Tampere University of Applied Sciences

Utilization of Cotton and Polyester Blend Textile Waste in Soil Applications

as Soil Improvers and the Risk of Microplastic leaching in Finnish Soils: Literature review

Jennifer Hyvärinen

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ABSTRACT

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With increasing amounts of textile waste, its inefficient disposal, and the complexity of textile composition, the concern for environmental impacts from textile waste have risen. Cotton and polyester blend textile waste are more challenging to recycle than non-blended textile waste, due to the bonding of fibers. This thesis aims to find alternative paths for textile waste to increase circularity. In collaboration with a Finnish sustainable fashion company, GlobeHope, the utilization of cotton and polyester blend textile waste in Finnish soil was investigated through a literature review.

This thesis project looked into three different methods allowing utilization of cotton and polyester blend textile waste in soils: separated fiber for soil enhancement, plastic mulching alternative, and geotextiles applications. Challenges of textile waste were studied and was found that microplastic and chemical contamination risks exist due to substances such as microfibers and dye dust that may be present in textiles. Factors affecting the degradation of polyester causing the leaching of microplastics were investigated to study whether cotton and polyester blend textile waste can be incorporated into soils in Finland.

It was concluded that the most suitable options for using cotton and polyester blend textile waste are geotextile and agriculture utilization, such as erosion prevention and plastic mulching alternatives. However, further studies and experiments must be done to further understand the interaction between textile waste and soil, to safely be used in soils.

Keywords: textile waste, cotton and polyester blend, soil applications

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ABBREVIATIONS

EPA	Environment Protection Agency
EU	European Union
PET	poly (ethylene terephthalate)
UV	Ultraviolet

1 INTRODUCTION

Textile plays a huge role in our society; according to Grandviewresearch, the size of the global textile market in 2021 was 994 billion dollars, with clothing applications accounting for over 73%, (Grandviewresearch, 2022) compared to the global automotive manufacturing market of 2.7 trillion dollars in the same year (Statista, 2022). Evidence of fiber weaving has been dated back to around 3000 B.C. showing that textile has been a part of history since the Neolithic period (Barber, 1992). The first synthetic fiber, nylon, was invented in 1935, and shortly after, polyester fiber was invented in 1941 (Twombly, 2016). Due to the increase in production, textile waste began to rise around the 1960s, according to the data from the Environment Protection Agency (EPA), contributing to waste in landfills and carbon emissions (EPA, n.d.). Global production of synthetic and natural fibers in 2020 was around 6,8 million metric tons for natural fibers and 74,1 million metric tons for synthetic fibers, with polyester (PET) fiber production at 57 million metric tons. (Fernández, 2021) Globally, 12% of textile material gets recycled and 73% of textile materials are landfilled or incinerated. (Todor et al, 2022) In 2019, Finland’s end-of-life textiles contributed to 85 773 tonnes of waste, 61% was recycled for energy, 18% was recycled for material, 4% was reused and 16% was exported (Dahlbo et al., 2021). Economic and population growth, along with the popularity of fast fashion and rapid change in trends, leads to the demand for textiles continuously increasing, and if not managed properly, results in environmental damage. (Henry et al., 2019)

Many EU countries are diverting organic waste (textile waste included) from landfills, due to the EU waste directive (Waste Act (646/2011), initiating more recycling and upcycling efforts. (Rahman et al., 2022) As of 2023, Finland expects to have a separate waste collection system for textile waste (Tiainen, 2017), which conforms to the European Union (EU) Waste Framework Directives 2018/851, stating that by 2025, textile waste must have a separate waste collection system (Directive 2018/851/EU). Therefore, exploring a potential usage for textile waste will allow a larger amount of waste to be reused to expand the circular economy.

Cotton and polyester blends are composed of cotton fibers and polyester fibers which are blended with varying ratios depending on the needs and usage of the textile. Cotton is categorized as a natural fiber and polyester as a synthetic one; the mixture of these two fibers allows the textile to combine the fibers' best features. Cotton fibers provide softness and air permeability to textiles whereas polyester reinforces to increases the durability of textile and crease recovery (the fabric's ability to return to its original state after the crease). (Clark, 2011) Cotton fibers are made from fertilized cottonseed, where the plant produces a flower containing the cotton fruit. The cotton fibers are biologically known as the seed trichomes or the seed coat hair, mainly composed of cellulose (88-96.5%), proteins, pectin, and inorganics. Polyester fibers are made of man-made polymers containing ester groups which are produced from chemicals found in petroleum through a condensation reaction between ethylene diglycol and terephthalic acid. There are many different types of polyesters, however, the most used type is poly (ethylene terephthalate) known as PET. (Clark, 2011) As new types of textiles emerge, with different materials, ratios, and blends, it has become a challenge to recycle and separate due to their tightly bonded structure, where cotton and polyester blend is a typical, widely used example of a bonded blend. (Ling et al., 2019).

Emerging innovations for recycling textile and increasing circularity have helped increase sustainability in the textile industry. There are many types of textile recycling processes such as mechanical and chemical recycling, with many new technology innovations emerging constantly for textile recycling. The recycling processes allow the extraction of materials from used textiles to be inserted back into the life cycle. Extraction of fibers can be done mechanically or chemically to allow fibers to be re-spun into yarn. Methods for recycling cotton and polyester blend textile exist, but face many difficulties regarding fiber separation, due to fiber bonding and heterogeneity. The quality of recycled fibers depends on the processes that it undergoes. Fibers that go through recycling processes are often found to have lower quality, for example when polyester fibers are put through degrading conditions, leaving them with a lower tensile property and lower molar mass distribution (Haslinger et al., 2019). Current methods of recycling polyester and cotton blends result in degradation of either component, thus new technology and methods of recycling are still needed. Therefore, other possibilities for the utilization of textile waste to prolong the life cycle should be investigated. (Subramanian et al., 2021)

