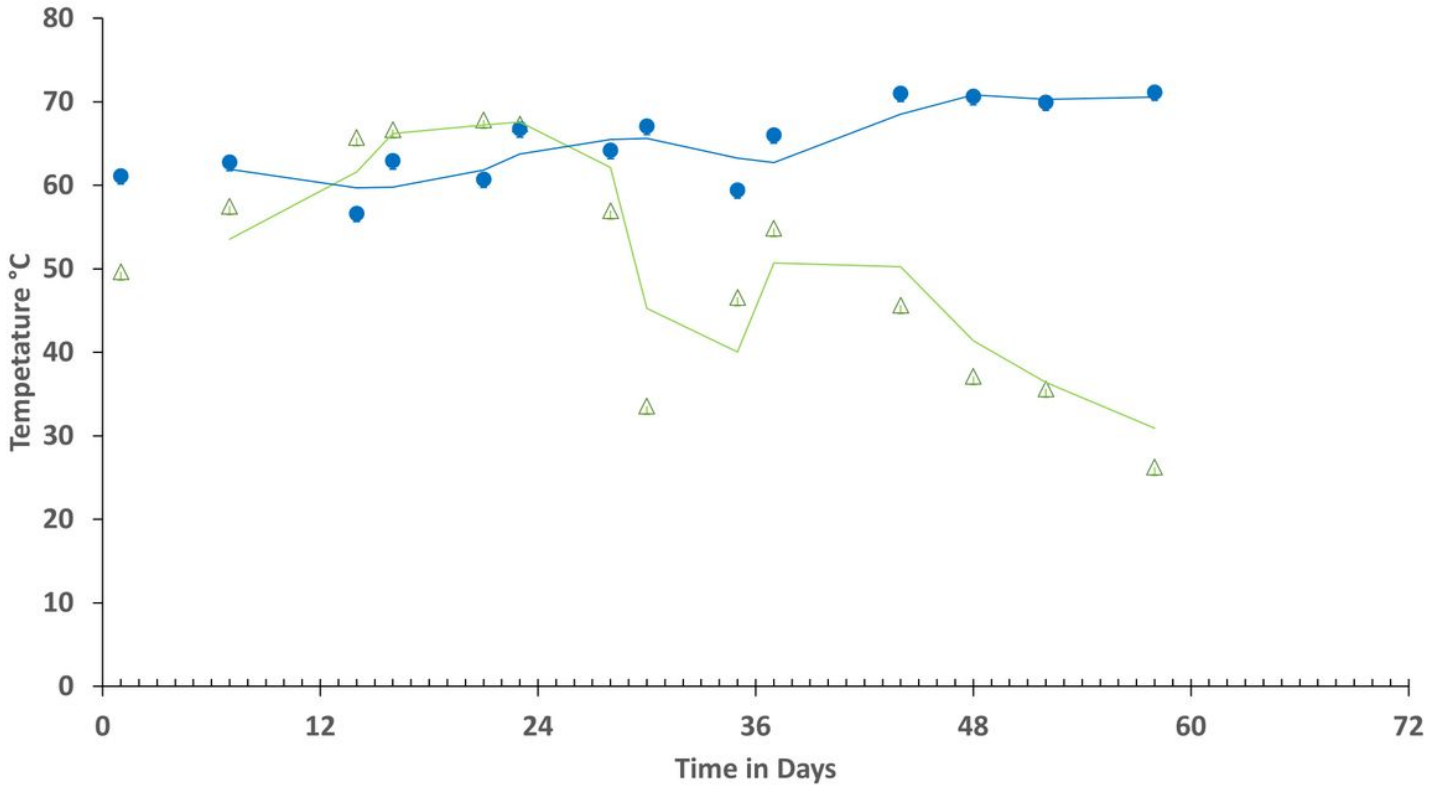

Figure 2

Showing the temperatures against time as recorded in test Δ and control ● piles. The test was started on 04/02/2020 and completed on 02/04/2020.

