SUMMARY AND CONCLUSION

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Every type of production leads to some kind of pollution and the alarm now poses a need to cling to sustainability and widen the recycling options. Textiles and clothing industry, in specific, expels various types of waste at every level. With the invasion of non-degradable synthetic polymers, the threat on non-biodegradable wastes has increased. On the other hand, unpopularity of recycling technologies, results in dumping of organic wastes, which could have been recycled, otherwise. The cotton bales collected from the field are cleaned several number of times to enhance uniformity in the process of spinning. In each cleaning process, different types of wastes of varied quality are expelled. Cotton being 'White gold', most of the wastes are recycled. However, repeated cleaning, in spinning of cotton, results in last trash, which is discarded in the landfill without any end use.

With an interest to take a regional problem, and find a solution, based on existing research gap, cotton wastes from spinning industry were explored. Promoted as "Spinning Hub of India", with 45-50% of total spinning capacity, Coimbatore, (Tamilnadu), landfills are polluted with huge amount of cotton wastes, without being recycled. This organic waste can be recycled and converted into a value added product by up-cycling. The results of intense review survey, defines this as lignocellulosic waste from spinning mills, commonly referred to as 'willow dust or willow waste'. Approximately, every year, 30,000 tonnes of this waste is thrown away in landfills. Thus to analyze the recycling possibilities of the selected cotton fiber waste, namely willow waste, research was planned. The major objectives of the study '**Exploring the Recycling Potentialities of Cotton Fiber Waste for the Development of Innovative Sustainable Products**' are to:

- elicit information regarding types of spinning wastes and identify unused cotton fiber waste,
- analyze the composition and properties of selected cotton fiber waste,
- conduct various pilot studies and find suitable recycling techniques in developing innovative sustainable products and
- to develop prototypes, test, analyze and compare the effectiveness of the prepared products and do cost analysis.

MATERIALS AND METHOD

PHASE I - Eliciting information and analyzing the selected cotton fiber waste

There were fewer reviews published on the life cycle spinning wastes and on the selected cotton fiber waste, willow waste. Thus information regarding this was collected from mill owners and cotton waste merchant association. Pilot study was done to identify possible products made from willow waste in a sustainable fashion. There are different types of waste from the spinning process. These are further taken to the open end spinning mill / willow mill, where the cotton fibers are cleaned again. Good quality cotton fibers obtained from this, are removed for non-woven process and the last trash waste is sold for Rs. 3-8/kg, depending upon the quality of cotton fibers. The final trash is however discarded in the landfills. This waste is found to be a mixture of cotton fiber and trash particles. Using an interview schedule ten professionals working with the willow waste industry were contacted and information regarding willow waste was collected. The willow waste was collected from the willow mills in and around Ondipudur and Thannerpandhal, Coimbatore, Tamilnadu (India). It was purchased for Rs. 3/kg transported to Avinashilingam Institute for Home Science and Higher Education for Women, (Coimbatore) for trial study. The willow waste was tested for pH, electrical conductivity, moisture, organic carbon, total nitrogen, total phosphorous, total potassium and C/N ratio, crude fiber, ash content, lignin, cellulose, calcium, magnesium, iron, copper, zinc, manganese, bacteria, fungi and actinomycetes, which laid the foundation for further research.

PHASE II - Identifying possible products through pilot study

Based on the availability of the wastes, composition of the selected waste, the existing literature gap, pilot studies were done to find the possible products as means of recycling willow waste. The selected willow waste was found to have the recommended C: N ratio suitable for composting. Apart from this, the previous studies did by the researcher help us to understand, that the selected cotton fiber waste, namely willow waste, can also be vermicomposted into bio-manure. The prepared willow waste bio-manure was a good source of carbon. Pot culture study showed that the prepared manure was effective on growth parameters and the plant products of the selected plant varieties. As a means of enhancing the wholesomeness of the bio-manure, a consortium of other textile and agro wastes were collected and explored for possibilities. With this objective, silk, jute, coir and water hyacinth were collected. The sericulture waste was purchased from Sericulture Unit, Ondipudur (Coimbatore). Jute sacks were taken from domestic household. Water hyacinth was collected from Singanallur Lake (Coimbatore), and sun dried. Coir waste was purchased from coir briquetting industry, Universal Hydraulics, Ganapathy (Coimbatore). The collected wastes were subjected to composting, using cow dung as decomposing source and observations were analyzed. Apart from this, cotton wastes from a reputed industry in Gujarat were approached. Three different cotton spinning industry wastes namely, cotton dust, white poom and blue poom were collected, composted and tested.