This thesis is a collaboration with Globe Hope aiming to study cotton and polyester blend textile waste, and the possibility of utilizing it as soil improvers in Finnish soils, while also focusing on minimizing the risk of microplastic leaching into the soil. Globe Hope is a fashion and textile company in Finland, working towards a circular economy by upcycling textile waste and creating new products. A new service that GlobeHope provides is called the Zero Waste Service, where they offer to recycle textile waste from companies and transform them into new items (GlobeHope, n.d.). Possible uses that will be looked into are fiber for soil improvements, soil covers, and geotextile. However, the use of cotton and polyester blend textile waste in soil carries a risk of potential microplastic contamination and environmental damages. Thus, a thorough study should be done to grasp a better understanding of the possibilities, as Finnish soil is characterized as being acidic and goes through long winters, which can affect the degradation of cotton and polyester blend textile waste when used in soil. (Finnish Meteorological Institute, n.d.)

Factors affecting the feasibility of textile waste such as polyester degradation in soil and challenges regarding risks of chemical and microplastic contamination will be discussed and taken into consideration. This allows the analysis and study of cotton and polyester blend textile waste suitability for improving soil properties.

2 SOIL APPLICATIONS OF COTTON AND POLYESTER BLEND

2.1 Separated Fiber for Enhancement of Soil

As previously mentioned, in order to recycle blended textiles, separation of fiber must occur for the recycling of each fiber type to happen. However, current fiber separation processes lead to the degradation of fiber, which leads to lower fiber quality. For recycled fiber to be made into textile, it is often combined with virgin material to reach the required conditions. Therefore, fiber enhancement of soil is an option for lower quality fiber to be used to improve the soil. (Haslinger et al., 2019).

2.1.1 Fiber Separation Methods

Through the separation of fibers, the cotton fibers can be utilized for soil amendments due to their biodegradability and potential benefits to soil, and polyester fibers can be recycled and re-spun into new yarns or other products. Fiber separation techniques are not yet commercially viable for most textile blends, especially cotton and polyester blend, due to their heterogeneity (Haslinger et al., 2019). The difficulties with blended textiles, especially cotton and polyester, are that there are only a few ways to separate them into their true components, limiting the ability to recycle the material. Existing recycling methods have disadvantages that hinder their viability to be commercialized. (Hou et al., 2018). The processes to separate fiber in the textile are underdeveloped, thus making it complicated and expensive to undergo. Utilization of separated fibers would make better use for value-added products, for example, cotton would be more beneficial in producing glucose for bioethanol production and polyester can be re-spun and reused as feedstock in the next textile production (Subramanian et al., 2020) with consideration to the degradation of polyester affecting the quality of the yarn (Haslinger et al., 2019). Separation of fiber from blended textile waste includes enzymatic hydrolysis, hydrothermal separation, ionic liquid, glycolysis, and alcoholysis.

Enzymatic hydrolysis involves breaking down cellulose from cotton, using enzymes mixed in water, which turns it into glucose, leaving polyester fibers for separation through filtration. The textile waste is pre-treated and mixed with enzyme solution before the process of enzymatic hydrolysis. Before the respinning step of polyester, the recovery phase occurs where polyester is filtered from hydrolysate solution, then washed and dried, followed by the granulation step. Other treatments may take place after this to improve the polyester, or virgin polyester may be added before the melt-spinning process. Also, the purification phase is where recovery of glucose-rich hydrolysate solution occurs, which can later be used in other production processes to make bio-based products. (Subramanian et al., 2020)

Under the hydrothermal reaction and acid catalyst, degradation of cotton occurs when the glycoside bond breaks. While cotton degrades to cellulose powder, polyester fiber remains the same, allowing filtration, thus resulting in effective separation. Using high temperature and pressure leads to hydrolysis of polyester. This process degraded the polymer into a monomer using methods with lower environmental impacts. The fiber separation is, therefore, possible for textile waste recycling. (Hou et al., 2018).

Ionic liquid has also been developed to dissolve cotton fibers in a cotton and polyester blend to help efficiently separate the fibers for recycling. To separate fibers using ionic liquid means that the method is less damaging to the environment compared to other existing fiber separation methods (Haslinger et al., 2019). According to studies, ionic fluid 1-allyl-3-methylimidazolium chloride (AmimCl), 1-butyl-3-methyl-imidazolium chloride ([Bmim]Cl), N-methylmorphine-N-oxide (NMMO), NaOH/Urea and other ionic liquids (IL) has shown that cotton fibers can be dissolved from cotton and polyester blend textile waste, thus leading to separation of fibers for further recycling. (Xia et al., 2021, Zhu et al., 2006, Shuhua et al., 2018)

For cotton and polyester blend textile waste to undergo alcoholysis, glycol and zinc acetate is added to the waste, then placed in a high-temperature reactor. After, the fabric gets filtered to separate cotton into solid form, which is then washed with glycol at 150 Celsius to purify cotton fiber. According to Zhi Li’s experiment, glycol alcoholysis is successful in fiber separation of cotton and polyester blend textile waste. Although the quality of polyester may decrease, it will still be within the requirements for recycling. To reach efficient alcoholysis, the glycol to waste fabric ratio should be at 1:6, the temperature at 196 Celsius, catalyst concentration at 0,10%, and for a period of 1 hour. (Li, 2020)

Lastly, glycolysis is the degradation of polyester fibers to separate them from blended textiles. In the glycolysis process, zinc acetate ($Zn(Ac)_2$) is often used as a catalyst, without a catalyst, degradation is slow and challenging for polyester. (Hu et al., 2020) This process has many advantages such as short reaction time as well as low energy usage. Glycolysis happens under atmospheric pressure with boiling ethylene glycol and metal catalysts. (Damayanti et al., 2021) These methods show that recycling blended textile waste through fiber separation is possible.

