Virgin Woolnonwoven Structures for Agricultural Applications: Potential Recycling Technology for Waste Wool

Moyo Fagbenro*[1], Bolajoko Adiji[1]and Tahir Shah[2]
moyofagbenro@gmail.com
[1]Industrial Design Department, Federal University of Technology, Akure, P.M.B. 704, Ondo State
[2]Advanced materials, Institute for Material Research and Innovation. University of Bolton, BL3 5AB, United Kingdom

Abstract
The increasing concern for environment and the desire to move towards zero waste economy, has driven a need to develop new and efficient ways of recycling materials especially textiles. Wool has significant recycling potential especially in agriculture as a good soil amendment and nutrient source due to its protein rich composition. This study investigated the potential for wool structures as fertiliser and as a carrier for controlled release fertilisers in order to evaluate the potential of waste wool for soil amendment to enhance nutrient delivery. Slivers of Australian Wool fibres are needle punched to produce a fabric with area density of 158gm^{-2} and a thickness of 4mm. The nonwoven wool is then coated with commercial CRF (Osmocote bloom) using calcium chloride crosslinked starch – urea as binder. Growth trial was conducted in a greenhouse using radishes and lettuce) in four treatments (**A**: plant + potting soil, **B**: plant + CRF, **C**: plant + uncoated nonwoven wool, **D:** plant + coated wool nonwoven). Plant height was recorded weekly and at the end of the cultivation period, dry plant weight was measured. Results showed that plants of treatment **C**exhibited the highest plant height for both plants and plant yield was of optimum quality. The uncoated nonwoven wool structure disintegrated within the period of cultivation for both plants, which proved that waste wool structures could potentially be used to fertilise plantswithout leaving structural residue in the field after cultivation period.

1. INTRODUCTION

In 2011, the Department for Environment, Food and Rural Affairs (DEFRA) (Defra 2011) published UK government's plans towards launching a "zero waste economy". As part of this plan, some of the areas the government set out to review include:

- Introduction of a landfill restriction on wood waste, metals, textiles and all biodegradable wastes. The Government will partner with the industry to drive innovation in reuse and recycling of these products before the start of any bans;
- Acceleration of recycling and waste reduction schemes with focus on the hospitality industry, paper, direct mail, textiles and construction wastes.(Defra 2011; DEFRA 2013)

This has driven a lot research on utilising textile waste in various ways. Agriculture is one area that seems to have shown potential for utilisation of natural fibre waste especially because natural fibres are renewable. Wool is a protein rich natural fibre obtained from several varieties of sheep and because of its organic nature; it has been widely explored for use as compost, soil amendment and fertilizer. Waste wool includes excess or low grade wool, wool scour sludge, waste from wool processing industries and unwanted finished textile products (Zheljazkov et al. 2009). Waste carpet wool has been composted and used as feed stock and nutrient for plants, but this failed because composting resulted in immediate immobilisation of nutrients, especially nitrogen.

Waste wool has also been used to reinforce soil structures as well as improve water holding capacity. Miraftab and Lickfold (2008) observed that 10% nylon pile waste added to substandard soil enhanced the soil's cohesion, strength and internal friction. However, the major limitation was the mixing process, in the laboratory it was easy to mix thoroughly with hands but this will be impractical in the field.

Waste wool as an organic nutrient source for potted plants is another investigated area, a lot of positive results have been recorded with significant percentage increase in plant performance and yield. Gorecki and Gorecki (2010) observed a 30% increase in plant yield of the pot cultivation of tomato, sweet pepper and eggplant using wool as fertilizer. They concluded that different types of sheep wool are "valuable and environmentally friendly fertilizers". Zheljazkov *et al.* (2009) also observed that a single application of waste wool to potted plants can support 4-5 harvests. Clearly, the use of waste wool as fertilizer has great potential but a lot of research is still needed to explore all possibilities.

Wool seems to be very beneficiary to soil health. There are certain soil health indicators that give information about the condition of the soil, they include:

- The presence of soil aggregates,
- Organic matter content of the soil,
- Soil structure and texture, and
- Water holding capacity of the soil

  (Kinyangi 2007; USDA Natural Resources Conservation Service 1996; Romanyà, Serrasolses, and Vallejo 2004)

Wool has the potential to increase organic matter in the soil due to its biodegradable nature, which will in turn result in the formation of aggregates (by the action of the organic matter in soil), and the excellent water holding capacity of wool will also contribute immensely to the water holding capacity of the soil.

