Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

IMPROVING PRODUCTIVITY ON DEGRADED LANDS USING A NOVEL TECHNOLOGY OF CULTIVATING CROPS IN BIODEGRADABLE MULTILAYERED STRUCTURES

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Abstract

Integrating degraded or contaminated lands into food production chains poses significant challenges and expenses. This study explores a novel technology for cultivating vegetables on degraded lands employing vegetal substrates in the form of bales. These multi-layered vegetal structures are strategically designed to offer essential support, nutrients, water, warmth, and protection against pests for the cultivated plants. The fertile layer within these structures was produced through composting vegetable waste produced from horticulture. The protective surface of the bale was made from a mixture of agricultural wastes, ensuring both a resilient structure and permeability. The structure was enhanced with two layers made of recycled cotton, aimed at retaining moisture efficiently. The research showed that the adopted technological solution can yield a 30-40% improvement in production of tomato and eggplant. Moreover, it demonstrates high adaptability, being easily applicable for crops establishing in contaminated, degraded environments, or even on concrete surfaces.

Key words: *composting, cultivation in bales, degraded soil.*

INTRODUCTION

Vast areas of land have experienced degradation as a result of chemical and physical aggressive interventions, while other agricultural soils face constraints in water resources, affecting the quality and suitability of the land for planting. Cultivating vegetables in innovative mediums such as multilayered structures could be a practical solution for establishing food crops in regions with degraded, contaminated, or disease-affected lands (Farag et al., 2015).
Extensive research has been undertaken to recycle agricultural residues, including rice straw, into diverse raw materials for the agricultural sector. These materials are often utilized as non-traditional mediums for cultivating specific vegetables. Planting vegetables in straw bales is an alternative and environmentally friendly farming practice that is regaining popularity among gardeners and farmers. This process involves placing seeds or seedlings directly into straw bales as growing media, thus including agricultural waste in the production cycle.
Studies on straw bale farming have primarily concentrated on vegetable crops with relatively short stature. These include cucumber (El-Aidy 1993; Vatchev 2012), lettuce (Bal et al., 2008; Riad et al., 2017), pepper (El-Marzoky, 2008; Gluntsov et al., 1997), strawberry and tomato (Abdet-Sattar et al., 2008). A research study (Rishead, 2016) evaluated vegetable cultivation on rice bales as growing media, established on a highly saline sodic soil, using treated drainage wastewater. Following one month of bale composting and three months of cultivation, the yields obtained were comparable to the average concurrent production in Egypt cultivated on fertile soils with irrigation.
The productivity of growing crops in rice straw using some pressurized irrigation system (Bakeer, 2013) showed that vegetables grown in as non-traditional media had a better development than the plants that grown in sandy soil. El-Marzoky examined the impact of

cultivating vegetables in rice straw bales versus natural soil, within an area where specific root diseases affecting peppers have been identified. Their objective was to assess the effect of the cultivation medium on disease infection by root pathogens. They found that plants cultivated in rice straw bales show vigorous vegetative growth, higher total yield, and improved fruit quality compared to those grown in naturally infested soil. Studies show that straw bale cultures may it could keep warm during the cold period, thermally protecting the seedlings when they are small.

Crops can develop directly in the straw structure if they are processed before by decomposition actions. However, research has shown that adding a small amount of compost can improve the development of vegetables, especially if they are planted small (Radziemska et al., 2019). A study conducted to enhance the rice straw media for growing eggplant under modified climatic conditions (Sadek et al., 2014), used compost and microbial inoculation solutions to increase productivity. They found that a combination of rice straw and twenty percent compost, inoculated with both *Azotobacter chroococcum* and *Paenibacillus polymyxa*, resulted in the highest crop yield and profit, compared to all the other tested options. However, high air temperature and a relatively high or low humidity may lead to a significant reduction in crop yield and net returns.

Toxic and saline environments pose challenges for optimal plant growth, necessitating the exploration of alternatives or solutions to mitigate the adverse effects of the primary pollutants (Delfine et al., 2000). A food production system supporting the synergic interaction between aquaculture and horticulture, proposed growing vegetables in straw bales in greenhouses (Nenciu et al., 2022). The results were highly favorable, with the bale production system yielding better results than the degraded soils.