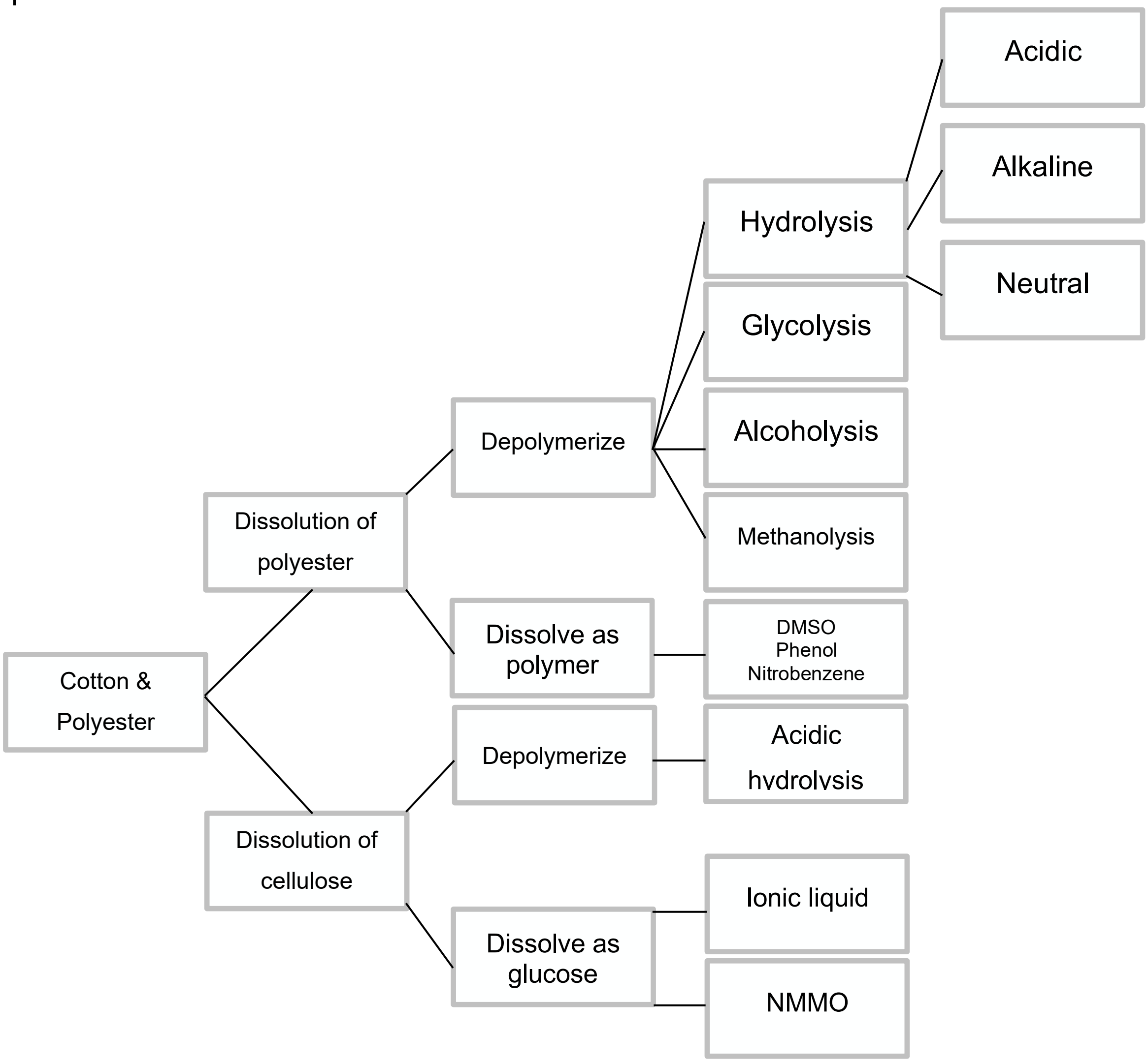

FIGURE 1. Diagram presenting options and products of different separation methods modified from Peterson's 2015 Master Thesis on Separation and characterization of textile fibers and blends (Peterson, 2015).

2.1.2 Polyester Fiber in Soil

After the separation process, polyester fiber is filtrated and can be used in soils for different purposes. Many studies have shown the potential use of textile waste in construction sites with sandy and clay soils, where synthetic fibers lead to improvements in soil mechanics and swell properties (Rahman et al., 2022). The characteristics of synthetic fibers such as polyester make them suitable for soil reinforcements in construction and geotechnical activity. The usage of short fiber in soils using polyester fibers to reinforce soils by improving strength and stiffness is possible. The advantages of short fiber in soils include availability, usability in most weather conditions, quick performance, etc. (Nguyen et al., 2015)

Rahman et al. observed that pre-consumer waste increased compressive strength by 170% when added to weak soil, showing the soil reinforcement capabilities of textile waste. (Rahman et al., 2022) The study of Kumar et al. found that the use of 8% lime and 15% fly ash, with the incorporation of polyester fiber, achieved stabilization of expansive soil. (Kumar et al., 2007) This indicates that the potential for textile waste fiber after separation exists, however, more research should be conducted and experimented to further investigate polyester fiber specifically and within different soil applications.

2.1.3 Cotton Fiber in Soil

Cotton is one of the most used natural fibers in clothing, with many research possibilities for recycling, such as producing carpets, geotextiles, and soil amendments. Cotton fibers from textile waste showed applicability for low-strength soil structural reinforcement. As cotton fiber is biodegradable, with potential tensile strength and material stiffness, it can be a beneficial soil enhancement in certain scenarios. However, due to the moisture absorption behavior, it may not be suitable for construction and geotechnical applications. (Rahman et al., 2022)

The incorporation of cotton fiber in the soil can improve soil fertility by adding organic matter and increasing moisture retention ability. According to Chang et al., cotton fibers recovered from denim jeans manufacturing wash water can be made into blue sludge, making great soil amendments from pre-consumer waste.

