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Waste wool technology in arid horticulture: Promoting sustainability and circular economy

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Arid and semi-arid regions face significant agricultural limitations due to environmental and soil-related challenges such as erratic rainfall, poor soil fertility, and extreme temperatures. These constraints hinder horticultural productivity, which relies on stable soil moisture and nutrient availability. To promote sustainability and productivity in these regions, attention has shifted toward using locally available resources. One such resource is waste wool, a by-product of sheep rearing is an important livelihood in arid zones. Though unsuitable for textiles, waste wool is rich in organic carbon and nutrients, making it an effective soil amendment. When applied to horticultural systems, it improves soil structure by increasing porosity, moisture retention, and organic content. This not only enhances plant growth in harsh climates but also promotes ecological sustainability. Moreover, utilizing waste wool reduces agricultural input costs, turning a low-value by-product into a valuable resource. This practice strengthens the resilience of arid-zone horticulture and supports rural economies by aligning with circular economy principles. Overall, use of waste wool offers a practical and sustainable solution to improve soil health, increase productivity, and support environmental stewardship in arid and semi-arid regions.

Keywords: Ecological, Rural economies, Soil health

A substantial quantity of organic waste and by-products is generated globally each year, much of which holds significant potential for reuse within agricultural and horticultural systems. Among these by-products, waste generated by the wool industry represents an underutilized resource with considerable value for sustainable farming. The global wool industry produces millions of tonnes of wool annually, but a large fraction of this yield is categorized as waste, as well as due to fiber irregularities or poor quality unsuitable for textile applications. Traditionally, much of this wool waste has been discarded in landfills or incinerated, leading not only to environmental degradation but also to a significant loss of potential organic resources. The growing recognition of the circular economy framework has emphasized the need to reintegrate such waste streams into productive cycles. Within this paradigm, agricultural and horticultural systems are seen as key sectors for integrating organic by-products, since soils can act as natural sinks for biodegradable residues.

The reutilization of waste wool in horticultural production thus fits seamlessly into this approach, providing a sustainable alternative to conventional practices that rely heavily on chemical inputs and non-renewable resources. The urgency of such innovations has been amplified by the increasing challenges facing global agriculture. Climate change has intensified the frequency of droughts, heatwaves, and erratic rainfall, particularly in arid and semi-arid regions where water scarcity severely constraints crop production. Additionally, continuous land use, overreliance on chemical fertilizers, and unsustainable cultivation practices have accelerated soil degradation, reducing fertility and organic matter content while increasing susceptibility to erosion and salinization. These challenges necessitate the adoption of ecologically sound and resource efficient methods that not only maintain productivity but also enhance the resilience of cropping systems. Against this backdrop, wool waste offers unique advantages as a renewable, biodegradable, and nutrient-rich material that can be harnessed to improve soil quality and plant growth.

Chemically, wool is primarily composed of keratin proteins, along with other fibrous proteins such as collagen and elastin. These proteins are rich in nitrogen, sulfur, and carbon, which are essential elements for

Waste wool application under drip irrigation in arid region

plant growth. During decomposition, wool fibers release these nutrients slowly, making them available over extended periods and reducing the risk of leaching losses that are often associated with synthetic fertilizers. This controlled nutrient release contributes to long-term soil fertility and supports sustainable crop production. In addition to its nutrient profile, the fibrous structure of wool improves the physical properties of soil. When applied as a soil amendment, wool enhances porosity, aeration, and water infiltration, thereby facilitating better root penetration and nutrient uptake by plants. Another important attribute of wool waste is its exceptional capacity for water retention. Wool fibers can absorb moisture up to several times their own weight, gradually releasing it into the soil and maintaining a more stable micro-environment around the plant roots. This feature is especially beneficial in arid and semi-arid regions where water availability is the most limiting factor for horticultural production. By conserving soil moisture and reducing the frequency of irrigation, wool mulch or amendments can help farmers adapt to water scarcity and improve water-use efficiency. Furthermore, when used as mulch, wool suppresses weed growth by limiting light penetration to the soil surface, reducing competition for water and nutrients. It also buffers soil temperature fluctuations, protecting delicate root systems from extreme heat in summer and cold in winter.

