Multifunctional fertilisers for enhancement of water retention in soil with controlled release of nutrients based on natural polymers and waste sheep wool

Climate and economic changes are increasingly affecting agriculture, which is also evident in Poland - according to the Statistics Poland (Central Statistical Office), in 2024 the cultivated area decreased by 2.3% compared to 2020, and grain production dropped by 4.5%. Farmers are faced with unstable weather and droughts, forcing greater use of water and fertilisers, which deteriorates soil quality and damages the environment. Traditional fertilisers, mainly based on simple mineral salts and plastics, are increasingly giving place to new, more advanced materials. Controlled-release fertilisers (CRFs), which last longer and more precisely thanks to processes such as diffusion or biodegradation, are of particular interest. By using biodegradable coatings, nutrients can be gradually transferred to the soil, minimising losses and environmental impact. On the other hand, hydrogel materials currently under development allow for better management of soil moisture. At the same time, there is growing interest in using organic waste and byproducts from the food industry as raw materials for fertilisers. This makes it possible to reduce the cost of their production and waste. Sheep's wool is one such material - it contains nitrogen essential for plants, can absorb water when cleaned, is locally available and is a waste product outside the textile industry. The selection and optimisation of such materials and the development of a fertiliser whose structure will allow the gradual release of nutrients and water requires an interdisciplinary approach that combines knowledge from materials engineering, process engineering and chemistry and physics with elements of environmental and agricultural engineering.

This research project aims to develop a fully degradable fertiliser using waste sheep wool and focuses on the link between the production process used, the structure obtained and, consequently, the way and effectiveness of performance of the material. The aim of the project is to optimise the manufacturing process and composition of a biodegradable polymer matrix composite using waste wool fibre and inorganic nutrients, so that it can serve as a CRF fertiliser during its degradation in the soil. The project will serve to determine the life cycle of the material and investigate the incorporation of wool fibre and fertiliser salts as active ingredients. The focus is not only on the functional properties of the fertiliser or on the material structure of the composite, but extends this to the optimisation of the manufacturing process and degradation, the final stage of the material life cycle, and further extends the process to the introduction of waste fibre into the production, which requires it to be properly adapted, due to the dispersion in the properties of the waste materials.

At the start of the project, the raw materials will be characterised in detail - both wool before and after cleaning and at different levels of fineness, as well as biodegradable polymers (such as PLA, thermoplastic starch or hydrogel materials such as alginates) and easily soluble fertiliser salts containing nitrogen, phosphorus and potassium, which are key elements for plant growth. The next step will be to develop methods to produce composites with wool and nutrients, varying according to the type of matrix, to ensure that they are effectively combined and to introduce optimal amounts of inorganic fertiliser salts. The composites produced will then be subjected to physicochemical testing to determine their porosity, stability and water storage capacity (in the case of water-absorbing matrices). Modern testing techniques such as infrared spectroscopy (FTIR), thermal analysis (TG, DSC), electron microscopy (SEM) or diffraction analysis (XRD) will be used. In the next phase, degradation tests in soil and measurements of the release rate of fertiliser components will be carried out - both under laboratory conditions and in plant pots under environmental conditions. Changes in the structure of the material, the amount of water retention and the effectiveness of fertilisation will be observed. The final stage of the project will analyse how the ingredients used and the production process affect the composite's decomposition rate and fertilisation efficiency. This will involve comparing the physicochemical properties of the material after, during and before degradation. This will help determine the kinetics of degradation and relate it to the composition of the material and the amount of fibre introduced in the manufacturing process.

The outcome of the project will not only be the creation of a fertiliser material with a strictly controlled operating time, but also a better understanding of the impact of natural fibres on polymeric materials and their rate of degradation in the environment. As a result, a new approach will be developed for advanced engineering planning of fertiliser manufacturing processes in line with the principles of a circular economy and growing environmental awareness.