Therefore, this would be more suitable for agricultural soil amendments. (Chang et al., 199

Fiber type	**Characteristics**	**Uses**	**Details**
Cotton	Hydrophilic, biodegradable, easy shredding	**Hydro-mulching**	Mixing water, seeds, cotton fiber and tackifier, for vegetation on slopes
Polyester	Hydrophobic, homogeneous, thermoplastic, resistant, non-biodegradable	**Fiber Soil composite**	Increase compressive strength, protection against erosion and stabilization of expansive soil

TABLE 1. Summary of uses of textile waste in composites (adapted from Rahman et al., 2022)

The option of utilizing both fibers could be possible for hydro-mulching, where short fibers are combined with seeds, water, and tackifier, to apply on soil surfaces, it normally utilizes wood fibers and paper pulp. This option for blended textile waste utilizes cotton to retain water and increase organic matter to increase soil fertility, and polyester fibers maintain air space, thus further optimizing plant growth. (Chang et al., 1999) However, more research should be conducted to test this theory, as adding polyester into soil has a high risk of environmental contamination, therefore making this option less feasible.

2.2 Plastic Replacement in Agriculture

Plastic waste in agriculture has been a big environmental issue, due to the high plastic practices and the lack of an appropriate waste management system. Plastic films in agriculture practices can be found worldwide due to their benefit in crop quality and quantity. (Steinmetz, 2016) The obstacles to this path of utilizing textile waste may be challenging to overcome, due to chemical leaching and microfiber leaching. It is still beneficial to investigate this path to rule out the potential. The agriculture industry can potentially gain benefits from using more environmentally friendly products, as they struggle with plastic waste, which is often disposed of improperly or burnt, releasing toxins in the environment. (Galati & Scalenghe, 2021)

2.2.1 Plastic Mulching Alternative

Plastic material is often used in agriculture for purposes such as mulching to cover the soil surrounding the crops to protect from weeds and pests, alter temperature, retain moisture, reduce soil compaction, lower soil erosion, etc. Mulching practices have been used since the ancient period, using leaves and debris to prevent penetration of sunlight from allowing weeds to grow. (Malinconico, 2019) The economical and production benefits of plastic mulching in relation to environmental effects are not fully understood, and thus require further analysis. Although plastic mulching contains many benefits, there is also a risk of environmental damage. Potential risks include plastic residue, increased pesticide runoffs, and plastic additives contaminations. (Steinmetz et al., 2016)

Plastic mulching is more efficient at heating the soil and reducing heat lost as it is less permeable compared to landscape fabric. (Waterworth, 2018) Textile waste as a fabric mulching can still offer benefits to agricultural use even when it is more permeable than plastic and the lower environmental impact can help reduce plastic waste pressure in the agriculture industry. (Agrawal, 2013) More research should be conducted to further investigate the processes cotton and polyester blend textile waste should undergo, be environmentally safe, and how it can be used as a plastic mulch alternative.

2.3 Geotextile Applications

Geotextiles are textile materials with permeable properties used in many different industries and for purposes such as soil reinforcement, separation, erosion protection, drainage, and filtration. It is considered crucial in civil engineering as it provides many useful benefits. (Rodriguez, 2018) There are different types of geotextiles, such as woven, non-woven, and knitted textiles, which are used in different scenarios. (Muresan, 2021) More research has been found on textile waste utilization in erosion protection, therefore providing more evidence of feasibility. Perhaps this is due to the placement of textile waste, being above ground for erosion protection, whereas soil reinforcement, separation, drainage, and filtration utilizes geotextile underneath the soil, which increases the risk of contamination of chemicals and microplastics.

2.3.1 Soil Reinforcement

When preparing a construction site, it is crucial to ensure that the ground can withstand the load of the building and the construction activities. Reinforcement of soil means increasing shear strength and stiffness in weak soil. There are many methods of reinforcing the ground to reach the desired qualities including shear strength, compressibility, permeability, shrink and swell ability. According to Leon et al., there is potential for utilizing blended textile waste (including pre-consumer polyester waste) as nonwoven geotextiles to use as construction site soil reinforcement (such as roads and railways). (Leon et al., 2016)

Natural fibers in geotextile soil reinforcement provide high initial tensile strength, although due to its biodegradability, the effective period is much lower than synthetic fibers, which leads to failure of soil reinforcement. (Wu et al., 2020) This suggests that cotton and polyester blend textile waste would not be feasible for soil reinforcement purposes.

2.3.2 Erosion Protection

As soil health diminishes due to overuse of soil and harsh weather conditions, the occurrence of erosion increases. Methods for erosion protection exist such as geotextile usage. Nguyen et al conducted research on the incorporation of textile waste in geotextile anti-erosion ropes. The study was done on the side of a gravel pit, with two different inclinations of 1:1 and 1:1.8. Two different types of textile waste were included, nonwoven merino wool and recycled natural and synthetic fibers. The ropes were left in place for 47 months with 2 visitations to analyze and test the soils. They found that the ropes made from wool biodegraded and thus did not retain any tension strength, whereas the synthetic and natural fiber blend, remained strong enough after 47 months to support the soil. Vegetation growth may be supported (seen in picture 2) due to the increased soil water content from 32,8% to 37,9%, in a location with anti-erosion ropes. This shows the rope’s ability to hold water, thus benefitting the growth of vegetation. (Nguyen et al., 2021)

Further research should be completed before the commercialization of erosion ropes made from recycled natural and synthetic fiber, to find efficient design and study its properties to see the effects on soil, especially microfibers as it still poses the risk of potential leaching. With geotextile ropes, the prevention of microplastic leaching could be implemented, as they can be removed after it has completed their purpose or apply treatment to prevent fiber degradation.