The most common advantages identified in the research studies highlight:

- *improved drainage*, straw bales offering excellent drainage capabilities, preventing waterlogging and fostering healthy root development in vegetable plants;
- *weed suppression* is facilitated by the absence of weeds within the straw, while the dense structure of the bale further aids in inhibiting weed growth. This reduction in weed competition enhances the availability of nutrients and sunlight for vegetable crops, promoting their growth and development;
- *enhanced aeration* within the plant root zone, facilitating efficient gas exchange and supporting the overall health of plants;
- *natural insulation*, bales acting as a natural insulator, regulating temperature;
- *recycling agricultural* waste used in the multilayered structures and mitigating environmental impact;
- *reduced soil-borne diseases* elevating plants above ground level with straw bales can mitigate the risk of soil-borne diseases and pests;
- *enhanced accessibility and versatility*, since cultures may be established in contaminated sites or on areas with poor or degraded soils, on concrete platforms or in greenhouses.

MATERIALS AND METHODS

An experimental plant growth substrate model was used, designed of a multilayered structure, each layer possessing distinct properties to confer specific advantages. The model was constructed using a straw bale, with three longitudinal cuts measuring 30 cm x 30 cm x 500 cm each, forming channels. The central cutting was filled with compost, while the lateral ones were filled with cotton obtained from shredded cotton textile waste (Figure 1).

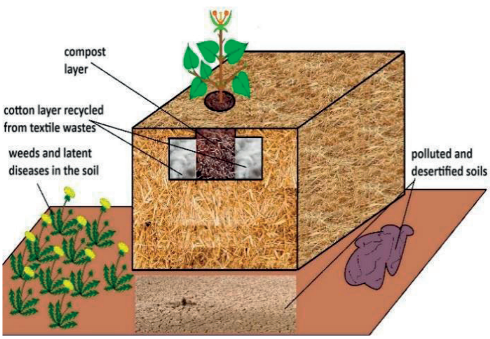

Figure 1. Experimental design for growing vegetables in biodegradable multilayered structures constructed of: straw bales, compost and cotton layer obtained from recycled textile wastes

The traditional methods of planting vegetables in straw bales suffer from a significant drawback: they require considerable water consumption. The straws within the bales tend to become excessively moist, affecting the insulation benefits during colder periods. Therefore, we conducted tests to reduce the amount of water supplied by incorporating absorbent cotton elements.

While some studies suggest planting vegetables directly into straw, our research has demonstrated that adding a layer of compost can significantly enhance plant growth in these artificial cultivation environments.

The comparative performance assessment of vegetable cultivated in the proposed multilayered substrate versus traditional soil was conducted in an unheated greenhouse from April to August 2022. (Figure 2).

Figure 2. Unheated greenhouse utilized for conducting comparative tests between cultivation on biodegradable multilayered structures and soil under an ecological approach

The greenhouse used for establishing experimental crops is situated within INMA Bucharest Institute, covering an area of 80 square meters. It is equipped with a drip irrigation installation and an automated monitoring system for cultivation parameters.

An ecological growing regime was adopted, where no chemical nutrients or pesticides were added. However, to ensure a fair comparison between the two cultivation methods, an equal amount of compost was added to the seedlings planted on the ground as was introduced into the straw bales.

Three varieties of vegetables were cultivated: tomatoes (*Solanum lycopersicum*, Rila F1 hybrid), long peppers (*Capsicum annuum* L., Kaptur F1 early hybrid), and eggplants (*Solanum melongena*, Kreola F1 hybrid). Planting was conducted on May 15th across all evaluated growing media. The soil was tilled to a depth of 28-30 cm, and manual weeding was carried out as necessary.

The straw bales were produced by compressing the straw generated from the institute's crops, utilizing the Abbriata M60 square baler. The agricultural waste used for this purpose was generated during the harvesting of crops such as wheat, mustard, and rapeseed (Figure 3).

Figure 3. Straw waste used to produce bales, as the main structure for the multilayer biodegradable structures

The compost was also produced by processing vegetable wastes (leaves, horticultural waste, chopped branches, etc.), for 8 months in compost piles with prismatic shapes. The piles were aerated and mixed using a windrow turner (Figure 4) and were moistened once a week using an irrigation system.

Figure 4. Producing compost from gardening waste, leaves, shredded branches and grass.

To preserve moisture in the straw bales for an extended period and conserve irrigation water, absorbent materials were incorporated at the border between the compost and straws.

Recycled textiles made of cotton were selected to create the absorbent environment for their biodegradability and ability to be composted along with the straws at the end of their lifecycle (Figure 5).

Sensors were installed in both the bales and the soil, activating the irrigation system independently when low levels of water were detected. Moisture monitoring was carried out with an ATLAS Industrial Monitoring Kit, a MitsubishiFX5U-32MT/DSS PLC, and Arduino soil moisture sensors. The amount of water consumed for the two types of crops was recorded daily, and reported. The objective was to administer a minimal amount of water, in order to reduce consumption (Figure 6).