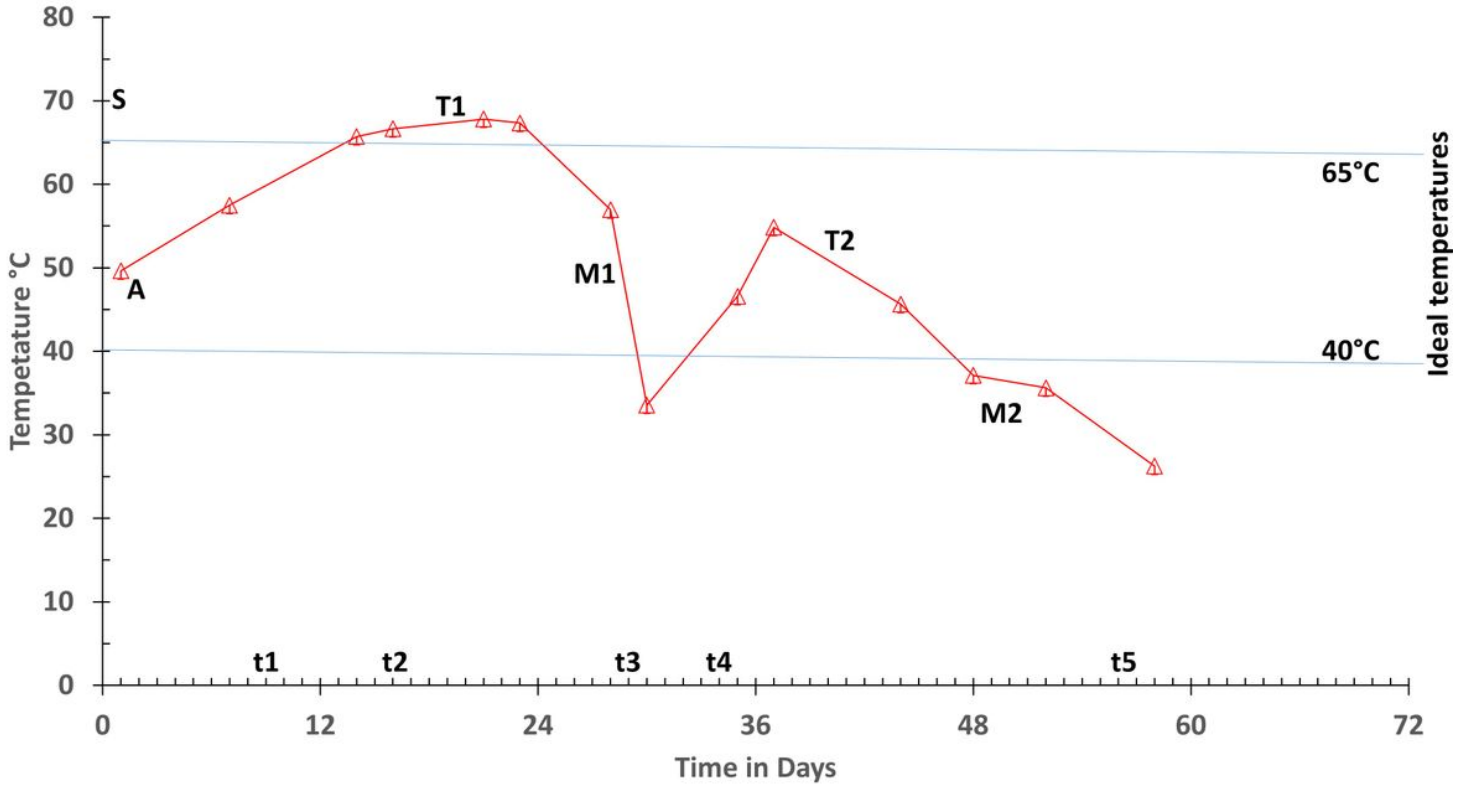

Figure 3

The stages of the composting process at the test pile, point A represents the first temperature recorded after the sanitisation phase (S) which extended for 4 days. T1 and T2 are the first and second thermophilic phase respectively. M1 and M2 are the first and mesophilic stages respectively. The turning points of the test pile are t1-t5.