PICTURE 1. Anti-erosion geotextile ropes slope, 09.02.2016. (Nguyen et al., 2021)

PICTURE 2. Anti-erosion geotextile ropes slope, 23.06.2016. (Nguyen et al., 2021)

In another study, Broda et al. 2016, conducted research on innovation geotextiles in clay-ground roadside ditch reinforcement, using nonwoven recycled fibers. The ropes were 12 cm in diameter and were manufactured using the Kemafil technology, using a special knitting machine. The study investigated ropes made of wool fiber and jute fiber, and recycled waste (natural and synthetic) fiber, bound together by a polyester multifilament thread. The investigation found that geotextile ropes helped reduce the flow of water from heavy rains, thus immediately effective in lowering the rate of erosions. The geotextile ropes also helped reduce water runoffs reaching the roads, improving road safety. Another finding from this study is that anti-erosion geotextile ropes helped vegetation survive during dry periods by releasing water slowly. Degradation of fibers in wet conditions leads to weakening of fiber properties, with organic fiber degrading, this leads to the growth of microorganisms, which provides nutrition to the soil as well as the secretion of enzymes from bacteria and fungi, further degrading the structure of erosion rope fibers. (Broda et al., 2016)

The results of these studies support the high potential for cotton and polyester blend textile waste to be utilized in erosion control. Textile waste can be seen to improve soil characteristics and plant growth. Regardless, research should be conducted further to understand whether this utilization poses environmental risks.

3 FACTORS FOR POLYESTER DEGRADATION

Feasibility analysis of cotton and polyester blend textile waste in soils requires the understanding of fiber degradation to avoid harmful applications. Cotton biodegrades naturally, therefore the focus of degradation of this textile blend will be on polyester, as it can persist in the environment for decades. Many factors contribute to the polyester fiber degradation process. Factors include Finnish soil and climate, soil characteristics (temperature, moisture, humidity, soil type, pH, etc.) time, microbial activity, and UV exposure. Many studies have conducted investigations to better understand how this complex procedure works, what affects it, and how it affects the soil. (Sang et al.,2020) Results from these studies vary, which makes it challenging to predict the rate of polyester degradation, as well as varying polyester products (plastic bottles, film, fibers, etc.) which can affect the results as the shape and size of polyester also affect the degradation time. (Guo et al., 2021) Other factors that may affect and even accelerate polyester degradation, are metal compounds, specifically iron compounds in wet conditions. (Sang et al., 2020)

3.1 Finnish Soil and Climate

Studying the physical and chemical properties of soil and whether it is suitable for the usage of polyester fibers, allows understanding of the potential risk of microfiber and chemicals leaching into the soil. Finnish soil, specifically topsoil, is naturally low in acidity, due to mineral components in soil. (Soil - Maa- ja metsätalousministeriö, n.d.)The temperature of soil depends on the average annual ambient temperature, duration of snow coverage, as well as the depth of the soil that is measured. According to the Finnish Meteorological institute's data, the average temperature in the south of Finland, Helsinki, in 2021 was -3.4 °C and the average precipitation was 86.8 mm(Finnish Meteorological Institute, n.d.). Soil data from the VESI-KHK project shows that in January of 2018, soil temperature at 5cm was around 1.25 °C, at 15cm was around 1 °C, at 30cm was around 2.5 °C and at 40cm the soil temperature averaged around 2.9°C (Soil variables - Finnish Meteorological Institute n.d.).

3.2 Soil Characteristics Affecting Degradation of Polyester

Exposure to polyester in a natural environment leads to slow degradation, this is shown by studies that look into environmental factors such as solar radiation, the permeability of oxygen, heat, humidity, wind, and rain. Temperature is considered a crucial factor, as thermal oxidation of polymers leads to material weathering. When polyester degrades at an ambient temperature of 20 Celsius, degradation of the material is slower, suggesting Finnish soil conditions would lead to slower degradation of polyester. (Lodi et al., 2008, Sang et al., 2020)

Finnish climate has long nights and short days, during winter, and vice versa during summer. This affects the moisture condensation of soil during night and daytime, which leads to material stress. Moisture is absorbed by the material leading to the outside's compressive stress and bulk tensile stress. The absence of moisture leads to drying thus creating bulk compressive stress and surface tensile stress. (Lodi et al., 2008) Degradation of polyester has been studied in a laboratory environment, with results showing an acceleration of degradation occurring at high temperatures at 100% humidity. These conditions do not occur naturally, implying that natural environments lead to slower degradation of polyester. (Sang et al., 2020, Chamas et al., 2020)

Polyester degradation in neutral pH conditions occurs slowly due to a slower rate of hydrolysis. However, the degradation rate increases with acidic pH conditions, the exact pH where degradation increases were not found. Regardless, polyester degradation in Finnish could increase due to high soil acidity. The process of polyester degradation leads to an increase in soil pH as well, as the by-product of the reaction releases CO_2. (Chamas et al.,2020)

3.3 Time Period

The time period of polyester degradation in textile blends depends on other factors such as temperature, moisture, microbial activities, etc. The longer polyester is exposed to high temperature, acidity, and microbial activities, present in the soil, the higher the degradation will be. This suggests that the utilization of cotton and polyester blend textile waste feasibility increases when the use phase is for a shorter period. (Li et al., 2022, Hosseini et al., 2007)

3.4 Microbial Degradation

Microbiome in the soil has been studied to have the potential to accelerate the degradation of polyester. Depending on the species of microbes present in the soil, along with other factors, the rate of polyester degradation could be estimated, however varying factors make it challenging. (Danso et al., 2019)

Evidence from studies found that these bacteria species, Ideonella sakaiensis 201-F6, Thermobifida species, and Thermomonospora species, breaks polyester into smaller building blocks of oligomers and monomers. These bacteria are gram-positive phylum actinobacteria members, with the ability to secrete enzymes, PETase, which performs hydrolysis on polyester leading to degradation. Currently, the studies on microbial degradation of polyester are conducted in laboratory environments, which supports optimal polyester degradation. This shows that micro-organism has the ability to degrade polyester. (Danso et al., 2019) In the organic layer of Finnish soils, an abundance of bacteria in the actinobacteria phylum was found, suggesting that microbes could degrade polyester in Finnish soils. Further research is required to understand the use of bacteria in natural environments, also to investigate what family of bacteria exists in Finnish soils. (Viitamäki et al., 2021)