Willow waste consists of very short fibers and trash content, hence weaving and knitting could not be done. This waste, however, can be made into non wovens, which does not require staple fibers. Cross lapping (webbing) is the preliminary step in any non woven technique. This was done in Technology Information Forecasting Assessment Council (TIFAC) – Core of the Kumaraguru College of Technology, Coimbatore. The existing eco-awareness and ban on plastic shopping bags, handmade paper from new sources has a huge market potential. Willow waste being a good source of lignin can be a made into handmade paper that can perform as an eco-friendly shopping bag and as package material. Willow waste purchased was soaked, grounded into a fine paste (without any additives), diluted with water and converted in hard boards.

For similar reasons, in converting willow waste into paper, the waste was also, analyzed to be made into a cleaning wipe. Disposals are material that are used once and thrown away after work. These find their major application in oil industry and domestic cleaning purposes. Currently such disposals wipes are made of non-degradable polypropylene. Considering opportunities in exploring a market for degradable wipes, the selected willow waste was combined with coir, water hyacinth and paper sludge. Among these, paper sludge was selected for its compaction ability with willow waste. It was collected from the GVG Paper Mills Pvt Ltd., Udumalapet, Tirupur and wipes were made in a hydraulic pressing machine at Universal Hydraulics, Ganapathy, Coimbatore.

The selected willow waste was made into a composite using a natural gum and a synthetic resin. Tamarind kernel powder (natural gum) purchased from

Krishnagiri (Salem, Tamilnadu), was made into a paste with water and mixed with willow waste. This was made into a composite in a compression molding machine at Technical Textiles Laboratory, Kumaraguru College of Technology, Coimbatore. Polypropylene (synthetic resin) was purchased from Zenith fibers, Surat (India) as staple fibers and sheets. Temperature, pressure and time were optimized in pilot study.

PHASE III - Development of innovative sustainable products based on pilot studies using willow waste

The selected willow waste was made into sustainable products and prototypes were developed based on inferences from the pilot study. Two decomposing sources namely cow dung and effective microorganisms Technology (EM Technology) were used for conversion of willow waste into bio-manure. Even though, cow dung is an excellent cellulose degrader, its cost effectiveness and availability, pose a blockage in practical application of this technique. Considering the beneficial facts in decomposing using cow dung, it was kept as one of the decomposing source. Since EM technology has taken a lead in waste management and considering its efficacy and popularity in other waste management systems it was taken as the second decomposing source.

Cotton is called as the dirtiest crop in the world. Being very fertilizer dependant cultivation, it consumes a huge share of fertilizer produced in the world. Analyzing the existing scenario growing trend for organic cotton, initiatives taken by the government to enhance organic cotton farming, cotton was selected for field study. Cotton was grown by supplying the prepared bio-manures from the study in real field conditions. Cotton was grown in Annur, Coimbatore for period of six months. Using Randomized Block Design (RBD), six treatments (with control sample) in four replications were planned and seeds were sown. The treatments include willow waste converted into bio-manure using cow dung (WWCD), willow waste converted into bio-manure using EM technology (WWEM), integrated nutrient management (INM), green manure commercially available (GM), recommended dose of chemical fertilizers (CHE) and control (C). The mean yield of cotton kapas, the cotton fiber properties, soil properties: before and after cultivation were tested, interpreted, compared and inferences were drawn.

