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ANALYSIS OF THE POTENTIAL OF PLANT RESIDUES AS A SOURCE OF HEAT IN HOTBEDS ON A FARM

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The paper presents an analysis of the possibility of using "green" plant residues generated on a farm as a source of heat for "hotbeds". Hotbeds - a technology of low-temperature substrate heating in beds or greenhouses. It consists in carrying out plant production on specially prepared beds, under which heaps of composted residues or manure are arranged.
The resulting heat heats the ground and the air in the plant germination zone. It is most often used in spring to speed up the yielding of spring vegetables. The paper analyses green residues that can be used in the hotbeds, arising in a typical farm with a horticultural production profile. The theoretical amount of heat in cultivating early vegetables was calculated on the amount of green mass residue. The investment cost of the proposed solution is PLN 250. Savings are PLN 300. The proposed device can be used for several years (in various configurations of green waste, e.g. in spring) - then the actual rate of return on investment will be much shorter and the profits higher. The energy analysis shows that the use of the proposed solution as a source of heat in agricultural production, for the management of the above-mentioned post-production residues, translates into savings of 2000 MJ of heat. If we produced this amount of heat in a coal-fired boiler, the CO_2 emission for primary energy would be 640 kg CO_2.

Keywords: *hotbeds, heat from residues, green waste*

INTRODUCTION

The growing energy crisis, progressive climate change caused, among others, by the extraction and use of fossil fuels is one of the greatest challenges facing humanity at the moment (ÓhAiseadha et al. 2020; Russo et al. 2022). Progressive warming - even if, according to some skeptics, there is no anthropomorphic source - is a fact (Li et al. 2022). On the other hand, there is a growing body of direct evidence that human activity is the cause of global warming. This is related to the emission of greenhouse gases - in particular CO2 and CH4. The source of CO2 emissions is primarily the combustion of fossil fuels - for the needs of transport, electricity and heat production (Voumik et al. 2023; Pistochini et al. 2022). The source of methane emission is, apart from partially natural causes (Jacob et al. 2022), such as swamps or melting permafrost, is agriculture. In particular, intensive livestock production (Bačėninaitė et al. 2022). At the same time, along with the growing world population, the need for more and more efficient agricultural production increases. This translates into a greater demand for energy carriers - fuel and heat required for intensive agriculture (Rahman et al. 2022). One of the directions for improving the situation is to reduce meat consumption (Funke et al. 2022) - the production of which, as written above, is associated with methane emissions - which, it should be emphasized, is a gas many times more dangerous than carbon dioxide as a greenhouse gas (Mar et al. 2022). It is true that its "life" time in the Earth's atmosphere is only several dozen years - but what should be emphasized, later it also decays into, among others, CO2 - affecting, already at a slower degree, climate warming (Staniszek et al. 2022). This translates into attempts to promote a vegan or low-protein diet among people as a reasonable alternative (Dixon et al. 2023).

However, plant production, although its energy efficiency in terms of cumulative energy intensity, is more efficient than animal production (Bryanta 2022) – it also consumes energy carriers – such as fuel for agricultural machinery and equipment and heat (Ragazou et al. 2022). In particular, heat consumption in plant production is associated with crops under cover in a temperate climate. If we are to consume more vegetables and fruits, they must be available on the market for a longer period of time. However, their production requires heat and light (Badji et al. 2022). In less favourable seasons of the year, e.g. in spring or autumn - it is associated with the need to, among others, greenhouse heating (Mohebi, Roshandel 2023). The work - as an attempt to find an ecological alternative to fossil fuels - coal, gas or wood used to heat greenhouses - shows the possibility of using green residues from previous crops as a source of heat for the next plants.

