SECTION 5. GENERAL AGRICULTURE

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5.1 Research of possibilities for utilization of solid pharmeceutical raw plant material waste for fertilizer production

In an era marked by increasing environmental consciousness and resource scarcity, the exploration of innovative avenues for sustainable practices has become imperative. One such area of focus lies in the utilization of solid raw plant material waste for the production of fertilizers. This novel approach not only addresses the pressing need for effective waste management within the pharmaceutical industry but also opens doors to a potential solution for enhancing agricultural sustainability. This research endeavor delves into the possibilities and prospects of repurposing discarded pharmaceutical materials into valuable fertilizers, thereby bridging the gap between pharmaceutical production and agricultural advancement. By harnessing the untapped potential within this symbiotic relationship, we aim to contribute to a more environmentally conscious and economically viable future. This study embarks on a comprehensive exploration of the methods, benefits, and challenges associated with this innovative practice, ultimately striving to forge a path towards a more sustainable and integrated approach to waste management and agriculture.

At the current moment, most of the Ukrainian pharmaceutical manufacturers use landfilling of the solid waste. Most of these landfills located not so far from the big cities, and do not have technical capacity of sorting waste materials received neither conceive any potential treads to the environment – including but not limited to ground waters, soil, animals et cetera.

Speaking of negative consequences of the landfilling, several major points have to be considered:

1. Methane Emissions: Improperly managed landfills can release methane, a potent greenhouse gas, into the atmosphere, contributing to climate change.

2. Leachate Generation: Landfills can produce leachate, a harmful liquid that forms as water percolates through the waste, potentially contaminating soil and water resources.

3. Air and Water Pollution: Landfills can emit various pollutants into the air and water, including volatile organic compounds (VOCs), heavy metals, and other hazardous substances.

4. Land Use and Aesthetic Impact: Landfills can occupy significant land areas and may negatively impact the visual landscape, potentially affecting property values and nearby communities.

5. Wildlife and Habitat Disruption: Landfills can disrupt local ecosystems, attracting scavengers and potentially harming wildlife through contamination.

6. Biosecurity Risks: Improper handling of plant materials in landfills can pose risks for the spread of pests, diseases, and invasive species.

7. Landfill Decommissioning and Remediation Costs: Properly closing and remediating landfills after they reach capacity can be costly and time-consuming.

8. Long-Term Environmental Legacy: Landfills have the potential to leave a lasting environmental impact on the surrounding area, even after they have been closed and capped.

No all of the considered points can be applied to the solid raw plant materials waste, as number of inspections and toxicology tests are performed on this waste to ensure pharmaceutical production wasn't affected by any kind of pathogens, toxins or microorganisms.

However, as we can notice, number of it is essential especially for the target waste materials. Which leads us to the research of possible solutions of this issue.

Landfilling is the most used method of utilization around the globe. But in the recent years, rise in awareness of the climate change problems, overpopulation and some other reasons resulted a number of legislations in this method. For example, according to the European Parliamentary Research Service, all the Members States of the EU are implying rises in the tax fees for the landfill uses, and banned disposal of the bio-degradable waste on the unsuited landfills.

This measures in the EU resulted significant decrease in the waste materials deposited onto or into the land (to 41% of the total waste treatment methods) and in the land treatment and water release (to 7% of the total). Non-energy recovery or recycling is now second most used treatment. Among other treatment methods, there are also incineration (up to 6% in total) and backfilling (10%). [209]

Considering other options for the utilization of the chosen materials, all of the above should be considered.

Backfilling is the use of the solid waste in the landscaping and slope reclamations. These methods are not significantly applied to the raw plant waste – its consistency is not firm enough, and it's degradable.

Incineration of the raw materials may not be a good solution based on the low burn energy of the material. However, several studies show good results in the usage of such waste as the fuel material after the preparations (pressing, drying, etc.). These methods could also be included in the future studies of the topic.

Which leaves recycling as the most efficient way of the utilization.

For the recycling purposes, composition of the material is the first interest of the research. However, different production lines and ways may contribute to the change of the total composition significantly. Different pharmaceutical manufacturers use different raw materials for the production, these materials come from different regions and were grown in different seasons.