The selected waste was soaked, grinded and handmade paper was formed. The sheets were made in an eco-certified handmade paper making mill, Jyothi Industries, Erode, Tamilnadu, which is certified by the Khadi Village Industries Corporation (KVIC). As a means of surface enrichment; screen printing, block printing and resist dyeing were done using synthetic (direct dyes) and natural dyes (Madder, indigo). The prepared handmade paper from willow waste was made into carry bags, files and pouches in different sizes, book album, lamp shades, bottle covers, photo frames, lamp shade, files, gift boxes, cake box and jewel box.

The developed prototypes using coir, water hyacinth and paper sludge with willow waste was very weak and found to break easily due to lack of internal binder. Thus handmade papers produced, were cut into 6 inches x 6 inches and given a finish using aloe vera and lemon at various concentrations and cured. The effect of wipes as kitchen cleaning material was tested using various tests.

Tamarind kernel powder (natural resin) was made into paste, mixed with willow waste was made into a composite in three ratios 40/60, 50/50/ and 60/40. Similarly, Polypropylene (synthetic resin), was used as sheets (on both ends) and as staple fibers (in the core along with willow waste). The samples were made based on time, temperature and pressure optimized in the previous pilot studies.

The selected willow waste was compressed into a boiler feeding material in compression molding machine. This was done with 100% willow waste and 50/50, willow waste and coir waste. The nomenclature used in the study is as below.

SAMPLE DETAILS	NOMENCLATURE
Willow waste	WW
Cow dung	CD
Effective microorganisms	EM
Willow waste compost made using cow dung as decomposing source	WWCCD
Willow waste compost made using effective microorganisms as decomposing source	WWCEM

Willow waste bio-manure made by vermicomposting the composted willow waste using cow dung as decomposing source	WWVCCD
Willow waste bio-manure made by vermicomposting the composted willow wastes using effective microorganism as decomposing source	WWVCEM
Integrated Nutrient Management, using both chemical manures and green manure	INM
Green manure (commercially available municipal solid waste compost)	GM
Recommended dose of chemical fertilizer for the cotton crop	CHE
Pre-sowing soil sample collected before sowing	PS
Willow waste wipes made finished using aloe vera and lemon	WWW
Polypropylene	PP
Tamarind Kernel powder	TKP
Willow waste composites made using synthetic resin polypropylene	WWCPP
Willow waste composites made using natural resin Tamarind Kernel Powder	WWCTKP
100% willow waste briquettes	WWB
50/50 willow waste with coir	WWCB

PHASE IV - Evaluation of the recycled products made from cotton waste

- **Testing the bio-manures obtained from willow waste**

The bio-manure prepared using two decomposing sources namely cow dung and effective microorganisms were tested for manurial properties, like pH, electrical conductivity, carbon, nitrogen, phosphorous, potassium and C/N ratio in compost stage and after vermicomposting. These results were compared with bio-manures obtained from other wastes and with the standards set in organic cultivation.

- **Comparing the yield of cotton kapas obtained and Ginning out turn (GOT)%**

The mean weight of the kapas from each treatment was compared and inferences were drawn. The ratio of weight of the cotton fiber to weight of the delinted seeds, helps in calculating the ginning out turn (GOT)

- **Evaluation of cotton fiber properties using High Volume Instrument (HVI)**

The cotton fibers in each treatment was tested in HVI for 2.5% span length, micronairre, uniformity ratio, elongation, tenacity, +b, Rd and true matt values. The results obtained from the study were compared with standards.

- **Comparing the soil properties before (pre-sowing) and after the study**

Pre-sowing (control) and the soil samples collected after the study, from the six treatments were collected and properties like pH, electrical conductivity, cationic exchange capacity, carbon, phosphorous, calcium, zinc, iron, sodium, nitrogen, copper, manganese and magnesium were tested.