One of such technologies is the technology of "hotbeds" - i.e. warm frames. It is a solution in which the heat generated during the thermophilic phase of composting is used to heat the substrate in greenhouses. The scheme of the warm glazing is shown in Fig. 1. The theoretical description has been known for a long time, but in practice, this idea is still not used. Many studies have demonstrated the possibility of using warm compost to heat greenhouses, e.g. in the works (Neugebauer 2018b) where it was shown how the heat from the compost pile itself inside the greenhouse affects the air temperature inside the greenhouse. In turn, in the work (Neugebauer 2018a), the effects of using exactly the hotbeds technology for the production of spring vegetables were shown, showing that the yield was over 1 week faster than in the case of an identical cultivation in a cold bed.

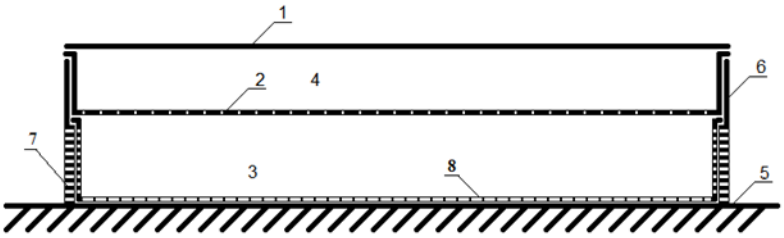

Figure 1. The hotbeds. Transparent cover; 2. Removable top shelf; 3. Composting space; 4. arable space; 5. The ground; 6. Sides of the inspection; 7. Air vents in the lower part of the sides of the inspection; 8. Removable bottom shelf.

This paper shows what is the potential to obtain heat for the hotbeds technology and the production of spring vegetables in autumn, using as "fuel" for them - green residues from the production of tomatoes under covers.

RESEARCH METHODS

The analysis was performed for a farm located in north-eastern Poland, in the Olsztyn poviat. It is a plant production farm with 6 greenhouses at the same time. Tomatoes are grown in these greenhouses. Illustrative photo - Fig.2.

Figure 2. The greenhose.

The dimensions of the greenhouse are 5 (width) x 21.3 (length) x approx. 3.5 (height) m. Due to technological paths - the available cultivation area in the greenhouse is 61.76 m2.

240 tomato bushes were planted in each greenhouse, which gives a planting density of 3.88 bushes per m2. And it complies with the guidelines for tomato cultivation - for medium-sized tomatoes - it is 3-4 plants per m2. Cultivation was carried out classically in the ground.

At the end of the growing season, after harvesting, 10 randomly picked tomato stalks were weighed. The results are shown in Table 1. Note that the plants were already slightly dry. Then, for two stems - closest to the average weight - the density was determined - the results are given in Table 1.

Table 1. Tomato stalk measurements.

Stalk No.	Weight (kg)	Density (kg*m^{-3})
1	0,206	
2	0,221	
3	0,236	0,24956
4	0,298	
5	0,199	
6	0,216	
7	0,243	0,26137
8	0,244	
9	0,273	
10	0,214	
average	0,235	0,255465

In total, for 6 greenhouses with 240 plants in each, this gives 340 kg of green mass of tomato stalks - rounded to tens of kilograms.

This green mass, as production residues, is removed and thrown on "compost", which, after ripening, is spread on nearby fields

RESEARCH RESULTS AND DISCUSSION

After measurements and calculations of the amount of available biomass, the area of hotbeds and the amount of heat possible to be obtained in this farm from the above-mentioned green residues were calculated.

In the author's research described in the work (Neugebauer 2018a) - it was shown that 70 kg of green waste and OFMSW - with a volume of 0.25 m3 - used as a "feed" for hotbeds allows heating the hotbed for a period of about 3 weeks after a 1-week period of the initial phase of the initial low temperature mesophilic. The extension of the duration of individual phases in comparison to other studies and literature is in this case related to passive, slow aeration - which results in a slower rate of reactions and processes during composting. At the same time, it is beneficial in this case - because it extends the operation time of the hotbeds and reduces the temperature available on the cultivation surface to acceptable values for the plants (Neugebauer 2018a).