Controlled release fertilizers (CRF) are a category of fertilizers that release their nutrients coinciding with plant demand i.e. the nutrients are released gradually over time and are triggered by certain factors such as temperature, water content etc. (Shaviv 2000; Hanafi, Eltaib, and Ahmad 2000; Trenkel 1997).

The major advantages of CRFs are based on two factors - matching nutrient supply with plant demand and maintaining nutrient availability, this results in reduction of plant toxicity, reduction of application cost, increased availability of nutrients for plants and the prevention of environmental issues such as nutrient leaching and the emission of greenhouse gases (Shaviv 2000; Trenkel 1997). It is clearly evident that CRFs are very useful and have a huge advantage over the conventional fertilizers but the disadvantages can cause a setback and hinder their effectiveness. These include:

- Unavailability of standard methods for the determination of nutrient release patterns.
- Non-biodegradable nature of polymer coatings which may leave synthetic residue on the field and accumulate over time.

- Occurrence of Burst release as a result of build-up of internal pressure within the granule after water absorption which leads to rupture of the coating and instantaneous premature release of the fertiliser

  (Shaviv 2000; Trenkel 1997; Sempeho et al. 2014).

Therefore, it is necessary to explore options on how to improve the performance of CRFs and to develop novel/new techniques for utilizing textiles and waste fibres especially natural fibres such as wool, which has found some use in agriculture. This study explores the use of wool as a biodegradable carrier for a commercial CRF. A nonwoven structure will be produced from wool fibres on which the CRF will be coated on to the surface using cross linked starch urea. Observations will be made to determine whether the presence of the wool enhances the performance of the CRF or not and also to examine the behaviour of nonwoven wool structures as fertiliser.

2. MATERIALS AND METHODS

The raw Australian wool used to make the nonwoven fabric was sourced from the textile laboratory of the University of Bolton. All chemicals used for the coating preparation – calcium chloride, potato starch and urea were obtained from Fischer Scientific. For the growth trial, radish and lettuce seeds were purchased from Suttons Consumer Products Ltd, the Eco biodegradable plant pots (10cm deep x 14cm diameter) were purchased from Greenhouse Sensation (www.greenhousesensation.co.uk). Sinclair Multipurpose compost, which was the planting medium and Osmocote Bloom (2-3 months) was the commercial CRF, purchased from JFC Monro. All other apparatus used especially in the laboratory was available at the University of Bolton**.**

2.1 Production of Nonwoven Fabric

The nonwoven fabric was produced in the textile laboratory of the University of Bolton, using the Automax nonwoven needlepunching line. The machine settings influence the property of the final product especially in terms of the area density and thickness. The machine parameters for the preparation of wool nonwoven are:

Feeding mechanism: manual

Approximate speed: 0.3

Needling speed: 200 strokes/min

Needle penetration: 14mm

Feed rate: 72cm

The fabric produced was about 4m long and the average fabric area density (FAD) was 158g/m^2, calculated according to ASTM D3776 (standard test for mass per unit area). Five 10cm x10cm straight and even samples were cut from random areas on the fabric for the calculation. Similarly, the thickness was also calculated using ASTM D5199 (standard test method for measuring the nominal thickness of geosynthetics. Using the same samples from the area density calculation, the thickness of the wool nonwoven was determined to be 4.2mm.

2.2 Preparation of Crosslinked Starch Urea Coating and Application ontothe Wool Nonwoven Fabric

This was prepared in the materials laboratory at the University of Bolton. The crosslinked starch urea binder used was prepared by adopting and modifying a method used by Chowdary and Chandra (2009) (Chowdary and Chandra 2009). To make 500ml of binder, 30g of potato starch was dispersed into 100ml of distilled water to make slurry and was set aside. Then 10g of calcium chloride and 10g of urea were dissolved into 400ml of distilled water with the use of a magnetic stirrer. The solution was then heated to boiling and while stirring with the magnetic stirrer the starch slurry was added to the solution, which formed a viscous solution. Heating was continued for about 10 minutes before setting the mixture aside and allowing to cool to room temperature.