Microbial activity degrades polyester by releasing enzymes, giving it the ability to break down the polymers (depolymerization), specifically the outer layer of the polymer. These enzymes target polymer structures, transforming them into smaller units, to complete the degradation process. The challenge for enzymes to fuller biodegrade polyester lies in the aromatic terephthalate units in the backbone, which restrain the mobility of the polymer chain. The exposure of aromatic terephthalate units to high temperatures allows them to be more flexible, thus improving the enzymatic degradation. The hydrolysis by enzymatic degradation occurs on the surface, which results in erosion. However, the hydrophobic characteristic of the polymer surface limits the ability for microbial attachment, thus lowering the degradation rate. (Glaser, 2019) Therefore, further studies and experiments must be conducted to mutate microbials to secrete enzymes optimized for full polyester degradation. (Sang et al., 2020)

3.5 UV Radiation Exposure

Weathering of polyester unwoven geotextile has been shown to accelerate due to irradiance exposure and permeability to oxygen. (Lodi et al., 2008) Polyester utilized in an environment that limits the performance of photodegradation such as buried polyester, leads to a slower rate of degradation. (Chamas et al.,2020) The absorption of UV by polyester, leads to the breakage of polyester bonds (seen in FIGURE 2), resulting in degradation. (Fechine et al., 2004) Based on these studies, it is clear that UV exposure influences polyester degradation which implies that polyester in cotton and polyester blend textile waste, will also degrade.

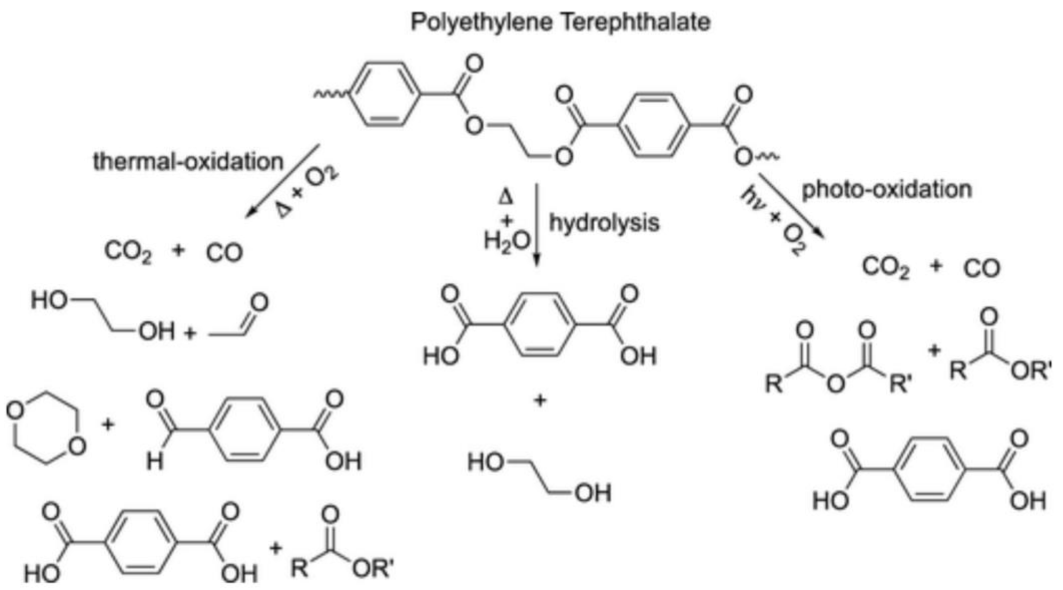

FIGURE 2. Environmental degradation reaction of PET, breaking the PET down into different smaller molecules. (Chamas et al., 2020)

4 CHALLENGES

Degradation of cotton and polyester blend textile waste in the soil can lead to chemical and microplastic contamination of soil. Chemicals and microplastics are believed to have negative environmental impacts. Nowadays, microplastics can be found almost anywhere, making it a hot topic for researchers as the lack of knowledge leads to limited understanding. There are many different routes of microplastic contamination, whether it be through water, air, or soil additives. (Kim et al., 2021) Studies have suggested that microfibers can absorb and carry toxic chemicals which can lead to further contamination. (Manshoven et al., 2022)

4.1 Risk Chemical Contamination

Textile waste may potentially release small amounts of chemicals that can disrupt the soil's living organism and change the soil's properties. One of the main groups of chemical contamination in textile waste usage in soil improvers is `dyestuffs´, which is any substance that can be used as a dye (oxford n.d.). According to the study by Kant et al., textile dye contributes to environmental degradation. This is because of carcinogenic compounds and toxins such as naphthol, acetic acid, vat dyes, chromium compounds, soaps, and heavy metals like arsenic, lead, mercury, and nickel. (Kant et al., 2012, Rahman et al., 2022) Fine dyestuff dust can be left behind after the dyeing process, which has been linked to skin irritations. Studies have shown that dye from textile and other chemical effects on soil, e.g., pH, porosity, water content, microbial activities, etc. (Manshoven et al., 2022)

Different textile waste varies in chemical composition, thus proper testing of waste should be conducted prior to incorporation into soil improvement methods. Depending on the textile finishing, the chemical additive used can vary from flame retardants to polybrominated diphenyl ethers (PDBE). (Manshoven et al., 2022) Heavy metals and other organic pollutants can also be present in the textile waste, as presented by Hou et al., as textile waste releases microfibers that can accumulate metals on microplastic. (Hou et al., 2021)

Further study should be conducted on how chemicals from textile and microfibers spread and progress over time, especially since further microfiber degradation can release potential chemicals into soils. The use-phase of textile can lead to exposure to different chemicals, with insufficient studies to support the understanding of textile and chemical interactions, it is not clear what chemicals can exist within the fiber. However, the concentration of chemical contaminants leaching from textile fibers would be considerably low. (Manshoven et al., 2022) Breakthroughs like Yousef et al., strategize to remove dyes in denim clothes, which would allow the use of textile waste in soils. (Yousef et al., 2019) With more research providing insights and solutions, the utilization of cotton and polyester blend textile waste will become desirable as the benefits increase, while the risk for environmental impact decrease.