- **Testing of handmade paper**

The paper from willow waste was tested for GSM, thickness, cobb value, elongation. tearing index, tensile index, burst, folding endurance number, water absorption and moisture content. The values were compared with the commercially available handmade papers prepared from textile and agro wastes.

- **Testing the effectiveness of the prepared wipes**

The prepared wipes were tested for its performance during wetness. Further, absorbency, flushability, run-off time and porosity were tested and compared with the standards.

- **Assessing the composites prepared using willow waste**

The composites prepared using natural and synthetic resin in three combinations was tested for tensile, flexural, modular properties in Universal Testing machine.

- **Testing the fuel properties of willow waste as boiler feed material**

The prepared boiler feed samples were tested for dimension, weight, burning rate, calorific value, briquette efficiency, ash content, moisture, specific fuel consumption, Thermogravimetric analysis (TGA) and bulk density.

FINDINGS OF THE STUDY

- **Composition of Willow waste (WW)**

The selected willow waste had pH of 7. 08, electrical conductivity was 1.51 dS/m, moisture 12%, carbon 19.2%, total nitrogen 0. 7%, total phosphorous 0.15% and total potassium 0.25%. The C: N ratio was found to be 27.4. The crude fiber was 47.43%, ash content was 8.5%, lignin 37.3% and cellulose 22.75%. The major nutrients namely Ca, Mg, Fe, Cu, Zn and Manganese were 0.12%, 0.05%, 1.25 mg/kg, 3.65 mg/kg, 3.12 mg/kg and 6.1 mg/kg. The bacteria, fungi and actinomycetes was reported to be 8 x 10^{7} CFU/ g, 6 x 10^{7} CFU/ g and 5 x 10^{7} CFU/ g respectively.

- **Characteristics of willow waste, decomposing sources, willow waste compost and willow waste vermicompost**

The pH of raw waste (Willow waste) and the decomposing sources (cow dung and EM) were 7.08, 8.8 and 3 - 4 respectively. After willow waste composted with cow dung and EM the pH was found to be 7.1 and willow waste vermicomposted with cow dung and EM the pH was found to be reduced to 6.9 and 7.2 and this may be due to production of carbon dioxide and organic acids that are a result of microbial decomposition in the process of bioconversion of waste.

Electric conductivity of the compost should be less than 4dS/m and it is 1.51 dS/m for willow dust. EC was 0.26 dS/m and 0.24 dS/m during composting; which further reduced to 0.11 dS/m and 0.12 dS/m in vermicomposting.

The moisture, carbon and nitrogen level and C: N Ratio was found to be reduced in willow waste vermicomposted with cow dung and EM when compared to willow waste composted with cow dung and EM. This may be due to loss of moisture in pit, porous structure and larger surface area of the manure. The reduction in carbon level may be due to the degradation of organic matter by microorganisms and the reduced nitrogen level due to leaching of nutrients by water and volatisation of ammonia.

Phosphorous content of the resultant manure from vermicomposting willow dust was 0.81 and 0.73 in WWVCCD and WWVCEM respectively. Potassium was 0.91 % and 0.87% in WWVCCD and WWVCEM respectively. It was found higher in vermicompost using cow dung WWVCCD, thus suggesting benefits of using cow dung for good values of P and K.

- **Comparing the mean weight of kapas in each treatment**

The mean weight of cotton kapas was found to be the maximum yield in WWEM as 1.43 kgs and least yield, was seen in control treatment as 0.81 kgs. The second highest yield was 1.26kgs as in INM, followed by 1.21 kgs in WWCD. The GM and CHE gave a yield of 1.14 kgs and 1.06 kgs respectively. WWEM has the highest yield of all which is due to the presence micro nutrients along with macronutrients.

- **Comparing the cotton lint weight and seed weight after ginning**

The samples WWVCCD, INM and CHE showed low seed weight and high fiber lint content as 34% and 38 % respectively. The maximum seed weight of 59% was in CHE followed by 58% in INM.