About twelve 10cm x 10cm square samples were cut from the fabric and 100g of Osmocote bloom (2-3 months) was spread out on a tray. One side of the fabric sample was dipped into the crosslinked starch urea binder and then placed on the CRF for the granules to stick to the coated wool surface; the same procedure was repeated for a second sample, which was dipped into the binder after the CRF coating again before joining it together with the first sample to form a sandwich structure. This was repeated so that six (6) sandwich samples were obtained. These samples were then placed in the oven for 22 hours and 40 minutes at 21°C to dry. After drying the samples were brought out and used for the plant growth tests.

2.3 Plant Growth Test Preparation

Radish and lettuce were the plants of choice because of their short cultivation period, which coincides with the upper and lower release periods of the Osmocote bloom (2-3 months). The radish purchased was of *zlata* variety and has a cultivation period of about 8 weeks while the lettuce was of Tom Thumb variety and has a cultivation period of about 12 weeks. For this growth trial, four experiments were conducted:

Treatment **A**: plant with potting soil (negative control)

Treatment **B:** plant with Osmocote bloom (positive control)

Treatment **C**: plant with uncoated wool fabric

Treatment **D**: plant with coated wool fabric

For each treatment there were 3 pots per plant, that is, there were 24 pots in all with two sets of A, B, C and D. After labelling, the pots labelled "A" were filled with the potting soil and watered. Then the pots labelled "B" were filled with the potting soil and about 4-6g of Osmocote bloom was added to the soil before watering. For the pots labelled "C", because the coated wool was a sandwich structure i.e. double wool layer, two (2) 10cm x10cm squares of plain wool fabric where placed in each pot with a little potting soil at the bottom and then covered with more potting soil and watered.

For the pots labelled "D", a little potting soil was placed at the bottom and then the coated wool fabric was placed on top, then it was covered with more potting soil and watered. After all the preparatory work had been done, the seeds were planted about 4cm from the plant surface, plants were watered and the plant height was recorded every week until harvest. After harvesting, the average plant weight for each treatment was also obtained for comparison.

3. RESULTS AND DISSCUSSION

3.1 Plant Height Comparison and Plant Yield of Radishes

The radishes were cultivated for seven weeks and plant height was recorded on a weekly basis throughout this period. The plant height measurements were taken from the second week of cultivation as the radishes were in the process of germination in the first week. The average plant height throughout the cultivation period is presented in table 1 and figure 1.

Table 1: Average Radish Plant Height throughout Cultivation Period

Treatments	Week					
	2	**3**	**4**	**5**	**6**	**7**
A: potting soil (cm)	6.6	11.6	12.2	13.9	14.2	14.2
B: with CRF (cm)	5.2	9.5	12.4	17.3	17.9	18
C: uncoated wool fabric (cm)	7.3	11.7	14.4	19.5	19.9	20
D: CRF coated wool fabric (cm)	5.2	7.9	9.5	12	12.6	12.8

As observed in Figure 1, the most glaring observation is that radish in Treatment C i.e. the plants with the uncoated wool fibre had the highest values for plant height. The Radish grew at a high rate until the 5th week where growth seemed to slow down and plateau. This shows that wool was sufficient to provide adequate nutrients for optimum growth of the radish during the cultivation period. It was also observed that the soil containing the wool was moist and did not dry up between watering periods.

This proves that wool helped in water retention of the soil, which also contributed to the growth of the radish, which appeared healthy, with very green leaves and tall stems. The initial growth rate of plants under Treatment A (plants with potting soil only) was similar to that of treatment C, however after week 3, no major growth increase was observed. This could be due to the fact that the plants had used up the inherent nutrients available in the potting soil, which was also drained very easily; thereby not retaining a lot of water and resulted in dryness in between watering periods. The plants had a lighter green colour and did not look very strong.

Figure 1 also shows that radish in Treatment B (plants with Osmocote Bloom), seemed to have an average initial growth rate but grew at the same rate with treatment C, albeit at a shorter height range. The similarities between the growth rate proves the validity of wool serving as a fertilizer for these potted plants as previously suggested by Gorecki and Gorecki (2010) (Górecki and Górecki 2010)and Zheljazkov et al. (2009) (Zheljazkov et al. 2009).