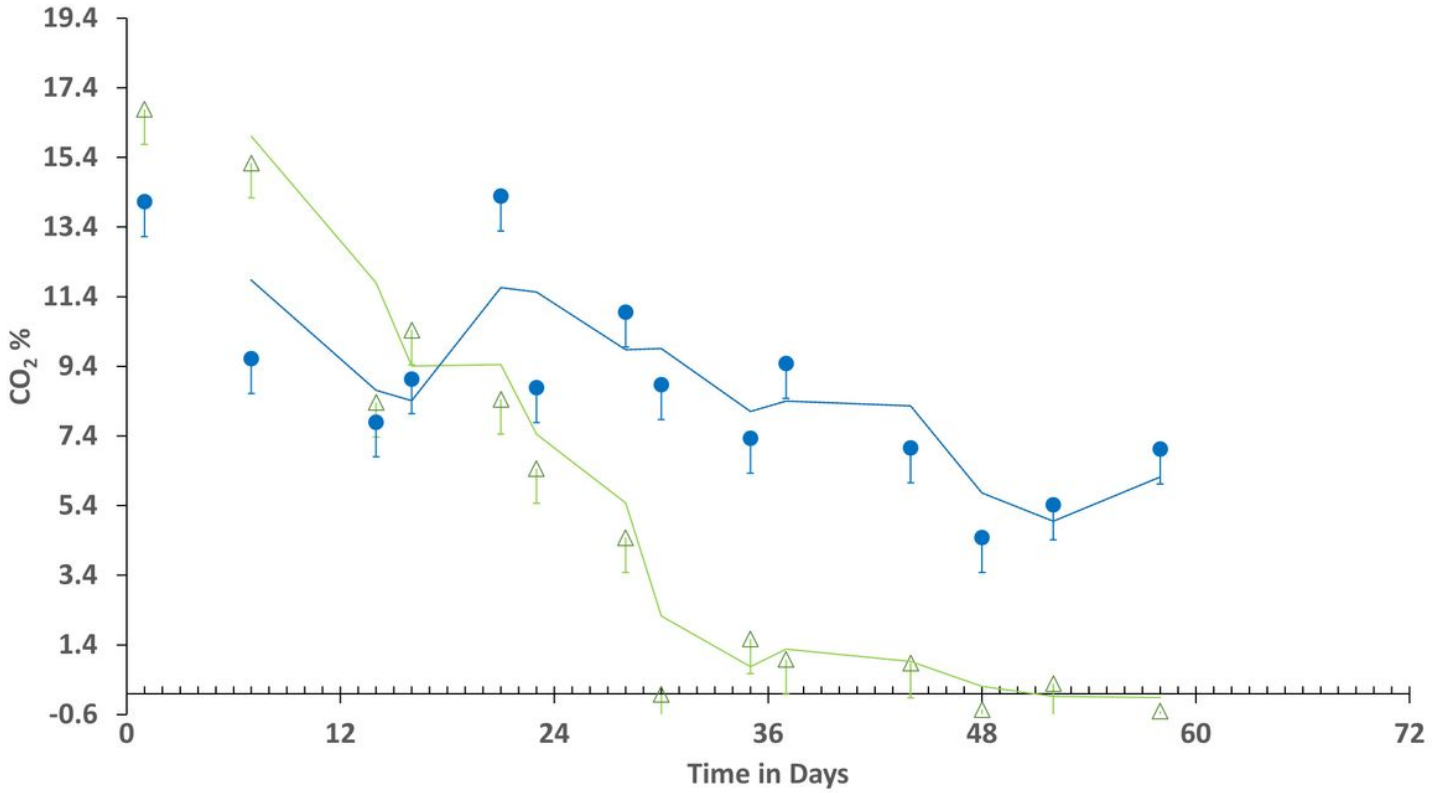

Figure 4

CO2 % levels in test Δ and control ● piles

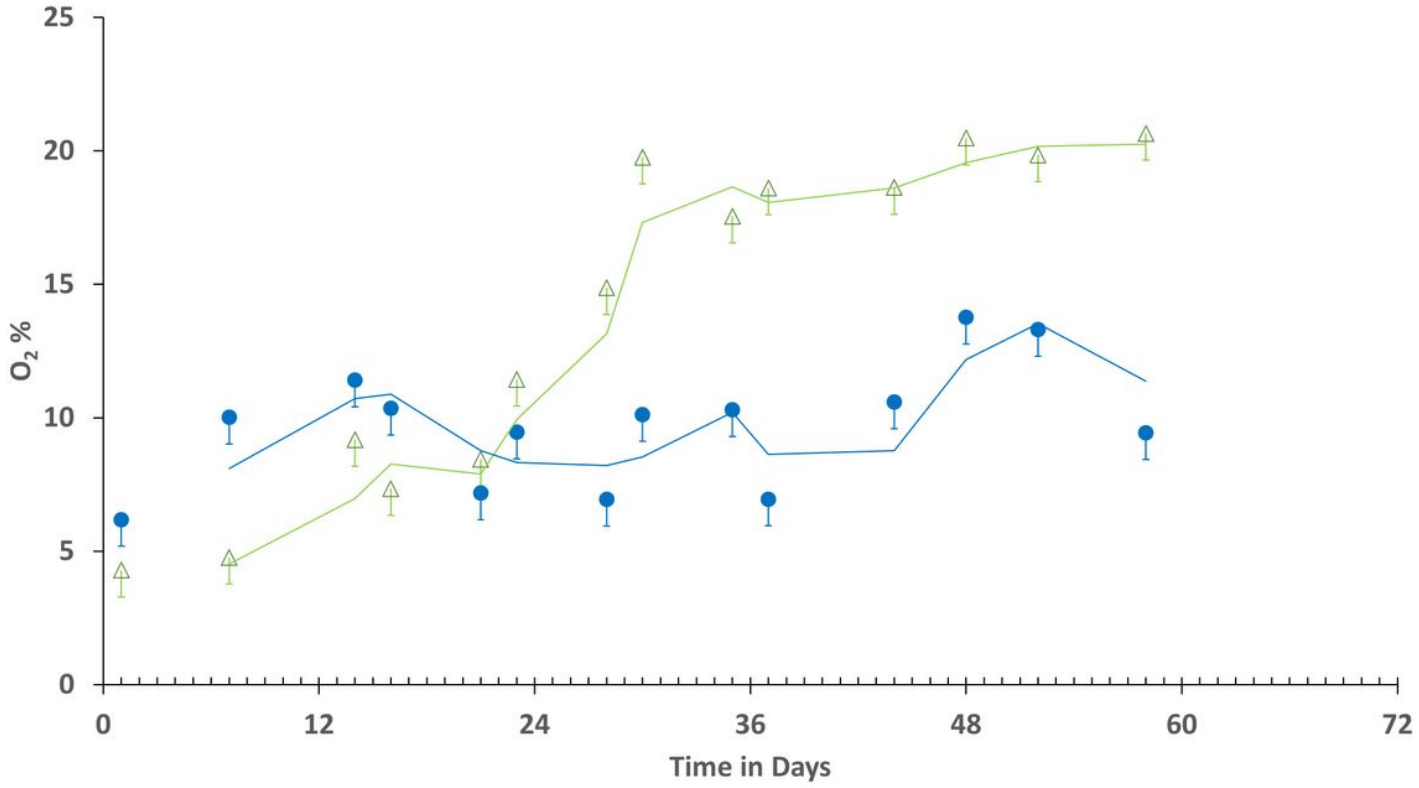

Figure 5

O2 levels in test Δ and control ● piles