- **Comparing the Ginning out turn (%) between the treatments**

The ginning out turn was found to be maximum in INM and CHE as 22%. It was 20% in WWVCEM and 18% in WWVCCD respectively. GM has 19% as ginning index. The ginning out turn percent was higher in CHE treatment by only 3% when compared to GM treatment.

- **Analysing the cotton fiber properties**

  - The GM has the highest mean span length of 33.22% followed by INM lint of 32.8 %, WWVCEM 32.65%, CHE 32% and WWVCCD 31.57% respectively.

The span lengths of all the cotton fibers obtained from the five treatments are close to the standard value 31.3 – 33.

- The uniformity ratio was found to be highest in WWVCCD (45.50) and lowest in GM (44). WWVCEM has uniformity ratio better than GM.

- Micronairre was found to be higher in INM and CHE as 3.73µg/inch and 3.68 µg/inch respectively. Manures from the research namely WWVCCD and WWVCEM were having the standard micronairre of 3.50µg/inch. The least value was reported in GM which indicates fineness of cotton fibers.

- The strength is found highest in GM, followed by INM, WWVCEM and CHE, lowest in WWVCCD as 24.63, 24.58, 23.95 and 23.93% respectively. The CV values show that the least was 1.26% in INM and highest was 4.94% in WWVCCD. The F-values help in understanding that there is a significant difference between treatments and control and samples obtained from WWVCCD and WWVCEM.

- As per the mean values between treatments, the maximum elongation was reported to be in WWVCEM and least in WWVCCD as 6.45 and 5.60 % cm respectively.

- Lower the yellowness (+b) value higher is the acceptability of the fiber. According to this, GM with the value of 8.38% is better and WWVCCD is the least acceptable with higher yellow index of 8.98%. Since all the yellowness values of treated samples are below 12 (standard value) the cotton fibers obtained from various treatments could be concluded to have good quality to reference with yellowness.

- The brightness was better in GM as 81.97% and lowest in INM 80.38% respectively. All the brightness index values for the treated samples range between the normal values (72-85). However the F-values show no significance difference between treatments.

- The whiteness index is found to be 56.83% the highest in GM and 54.49%, the lowest in INM respectively. It is 54.74% in WWVCCD and 55.19% in WWVCEM. The CHE has 54.93% of whiteness index.

- The INM treatment shows the maximum true matt value as 1.02. All the other treatments show values between 0.91 - 0.93. These values range between the normal values 1.26-0.87. Among replications, the variation in true mat value is more in WWVCCD compared to others and least in CHE.

- **Analysis of the composition of soil before and after treatment**

- The pH of soil before and after the treatments shows only slight difference as 7.20 for soil before the study (pre -sowing), willow waste vermicomposted with cow dung and EM has 7.18 and 7.30 respectively. The maximum recommended pH 7.48 is found in CHE and the control has the highest pH as 7.50. INM and GM have a pH of 7.22 and 7.20 respectively.

- The EC of the soil before test is 0.30 dS/m. The highest EC was in WWVCEM as 0.60 dS/m which is due to the presence of microorganisms in the EM solution used. The EC was 0.40 dS/m in GM and 0.30 in WWVCCD, INM and CHE respectively.

- There is an increase in organic carbon content in all the treatments when compared to the pre-sowing soil samples. Among the treatments INM has the highest carbon content as 0.63%, followed by GM of 0.62%, WWVCEM and WWVCCD show a carbon content of 0.61 and 0.58 % respectively, which is closer to the GM that has carbon content of 0.62%. The least value was seen in CHE as 0.48

- The pre-sowing sample has 20.20% of cationic exchange capacity which is found to have decreased in all the types of treatments. The maximum decrease is seen in control followed by CHE as 11.80 and 12.10 % respectively.

- The nitrogen content was high in the pre-sowing sample as 98%, which has reduced after the treatments in all the soil samples. The control sample shows the maximum reduction as 44.20 % followed by GM as 46.3%. WWVCCD and WWVCEM have 55.3% and 53% of nitrogen, which is closer to nitrogen content in CHE (53.5%). Thus, it can be suggested that WWVCCD and WWVCEM have appreciable nitrogen levels and can be a replacement for using chemical fertilizers on soil.