Figure 5. Preparing cotton textile waste for the production of the moisture-retaining layer

Figure 6. Positioning the bales within the greenhouse and establishing the compost and moistening layers

RESULTS AND DISCUSSIONS

The results demonstrated excellent plant performance in the multilayered structures, showing faster seedling growth compared to the soil substrate. That was attributable to the compost substrate, which had a major effect in the faster growth of plants (Figure 7).

Particularly in the case of tomato development, an enhancement in growth rate was observed, attributed to a combination of factors. The increased height of the plants established on the bales facilitated improved light exposure, while the absence of weeds and diseases in the bales contributed to healthier growth conditions. Additionally, the humidity level was better maintained in the straw bales (Figure 8).

Figure 7. Planting vegetable seedlings in the biodegradable multilayered structures

Figure 8. Caption of a plant growth stage

A reduced water consumption is a primary indicator for the present research, particularly since the experimental design was developed for arid regions with challenging terrain.

Figure 9 illustrates how the bales, equipped with the absorbent cotton layer, successfully maintained a humidity level comparable to that of the soil, but with a more reduced water consumption. Consequently, the cumulative water savings achieved through the implementation of the new technology was recorded at 14.7% per season.

The total amount of recycled textile waste using the technology is 1-1.5 kg per each straw-bale. Therefore, a greenhouse operating at full capacity (similar to the one employed in the experiment), could potentially recycle up to 144 kg of waste. Consequently, the environmental impact regarding waste reduction could be substantial.

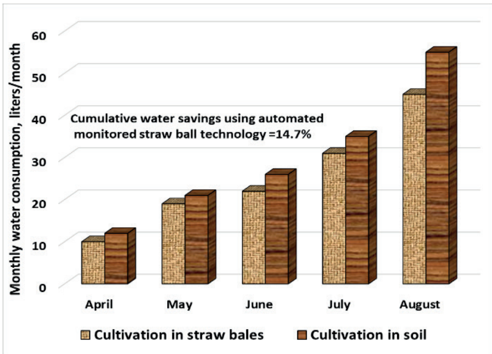

Figure 9. Comparative assessment of water conservation in vegetable cultivation using the evaluated technologies

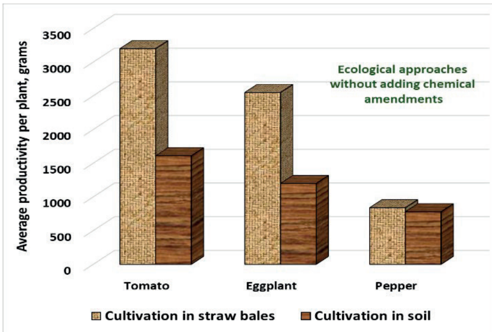

Figure 10. Average productivity under the imposed ecological approach (without chemical amendments)

The temperature inside the straw bale showed an average 0.5-degree higher values that the temperature measured in the soil, during April and May. However, throughout the months June to August, no significant differences were observed. The deviation in findings compared to other research studies can be attributed to the controlled indoor environment (greenhouses).
Despite the absence of an active heating source, the greenhouse maintained a high thermal inertia, which led to a stable temperature environment. This stability contrasted with outdoor conditions, where temperature fluctuations are typically more pronounced.

The productivity in both scenarios was relatively low, primarily due to the absence of heating and secondary due to the ecological approach, which avoided chemical interventions. Have been however observed notable differences between the crops planted in soil versus those in straw bales were highlighted (see Figure 10).

CONCLUSIONS

The primary objective, which focused on integrating waste into production activities, was successfully accomplished. The biodegradable multilayered structures, comprised of straw wastes, textile waste, and composted horticultural wastes, demonstrated production of a growth substrate with significant potential.
The utilization of biodegradable multilayered structures resulted in a 14.7% reduction in the amount of water required for vegetable cultivation. However, this percentage could potentially increase further with optimization of the shape and dimensions of the moisture-retaining layer.
The straw bales did not bring a significant benefit in maintaining the temperature, but this happened because of the growing environment in the greenhouses. In outdoor space, the variation could be more important.
The productivity was somewhat constrained due to the unheated greenhouse; however, with enhancements to the cultural conditions, higher yields can be achieved.
The experiment succeeded in demonstrating the functionality of biodegradable multilayered structures. Future research includes enhancing the design of these structures and establish more favorable cultivation conditions, to promote vegetable development. Additionally, comparative evaluations with chemically treated crops will be conducted.

ACKNOWLEDGEMENTS

This research was supported by The Romanian Ministry of Research, Innovation and Digitalization, **Project PN 23 04 02 01**: Innovative biofertilizer production technology used to restore soil biodiversity and reduce the effects of drought on agricultural lands and MADR **ADER 16.1.1** Research on the potential

for enhanced utilization of the Cannabis sativa species for food-related purposes.

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