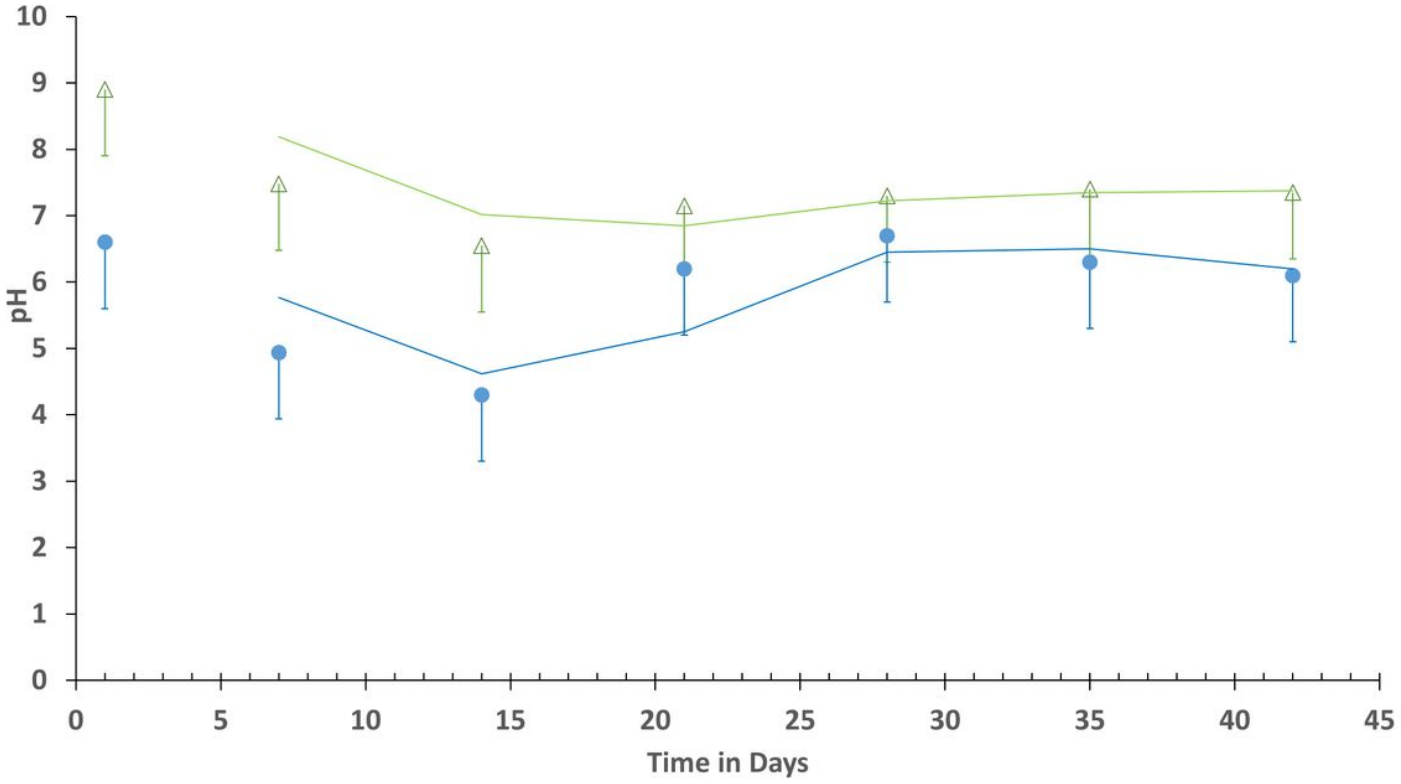

Figure 6

The pH levels in test Δ and control ● piles

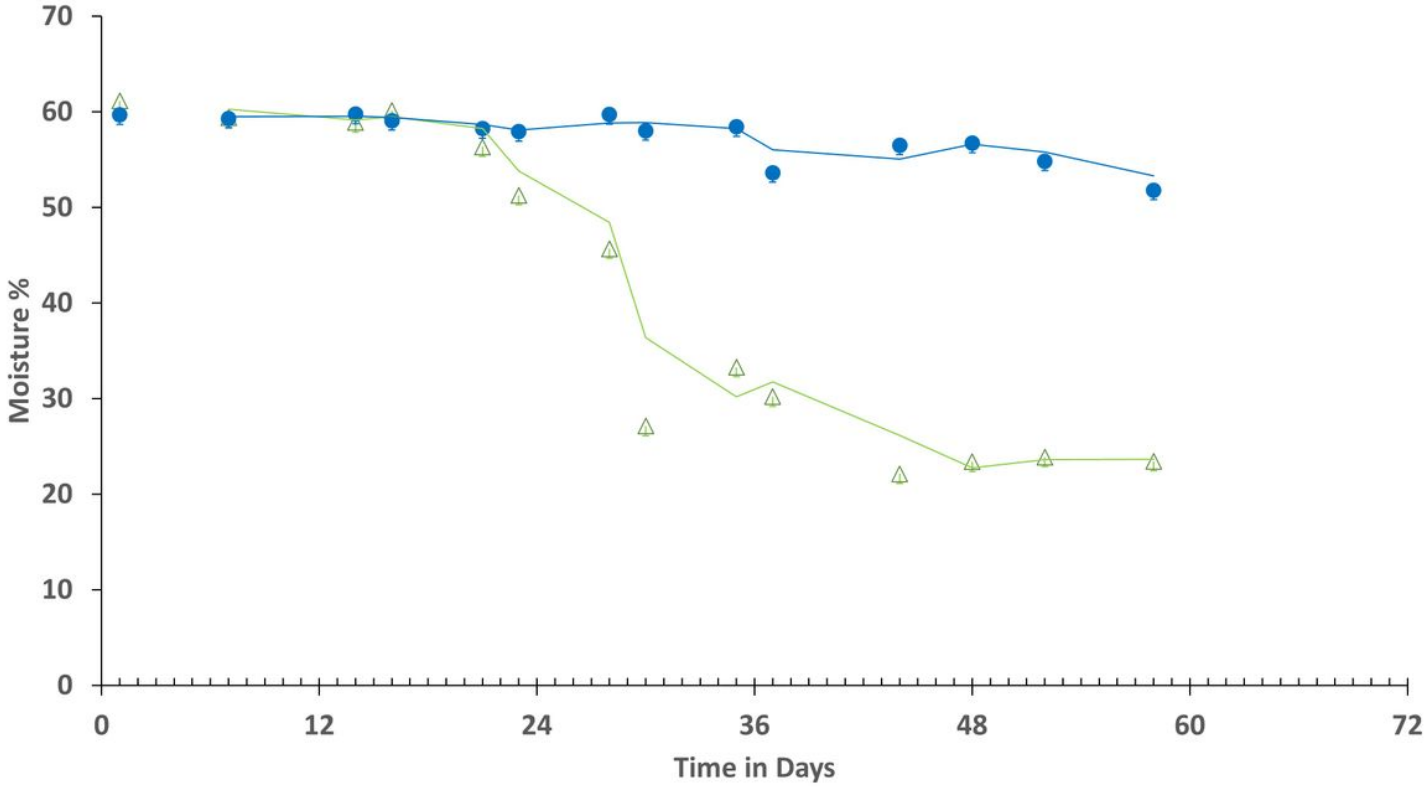

Figure 7

The moisture levels in test Δ and control ● piles

Figure 8

This figure shows more white filamentous materials in the test pile (marked by the yellow arrows) compared with the control one (Image scale 1:20), indicating the achievement of stabilisation stage in the test pile after six weeks of the test.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- S1.jpg
- SupplementaryMaterialMYaseen.docx