- The pre-sowing soil sample has 4.5% of phosphorous. It is found to have reduced in WWVCEM to 4.25% and control sample as 4.10%respectively. In all the other treatments the phosphorous levels raised. The maximum phosphorous was in INM (6.12%). This is because of the supplementation of NPK at appropriate levels in a readily available form as fertilizers. The GM has 5.5% phosphorous.

- The potassium level has increased in all the treatments compared to the pre sowing sample expect in case of control soil sample. It is seen that the manures obtained from the study are very good sources of potassium. WWVCCD and WWVCEM have doubled in the potassium content.

- The sodium level was 1.96% in pre-sowing soil sample. At the end of the study, the sodium content reduced in WWVCEM, CHE, GM and control to 1.41%, 1.63% 1.74% and 1.03 % respectively. The sodium content increased in WWVCCD and INM by 2.15 and 2.26% respectively.

- The soil had calcium content of 6.5% before sowing (PS) which has decreased in all the soil samples expect WWVCCD which indicate an increase of 7%, which can be further explained as the result of cow dung. Sample WWVCEM shows a minimum decrease of 6.13%.The calcium level has decreased in INM and CHE by 5.13% and in GM and control soil samples by 5.25 and 5.10% respectively.

- The initial magnesium content is 8%, which increased in the soil after all the treatments expect the control sample. Among the treatments, the maximum increase was observed in CHE as 19.62%. The GM recorded the next highest level of magnesium as 13.62% and the INM sample has an increase of 12.75% respectively. Among the two manures obtained from the study, WWVCEM had higher level Mg of 9.25%, compared to WWVCCD with 8.38% of Mg.

- The pre-sowing soil sample has 3.24% iron, which increased in GM and WWVCCD to 3.53% and 3.42% respectively. The iron content of WWVCEM was

3.16, which was closer to INM iron content 3.2%. Iron content was least in CHE as 2.95% soil sample, since it had only NPK in its composition.

- The WWVCCD has the highest manganese content 3.08%, which increased from 2.8% the PS sample manganese level. Except WWVCCD, all other treatments reduced from the initial value. GM has the second maximum manganese content of 2.77%. WWVCEM and CHE have similar manganese content of 2.37% and 2.38%respectively and INM had the value as 2.25%.

- The initial zinc content of the soil was 0.79% in PS sample; it further increased in all the treatments and decreased in control sample which shows zinc content of 0.6 %. The highest content was found in WWVCCD and WWVCEM as 1.09% and 1.03% respectively. INM and CHE have 1.02% of zinc. The GM has the lowest zinc content of 0.91%.

- Copper is highest in the PS sample as 1.24%. It reduced in all the treatments. GM has the highest copper content 1.13%. WWVCCD and WWVCEM samples have 1.03% and 0.99% of copper, where as INM and CHE have 1% and 0.96% respectively.

- **Evaluation of willow waste handmade paper**

The GSM of handmade paper is 410 g/m^2 and thickness 1166 microns. The cobb's value is tested to be 530. The elongation of the paper is 5.4%, tearing index is 8.8 mN.m^{2}g, tensile index is 10.52 Nm/g and burst is 0.81 Kpa.m^2/g respectively. The folding endurance number or foldability is 77. The water absorption is 4 mm/min and moisture content is 6.9% respectively.

- **Evaluation of willow waste wiping sheet**

The pH of the aqueous extract is 4.22 and in water it is 6.87. The sinking time of the willow waste wipe is 3.4 seconds. The water holding capacity is 96%. The wetting time top (sec) is 5.831 seconds, wetting time for bottom is 7.3124, the top absorption rate 59.6601(%/sec), the bottom absorption rate 40.3677 (%/sec), the top max wetted radius 17 (mm), the bottom max wetted radius is 17 (mm), top spreading speed is 2.1567(mm/sec), the bottom spreading speed is 1.8946 (mm/sec), the accumulative one-way transport index 143.6603(%) and the overall moisture management capacity (OMMC) was calculated to be 0.1623.