For the theoretical approach to the problem, we'll be concentrated on the general composition, rather than precise figures. Usually, any plant solid waste includes such components:

- Cellulose and hemi-cellulose – 70%
- Lignin – near 25%
- Leftovers of the target production compounds
- Other impurities[210]

Such composition provides us with only several possible recycling ways. But as far as the main component of the waste is cellulose and lignin, we'll concentrate more on the methods based on its recycling.

One of the most famous ways – biogas production. Microorganism fermentation of the carbon-based molecules will produce efficient amounts of the methane, which can be collected and used as common energy source.

However, biogas production requires quite high investment amounts and qualified staff for the maintenance of it, and economical efficiency of such recycling may be under question for the local pharmaceutical manufacturers, as well as concerns about efficiency of the production – solid raw plant waste usually consists of the several different varieties of the plants, which leads to longer degradation time as well as lower yield of the methane.

Another possible problem with this method is possible presence of the inhibitory compounds, such as tannins or phenols (as a part of the leftovers most commonly) which will inhibit the growth of the microorganisms which, again, affects yield, duration and overall economical value of the recycling.[211]

Another option of recycling is usage of the waste materials as the feed materials for the animal production. High cellulose values may be a relatively good feeding materials to the ruminant animals such as cows or goats.

But yet again, composition of the waste may be an issue, as there are number of the leftovers, that have to be purified beforehand. Also, nutritional value of the waste materials is much less than in traditional feeds, such as soybean, corn or wheat.

All these factors leave only fertilization as the most efficient way of the recycling. In particular, based on the nature of the waste, composting is the most convenient way.

Multiple reasons in favor of this method can be considered:

- Investment costs of production are quite low, comparing to the other methods.
- Quite high efficiency can be achieved in this case, using different side materials to contribute in it.

- High market demand – as one of the biggest world agricultural producers, Ukraine has high demand in the fertilizers.
- Ecological fertilizer – as far as such fertilizers may not require any chemicals to fulfill needs of the plants, they can be considered ecological.
- Low pathogens count – in the composting process temperatures reach quite high, resulting partial sterilization of the material.

At the same time, aside from advantages, disadvantages should be considered as well:

- Severe area demands – as far as duration of the composting is long and all the waste should be disposed in the ground, it may be problematic to find needed areas for it.
- Process duration – usually composting process takes from 12 to 18 months to complete. This still leaves need to deposit all of the waste materials in 12-18 months period for the composting.
- Need in the additional supplements – as the main efficiency value of the fertilizer C:N ratio usually used. This means that supplements should be added to the waste to keep this ratio in the target diapason.
- Possible filtrate production which still can affect soils as well as ground waters.[207]

Some of these advantages and disadvantages are dependable on the process of the composting itself, which brings us to the need to be more specific at the methodic used for it.

Composting process may be diversified into aerobic and anaerobic. As comes from the names, it considers presence of the oxygen in the process.

Anaerobic composting consist in dense load of the materials in hermetically closed environment (under plastic covers, or else). This way no oxygen presented in the process, and composting is performed by anaerobic microorganisms. This keeps composting quite cool comparing to the other method (25-35℃). This leads to lose of some of the advantages and additional problems with the processing. Materials are not being sterilized – considering high humility rate needed for the composting, development of the different fungi, pathogenic microorganisms and even possibly helminths are not under question.

Also, in the process of anaerobic conversion, chances of filtrate forming is quite high, which brings additional ecological concerns as well as economical expenses in the hermitization of the surfaces from the filtrate accessibility.

Aerobic composting, on the other hand, is much more pure and safer process to follow. Aerobic microorganisms involved in it, have a tendency to keep high temperatures for a quite long period of time, which allows compost so "self-sterilize" from pathogenic microorganisms and helminths, at the same time together with the good ventilation prevents fungi from active growth.

Aerobic process includes 3 main stages:

- Mesogenic, or mild temperature stage
- Thermophilic, or high temperature stage
- Stage of cooling and maturation

Starting on the first stage, mesogenic microorganisms are developing, quickly rising the substrate temperature. It's happening due to the consumption of the simple composites, such as proteins, monosaccharides and starches. Temperature rapidly rises from 20-25°C up to 70-80°C, which makes mesophilic bacteria less dominant and increase concentration of the thermophilic organisms. This stage may take from a few days to the 2-week period.