4.2 Risk of Microplastic Contamination

Microplastics have become a concerning topic that is currently discussed as they can be found almost everywhere and studies on the effects of microplastic in the environment are increasing, to allow the understanding of microplastic to improve. Microfiber is defined as a synthetic fiber, usually from man-made fibers such as nylon, polyester, acrylics, and polyolefin, that has a diameter smaller than 10 micrometers. (Liu et al., 2019)

Due to the broad nature of this topic, many areas still require further research to fully understand it. Textile-sourced microplastics are heavily studied due to the high microplastic (specifically microfiber) contamination level found in wastewater from the washing phase of clothing. Microfibers from textiles are one of the most common forms of microplastics. Due to the high consumption of cotton and polyester blend fabrics, the presence of polyester microfibers can be seen in large amounts in the environment, especially in the ocean, air, and soil. (Manshoven et al., 2022)

The main route of microfiber contaminants to the ocean and soil is through washing processes which end up as unmanaged wastewater. Wastewater sludge is often applied to agricultural land for fertilization and is one of the biggest reasons for microfiber soil contamination (Milojevic & Cydzik-Kwiatkowska, 2021). Microplastics also enter the soil through vehicle tires erosion, road markings, as well as city dust, and unmanaged landfills. Finally, soil and water contamination can occur when microplastics are released through the air from waste incineration. (Manshoven et al., 2022)

Another factor that increases the release of microfiber is poor textile quality from the fast fashion trends. Studies have shown that the first wash of textile excretes the greatest number of microfibers, leading to textile that degrades quicker, thus increasing the disposal and consumption level. Microfibers can be released at all phases of the textile life cycle, from the production until the end-of-life phase. (Manshoven et al., 2022) Research has been done to compare the leaching of microfibers between recycled textile and virgin textile, which showed that recycled polyester textile excreted 2.3 times more microfibers per wash than those textiles made with virgin materials. The research proposes that the reasoning for this is due to the fiber length; recycled polyester is composed of shorter fibers compared to virgin polyester. (Özkan & Gündoğdu, 2020) Perhaps this could imply that the application of recycled textile waste in the soil would lead to an increase in microfiber contaminants, as shorter fiber lengths are more prone to leaching.

The threat of microfibers leaching from textile waste into soil exists, and the natural degradation period for polyester can be for many decades due to polyester characteristics like high molecular weight and hydrophobicity. However, there are possible methods like specific polymer degrading organisms that can aid the biodegradation of microfibers in the soil to allow the utilization of cotton and polyester blend textile waste in the soil. (Milojevic & Cydzik-Kwiatkowska, 2021).

Overall, there are not a sufficient number of studies on the microfibers' release mechanism nor are there enough studies on how these microfibers affect the soil. To better understand microplastics, proper standardized measurements, as well as sampling methods, must exist. There are still many areas to study regarding microorganisms and microplastic degradation and challenges to the degradation methods, where solutions would allow commercialization to remediate contaminated soils. (Danso et al., 2019)

4.3 Effects on Soil Properties and Plant Growth

The presence of microplastics can affect the soil in many different ways, with varying effects depending on the type of plastic and size of the microplastics. The impact on soil can further affect plant growth due to changes in soil properties leading to effects on soil fertility. (Guo et al., 2021)

The soil contamination of microfibers can lead to negative effects such as nutrition loss due to loss of microbial activities, reduced bulk density, increased water repellency, and decreased soil porosity. (de Souza Machado et al., 2019, (Zhang et al., 2019) Lower microbial activities lead to a decrease in organic matter, thus less nutrition is available making the soil less fertile which negatively impacts plant growth. Conflicting information also indicated that the effects of microfiber on soil microbiome and enzymatic activities had little effect on the soil microorganism diversity. Bacteria can be varied and abundant on microfibers, as they colonize the surface of microfibers. (Guo et al., 2021)

Earthworms play an important role in maintaining soil fertility, effects of their ingestion of microfibers have shown effects on its growth rate as well as histopathological damage, which adversely affects soil quality. (Huang et al., 2021) It is also possible for earthworms to transport microplastics from topsoil, deeper down into the ground. It is unclear what effects microplastics have in deeper layers of soil. (Henry et al., 2019)

The effects of microplastics on plant growth are uncertain due to a lack of research. A study on microplastics on spring onions showed lengthening of plant roots, a decrease in root diameter, and an overall biomass increase. Root colonization is negatively affected with up to a 50% reduction in colonization. This suggests that microplastic affects plant growth by inhibiting root colonization. (De Souza Machado et al., 2019) There is insufficient research on microplastic effects on soil compared to in the ocean. Therefore, more research is required to further the understanding of microplastics' impact on soil properties and plant growth.