It even goes further to show that wool can produce better results than commercial controlled release fertilizers for potted plants. Dryness of the soil in between watering also occurred for radish in Treatment B which accounted for the lower performance, since the soil could not retain enough water in between watering periods.

Plants in Treatment D (plants with Osmocote bloom coated wool) had the lowest values of plant height, even performing less than plants in Treatment A. This may be due to various reasons associated with the coating medium, the coating method and the coated material itself. Throughout the cultivation period, even after watering, the soil appeared dry which indicates that the coating medium could have blocked the pores within the fabric preventing it from retaining any moisture, thereby eliminating the desired water retention property of wool.

The blocked pores of the fabric could also account for the poor diffusion of nutrients from the CRF to the soil, since it was difficult for water to penetrate the fabric structure which contributed to the poor performance of the plants. Although the values of plant height from Treatment D was poor, the quality of the plants was not seriously affected. The leaves were very green and plants looked apparently healthy, the inherent nutrients of the potting soil may have contributed to this observation. The growth rate was relatively steady and in line with the other treatments, plant height began to plateau after week 5.

It is quite evident that either the coating material (crosslinked starch-urea) or the method of coating (sandwich structure) greatly retarded the action of the controlled release fertilizer and also adversely affected the desirable qualities of wool, especially the water retention property. After harvesting, the radishes were weighed in grams using a measuring scale in the laboratory at the University of Bolton. The values obtained showed that the radishes in treatment C were slightly bigger than the other radishes, while the radishes in Treatments A, B and D were about similar in size.

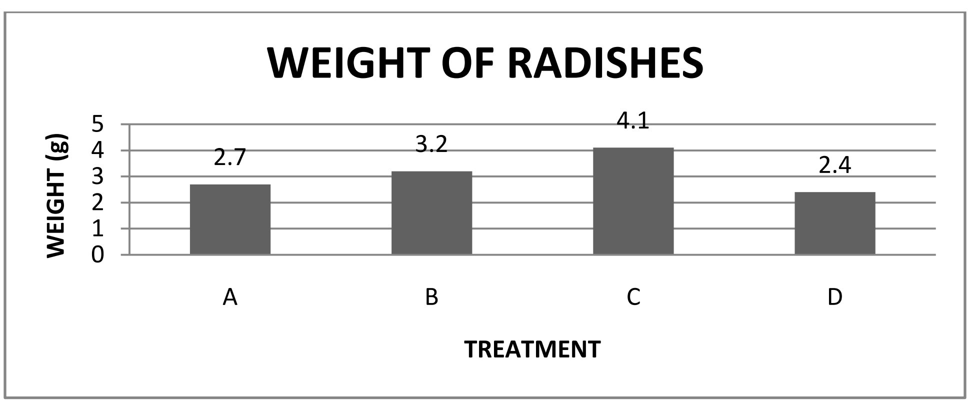

Figure 2: Bar chart showing the radish weights of the various treatments

3.2 COMPARISON OF PLANT HEIGHT IN LETTUCE

The lettuce was cultivated for seven weeks and plant height was recorded on a weekly basis throughout this period. The plant height measurements were taken from the second week of cultivation as the lettuce was in the process of germination in the first week. The average plant height throughout the cultivation period is presented in table 2

Table 2: Average plant height (cm) in Lettuce during the cultivation period

Week	**Treatments**			
	A (potting soil)	**B** (with CRF)	**C** (uncoated wool fabric)	**D** (CRF coated wool fabric)
2	3.3	3.2	3.5	3.3
3	6.3	3.5	6.1	5.6
4	8.7	4.7	7.8	6
5	8.7	7.8	10.7	7.5
6	8.9	7.8	11.2	7.7
7	9.1	8.1	11.7	8.1
8	9.1	8.4	12.2	9.1
9	9.2	8.6	12.3	9.3
10	9.2	8.7	12.4	9.4
11	9.2	8.9	12.5	9.5

As presented in Figure 3, Lettuce seemed to show a unique result compared to radish. Lettuce in Treatment C (uncoated wool fabric), similar to radish, recorded the highest values in plant height. The major nutrient requirement for wide and juicy leaf growth in lettuce is nitrogen(Seaman, n.d.), which may account for the high performance of plants in treatment C as well as the other desirable properties of wool fibres, especially water retention.