In summary, the utilization of waste wool in horticultural systems offers a compelling example of how agricultural by-products can be reimagined as valuable resources. Its rich nutrient composition, water-holding capacity, biodegradability, and soil-improving properties make it a promising input for sustainable horticulture. At the same time, it addresses pressing challenges related to waste management, soil degradation, and water scarcity. By aligning with the principles of the circular economy, adoption of wool waste technology contributes not only to enhancing productivity and resilience in arid regions but also to reducing the environmental footprint of agriculture. As research and innovation in this field continue, waste wool has the potential to play a significant role in shaping future strategies for sustainable and climate-resilient horticulture.The utilization of wool waste as a soil amendment offers numerous benefits, primarily due to its inherent properties that enhance soil health and support sustainable agricultural practices.

- ***Moisture conservation:*** Waste wool, rich in nitrogen and protein, acts as an effective mulching material. It significantly conserves water by reducing evaporation from the soil surface, making it particularly valuable in arid and semi-arid regions. This property can partially or fully replace conventional chemical fertilizers, promoting resource-efficient farming.
- ***Organic mulch:*** When applied as an organic mulch, waste wool enhances the soil's water-holding capacity and creates a more favourable environment for soil microflora, boosting microbial activity and biodiversity. It also stabilizes soil temperatures, protecting plant roots from extreme thermal stress. This leads to improved soil health and better plant performance.
- ***Soil amendment:*** Incorporated into the soil, waste wool fibers improve soil structure by increasing porosity, which enhances air circulation and water infiltration. This is especially beneficial for sandy or degraded soils, improving their water retention and supporting better plant growth and drought resilience.
- ***Organic fertilizer:*** Waste wool is a valuable organic source of essential plant nutrients, typically containing about 50% carbon, 16–17% nitrogen, and 3–4% sulfur. It functions as a slow-release fertilizer due to its complex chemical structure, which resists rapid microbial degradation. While pre-treatment methods like hydrolysis can accelerate nutrient availability, its application demonstrably improves soil organic carbon and nitrogen, enhancing long-term soil fertility and productivity.

Waste wool: A sustainable solution for horticulture in hot arid zones

Hot arid zones globally grapple with agricultural challenges like low and erratic rainfall, extreme temperatures, poor soil fertility, and limited organic matter. These factors restrict crop productivity and

Crop performance under waste wool application

threaten the livelihoods of farming communities. Interestingly, these very regions are also home to significant sheep-rearing activities, which generate large quantities of waste wool that is unsuitable for textile industries due to its coarse texture, contamination, or low quality. This waste wool presents a remarkable opportunity for horticulture in arid ecosystems. When applied to barren or degraded soils, waste wool helps create a favourable micro-environment for plant growth. Its fibrous structure captures and retains atmospheric moisture, fostering a localized humid microclimate that stimulates microbial activity. This microbial proliferation enhances nutrient cycling, improves soil structure, and gradually increases organic matter, making the soil more fertile and conducive to crop production. Waste wool also functions as a natural mulch, conserving soil moisture, regulating temperature fluctuations, and suppressing weeds critical benefits under arid conditions.

Crops grown with wool based amendments can serve as fodder for sheep, reintegrating livestock and horticultural systems while closing nutrient loops. This innovative recycling model minimizes waste, enhances resource efficiency, and reduces reliance on external synthetic inputs. Environmentally, it promotes soil rehabilitation, combats land degradation, and supports the establishment of vegetative cover in fragile landscapes. Economically, it lowers input costs, increases sustainability, and provides added value to otherwise discarded wool, benefiting resource-constrained farming communities.Thus, waste wool emerges as a low-cost, eco-friendly, and sustainable solution for improving horticulture in hot arid zones while simultaneously strengthening livestock-crop integration.

SUMMARY

Integration of waste wool into arid horticulture provides a sustainable resource efficient approach to address the challenges of arid zone. The waste wool has the potential of being used as a mulch, soil amendment and organic fertilizer owing to its fibrous structure, nutrient content and moisture retention capacity. Owing to resource poor structure of arid zones, use of waste wool as a horticultural or horticultural input contributes to circular economy and prevents environmental biodegradation. The environmental benefits of waste wool use along with its economic advantage makes it a suitable option for promotion of sustainable horticulture in arid zone.

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