5 DISCUSSION

The complexity of blended textile waste restricts its recyclability as the options for recycling are limited. Incentives for research on possible uses of textile waste have increased due to the abundance of waste and new waste directives. Due to the EU waste directive which states that organic materials can no longer be landfilled (Waste Act (646/2011)), textile waste has become a great challenge. Therefore, the textile waste blend is often incinerated for energy, unless it is suitable for recycling to extract fibers. Other materials such as waste tires, paper, and pulp by-products, have been used in the soil as a method of diverting waste from landfills and make better use of it by improving soil properties such as tensile strength (Abbaspour et al., 2019, Camberato et al., 2006). More research for other possibilities for textile waste handling is still required to help the waste management system while keeping factors such as microplastic leaching in mind. (Lounais-Suomen Jätehuolto, 2018)

The issue with microplastic leaching when incorporating textile waste in soil could be resolved with microorganisms, as studies have shown possibilities of polyester degradation. Microorganisms show the possibility of degrading plastics in contaminated areas such as soils and landfills (Hou et al., 2021) This could be a solution to solving microfibers in soils, after the application of cotton and polyester blend textile waste in soil, as studies show evidence of actinobacteria usability in microplastic contaminated soils. (Danso et al., 2019). Increasing incentives for studies on microbial plastic degradation helps researchers pursue the path of improving the existing knowledge of soil microbial communities to fully understand their function and how they can help reduce microplastics in soils (Viitamäki et al., 2021). Currently, the biggest obstacle with enzymatic polymer degradation is its high crystallinity; There has been evidence that some bacteria and fungi can degrade low crystalline polyester (Hou et al., 2021). In the future, innovative solutions for enzymes to degrade polyester at a commercial scale must be found, allowing the remediation of microplastics in the soil ecosystem to help maintain soil quality and fertility. (Henry et al., 2019)

Recently, however, climate change, population growth, and overuse of soil, chemicals like pesticides, herbicides, and fertilizers, have led to a decrease in soil quality and fertility, to the point that the Food and Agriculture Organization of the United Nations estimations have suggested that humanity has enough fertile soil for approximately 60 years. (Milojevic & Cydzik-Kwiatkowska, 2021). Finding ways to improve soil health as well as reduce textile waste is important in increasing sustainability and reducing environmental impacts. Other than finding solutions to textile waste, more focus should be directed at solving the problem from the beginning of its life cycle. To increase circularity and sustainability, textile industries should find environmentally friendly alternatives to harmful chemicals such as dyestuff and reduce fiber blends to reduce complexity. (Palacios-Mateo et al., 2021)

Using cotton and polyester blend textile waste in the soil is one possible solution, including three options: separated fibers for soil enhancement, plastic mulching, and geotextile.

The option of separated fibers would allow cotton fibers to be suitable for soil amendments in open and unmanaged soils, and polyester fibers to be used for soil reinforcements or composites (in areas such as construction and roadworks, where the soils are controlled and managed). However, using fiber-separated cotton and polyester in soil, is not its most beneficial utilization, as there are other value-added options for separated fibers, such as using cotton for bioethanol production. (Subramanian et al., 2021)

Another utilization option is the substitution of plastic mulching with cotton and polyester blend textile waste, which reduces the current agricultural use of plastics. Cotton and polyester blend textile waste can provide weed and pest protection, and retain soil structure and moisture content, although it might not be as effective as plastic mulching due to its air permeability. More experimentation must be conducted to determine the most suitable time period and environmental factors for textile usage to minimize the release of microfibers. For example, a shorter period of time of textile waste being utilized in soil may not lead to the release of microfibers. (Malinconico, 2019) New technologies may have solutions to microfiber release from textile waste, such as environmentally friendly coatings to lower degradation. For example, there are implications of improved characteristics of geotextiles, made with banana leave fibers, by coating them with latex. Where studies have shown increased thermal conductivity in geotextile coated with latex. (Souza & Mendez, 2019) This implies that it could be possible to extend the lifespan of cotton and polyester blend textile. However, this application still has the risk of leaching microplastics into Finnish soil. Evidence shows that polyester degrades faster in acidic conditions and freeze-thaw cycles, both present in Finnish soil. Thus, more research and test must be conducted to make a solid conclusion.

Lastly, geotextile utilization is seen as the most appropriate option with studies providing evidence of its suitability for soil improvements, especially in erosion protection. This application is supported by Nguyen et al., a study of textile waste application as erosion protection on slopes, which suggests high potential. (Nguyen et al., 2021) It is hypothesized that textile waste could be the most beneficial for geotextiles usage, as there is a big market for this, with the possibility of reducing the usage of virgin material and providing a route for textile waste utilization. (Leon et al., 2016)

Throughout this literature analysis, many gaps in information were found as many studies did not apply to the soil. A lack of studies on topics such as microfiber degradation and effects on soil, leaching of textile chemicals in soil, and textile degradation in soil, made it more challenging to produce a risk-benefit analysis to provide a solid conclusion on the feasibility of textile waste in the soil. Therefore, more research and data, specifically on cotton and polyester blend degradation in soil, is required to determine the best use of the blend.

6 CONCLUSION

After literature review and analysis, the conclusion drawn suggests that a fiber separation method would currently not be suitable for Globe Hope’s Zero Waste Service. However, if the company grows and decides to venture on to this path of fiber recovery, it is worth looking into. Agriculture and geotextile utilization are the most suitable options. Waste can be processed into an environmentally friendly alternative to plastic mulching, which should be used only for a short period of time to limit polyester degradation and the risks of microplastic leaching into soils. Geotextile utilization has high potential and value, specifically in erosion protection. One option for erosion protection is through the use of ropes, made from cotton and polyester blend textile waste would also be feasible, with studies suggesting it, however, the release and effect of microfibers are still unclear.

The risk of microplastic and chemical contamination still exists. Perhaps method of microplastic containment or efficient removal of contaminants, will allow the usage of cotton and polyester textile in the soil to replace geotextiles and plastic mulch. For example, there are possible methods to prevent these contaminations such as environmentally friendly textile coating, which reduces the release of microfibers, and testing textile waste to remove dyes and other chemicals, to minimize harmful contaminants entering soils.

With this information, further innovation and research can help make a solid conclusion on the usage of cotton and polyester blend textile waste in soils. The lack of research and tested evidence on this specific topic limits the ability to apply this knowledge in real life.

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