The soil was moist throughout the cultivation period and the Lettuce leaves were very green and wide and even covered the entire opening of the pot. The porous structure of the uncoated nonwoven wool fabric also contributed to the water retention property and also allowed microorganisms to have easy access to the fabric for decomposition; thereby releasing nitrogen. Plant height reached its peak in week 9, after which it started to plateau.Lettuce in Treatment A (potting soil only) showed similar results to those obtained with radishes in its initial rapid growth and consequent plateau after four weeks of growth.

It had the highest initial plant height until the 4th week, during which it may have used up the nutrients in the potting at that time. The soil appeared dry in between watering periods and by the 7^{th} week, lettuce leaves began to shrink and were not as wide. Lettuce in Treatment D (CRF coated wool fabric) seemed to perform much better than the radishes. There was steady growth until the 8^{th} week before growth started to plateau (Figure 9). Even though plant height was at the same level with lettuce in treatment A, there was slightly better performance than lettuce in Treatment B (CRF only).

The soil also appeared dry in between watering periods, and leaves did not appear to shrink even during the plateau stage. Lettuce in Treatment B which seemed to have the poorest performance has a different curve from the others. The first four weeks showed very poor growth, and then there was a sharp growth spurt in week 5, after which growth seemed to slow down and plateau. It is quite difficult to explain the sudden growth spurt in week 5, it is presumed that there was a burst release of nutrients from the commercial CRF. Burst release is the instantaneous release of fertilizer from the coating due to build-up of internal pressure within the coating structure (Shaviv 2000; Trenkel 1997; Sempeho et al. 2014).

Overall, Treatments A, B and D seem to plateau around the same level, leaf shrinkage was observed in treatment A, leaves of plants in Treatments B and D did not shrink, however they were not as well developed as the leaves of plants in Treatment C.

For both radish and lettuce, the use of the uncoated wool fabric seemed to exhibit superior performance when compared with the other treatments; with the leaves of both plants being very green and the plants seemed quite strong. The wool also contributed to the water retention of the soil as the soil was moist even in between watering periods. The porous structure of the non-woven fabric may have also encouraged the action of microorganisms, thereby releasing nitrogen and other nutrients fast and regularly throughout the cultivation period of the potted plants.

The soil in the pots of treatments C and D were examined for wool structure disintegration. In the case of radishes, it was discovered the uncoated wool fabric for treatment C was totally disintegrated within the seven weeks of cultivation. This shows that microbial activity was high and decomposition occurred at a fast rate which could account for the high plant height and higher radish weight recorded in treatment C.

There was little or no trace of the fibres in the pot which shows that the plant utilized all the nutrients from the wool fabric. However, for Treatment D, there were still traces of the fabric as well as the CRF Osmocote Bloom, even though some disintegration had taken place. This could be the reason why the plants performed very poorly since they could not obtain adequate nutrients either from the wool or the CRF. Similar results were observed for Treatments C and D in lettuce, therefore, it can be suggested that the wool decomposed at the rate of plant growth, releasing nutrients as the plant was developing within the cultivation periods for both radishes and lettuce

4. CONCLUSION

From the study conducted, it is clear that the addition of wool to the potted plants produced plants with the maximum plant height and also yielded optimum quality. Wool kept the potted soil moist contributing to the water retention of the soil and the decomposition provided nutrients for the potted plants. This supports the claim that wool can be used as fertilizer for potted plants (Górecki and Górecki 2010; Zheljazkov et al. 2009).

The fact that the wool structure disintegrated for the plants with different cultivation periods shows that decomposition of wool was at the same rate as plant growth. This means that wool can supply nutrients for the plants during the cultivation period regardless of the length of time (as long as it is within a certain range of time). It should be noted that pure wool was used for this study and the ultimate goal is to utilize waste wool fibres for agricultural use. Nonetheless, this is a positive step in that direction and future research will be needed to utilize waste wool in various fabric structural compositions and compare results obtained.

For the CRF coated wool fabric, although results obtained were poor, there is a potential for more research to be conducted. The method of coating, type of coating used, structure of fabric, drying time and temperature are some of the parameters that can be studied further before the idea that a synergy can exist between the use of wool fibres and CRF can be completely elucidated.

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