The flushability tests confirmed that the complete breakdown after 115 cycles. The overall weight loss during the test was found to be 8.5%, indicating low particle disintegration, which may be due to the absence of pre-processing in terms of size reduction to produce the wiping sheets. The maximum weight loss was in sieve of 4mm diameter and minimum in 12mm diameter.

- **Evaluation of composites**

The tensile strength is 27.4 kg/cm^2, 44.65 kg/cm^2 and 45.7 kg/cm^2 in 60/40, 50/50 and 40/60 of WWCPP. It is 1.86 kg/cm^2 in 60/40 of WWCTKP. The elongation was 2.14%, 2.49%, and 2.16% in the 60/40, 50/50 and 40/60 ratios of WWCPP. It is 3.13% in 60/40 of WWCTKP. The modulus @ 5% was found to be 2.23 kg/cm^2 and 3.4 kg/cm^2 in 60/40 and 40/60 of WWCPP and 1.32 kg/cm^2 in 60/40 of WWCTKP. The flexural is 8.4 N/q.mm, 13.3 N/q.mm and 11.5 N/q.mm in WWCPP and 1.02 N/q.mm in WWCTKP.

- **Evaluation of willow waste briquette**

The average dimension of WWB was 8x4x4 inches and 9x6x4 inches for WWCB. The average weight of each briquette was 0.75-1.29 and 2.5-2.8 kgs for WWB and WWCB respectively. The moisture percent was high as 7.8% in WWB and 6.6% in WWCB. There is more ash content as 16.4% in WWCB and 13.5% in WWB. The calorific value was 3248.3 – 4767 Kcal/ kg for WWB and 4358 Kcal/kg for WWCB respectively. The burning rate was 12.5 g/min in WWCB and 11.12 g/min in WWB. The specific fuel consumption was 1.275 kg/litre for WWB and 1.132 kg/litre for WWCB respectively and the bulk density is 5.8.3 kg/m^3 for WWCB and 709.53 kg/m^3 for WWB respectively.

Conclusion

The investigations in the study were focused on recycling and upcycling hitherto polluting willow waste into sustainable products for future. Basic investigations were done and prototypes developed were tested and results were compared with the standards. Waste was seen as a wealth potential and simple, eco-friendly; low investment techniques with sound commercial viability were experimented. Willow waste bio-manure was found to be a good amendment to chemical polluted soils. The handmade paper will be a purposeful carry bag with lot of advantages that will discourage the use of plastic carry bags. The wipes tested to be fast absorbing and quick drying from the ring test, shows the opportunities to convert willow waste into wipes. Willow waste polypropylene composite had very good tensile and flexural properties that can be engineered based on the end uses. To reduce the dependence on woods for textile wet processing, willow waste briquettes can be a good alternative to wood and coal. This can be a sustainable solution to the spinning mill owners, cotton waste merchants, cotton textile processing industries, companies moving towards sustainability and eco-certification for exports and more essentially for farmers who are interested in shifting towards organic cultivation.

Recommendations to the government

- Willow waste recycling techniques can be encouraged for entrepreneurship and popularizing the concept, bringing rural upliftment and empowering women
- Utilization of willow waste for bio-manure production can be made mandatory in every spinning mill

Recommendations for further research

- By reduction in particle size, absorbents suitable for industrial applications can be developed
- Development of willow waste wipes and application of various functional finished using extracts obtained from natural sources
- Fabrication of eco-friendly composites using willow waste for specific end application can be developed
- Composites and briquettes can be further done extensively using willow waste along with other agro biomass residues

Limitations

- In willow waste briquettes, the volatile content and fixed carbon content could not be tested due to the heterogeneous nature of the waste.
- The analysis of gas obtained from burning could not be tested due to error in the equipment during the testing of the sample