At the thermophilic stage, dominant forms of the microorganisms are thermophilic. However, here the difference in oxygen supply plays significant role. Levels of oxygen in the substrate have almost direct dependance on the aerobic and anaerobic bacteria rate. The more oxygen available for the process – bigger concentration of the aerobic microorganisms will be presented and vise-versa.

Meanwhile, thermophilic microorganisms are able to degrade more complex compounds – hemicellulose, pectin, cellulose and chitin. As was presented earlier, cellulose is the main compound of the target waste material and chitin is the main carbohydrate of the cell wall for the fungi, that are probably already presented in the media after the previous stage.

Another prospective of this stage is sterilization. As was mentioned, fungi are mainly destroyed by the thermophilic organisms by destroying their cell wall. At the same time, most of the pathological microorganisms are not destroyed by direct degrading – rise of the temperature is happening quite rapidly, but stays for quite a time. Duration of this stage may vary between a few days up to several months. Normally, to reach up to 90% of sterilization efficiency, temperatures above 55 °C should be maintained during at least 1 week. Efficiency increases with longer exposure. [206,208]

Eventually, concentration of the complex compounds decreases, which leads to the decrease of the thermophilic bacteria count, with the decrease of temperature. This causes development of the mesophilic organisms described before, but at this time, rise of the temperature limited to the optimum of this mesophilic bacteria, as thermophiles no longer have needed substrate.

This transition to the last stage of maturation can last for at least 6 months. During this stage already simple compounds left can be degraded by the mesophiles and form simple molecules accessible for the plants. Mainly, this stage leads to the rise of the NO_3^- rate in the compost. [207]

For the successful composting and efficient final product several other characteristics should be considered.

First of all – moisture. This parameter should be maintained quite strictly, in the range of 50-60%, which keeps water availability high enough to develop microorganisms' growth, and keep oxygen availability on the preferable level.

Secondly, for the efficiency of fertilization, compost should have acceptable C:N ratio and can vary within 25:1 – 40:1 range. This ration considered mostly “ideal” for the active composting. Lower values considered insufficient in terms of the Nitrogen consumed. At the rate lower then 20:1, Nitrogen will not be consumed by the bacteria in full, resulting losses of it in the forms of ammonia or nitrous oxide, both of which considered greenhouse gases thereby contributing to the climate change.

At the rates too high (60:1+), there are not enough Nitrogen for the target microorganisms to grow, which will slow composting process, or even stop it completely. But values up to 60:1 might turn out as a reasonable practice in terms of less concentrated compost odors as well as decrease in maintenance need.

Some other microelements should be considered as well, such as potassium and phosphorus with sulfur. C:K, C:P and C:S ideal ratios are 100-150:1, 120-250:1 and 100:1 respectively. This values should be determined for specific plant waste materials.

In terms of additional components of the efficient compost, initial waste materials should be combined with poultry, bovine or pigs droppings at rate between 1:1 to 1:2. This will bring needed amounts of nitrogen to the compost. In addition other plant waste, such as leaves or stems of other cultures may be useful. These components will increase the aeration and moisture efficiency of the compost resulting lower maintenance need.

Considering nature of the pharmaceutical production waste, it's recommended but not obligatory to grind initial materials. These practices have great influence on both moisturization and aeration of the compost.

There are studies presented in Ukraine, that proposes similar way of solid plant waste utilization from PJSC SIC "Borshchahivskiy CPP". Study proposes to utilize poultry droppings and leaves waste, but there is not enough theoretical study to fully implement proposed method in the production.

All these methods of the utilization of the solid plant materials can have great economical and ecological value for the pharmaceutical production processes. However, for the complete implementation of the mentioned practices, full-scale research must be conducted in order to determine best ratios and processes.

Also, future researches may show some advantages of the alternative ways to utilize these solid waste materials. Ever though incineration of the waste as it is probably not as efficient, but additional processing of the initial material may increase it, which will be studied after.