Using the information provided by the author in the above-mentioned (publication - it can be assumed that in the analysed case it is possible to use the green waste of tomatoes (directly the stems themselves) for hotbeds with an area of 5 m2. When installing hotbeds, the stems should be shredded. Assuming a yield of about 2.5 kg of radishes per m2, you can obtain 12.5 kg of radishes in the proposed solution, the value of which on the market (on sale) as of August 30, 2023 is only PLN 2 per kg. However - with each day, due to the decreasing temperature, their price will increase - and assuming hotbeds now (end of August) - crops can be expected in about 1 to 1.5 months. Under similar conditions in 2022, at the beginning of October, the price for 1 kg of radishes was more than twice as high as at the end of August - analysis based on data from (https://wiescirolnicze.pl/ceny-rolnicze/rzodkiewka/?data=2022-10-03). In the current year - it can translate into a price of about PLN 5 / kg - which gives a total of PLN 62.5. The prices given are wholesale prices - in retail sales, the price for 1 kg is about five times higher (analysis based on, among others, the offer of retail chains). It may not seem like much, but if the grown radish is used by the farm owners, a real saving of about PLN 300 can be assumed.

It is not much - but it should be noted that the proposed hotbeds solution is one of the simplest, which translates into a low price - currently it costs about PLN 250, without labor costs - the main component of the cost is the purchase of a polycarbonate plate - the price is about PLN 200 for 12 m2 - see (https://sklepdecor.pl/pl/p/Plyty-6-x-2.1-komorowe-z-poliweglanu-BEZBARWNY-Natur-Garden-/3422?gclid=Cj0KCQjw9MCnBhCYARIsAB1WQVWZqR5S6Ww8dZb6Nebd8KPmF2B4B78BTg8pNxB8A-ye-a2rlzBd25oaAlRpEALw_wcB). The cold frame itself can be used for years, its construction is without any additional mechanical elements - other similar solutions involving the recovery of heat from compost use pumps, coils, etc. elements in the heat collection system - compare e.g. (Roman 2015). On the other hand, it should also be emphasized that the production residue, i.e. tomato stalks, which must be composted or otherwise removed from the greenhouse, is used as input.

The proposed construction enables the effective use of 2 MJ of heat from each kilogram of green waste to heat the substrate (Neugebauer 2018a). Taking into account heat losses and heating of the air inside the hotbed, it can be assumed, based on the calculations made in (Neugebauer 2018b), that 6MJ of heat can be effectively obtained from 1 kg of biomass in the composting process. Which gives only 50% efficiency in relation to the theoretical maximum thermal efficiency - given in (Jędrczak, 2007), which is 12 MJ/kg.

Relating this to a total of 340 kg of stem weight - this gives about 2000 MJ of heat. In practice, this corresponds to about 90 kg of coal - if you want to get this amount of heat from its combustion - assuming 100% efficiency of the combustion process itself. And taking into account the efficiency of the boiler and the entire heating system for the greenhouse (in the case of heating crops) - about 50% (Viessman materials - https://www.viessmann.pl/) - this gives "savings" of about 180 kg of coal, which in turn translates into approximately 640 kgCO2 in exhaust emissions. This is a small amount, but due to the energy transformation, which determines the pursuit of zero emissions - each heat source should be used effectively - in particular those that simultaneously manage waste from other production processes - as in this case.

It is also possible to increase the cultivation area of hotbeds by supplementing tomato stalks with other green residues produced on the farm - e.g. leaves, other vegetables, etc. As they were not available on this farm, they were not included in this analysis.

CONCLUSIONS

The solution proposed in the article - consisting in using the stalks left over from growing tomatoes in greenhouses as input for hotbeds - is a solution that fits into the "zero waste" strategy.

For the farm under study - 340 kg of tomato stalks can be used - post-production residues, which still need to be removed and managed somehow. This will allow you to "power" 5 m2 hotbeds for a month - just the time needed to yield radishes.

The investment cost of the proposed solution is PLN 250. Savings are PLN 300. The proposed device can be used for several years (in various configurations of green waste, e.g. in spring) - then the actual rate of return on investment will be much shorter and the profits higher.

The energy analysis shows that the use of the proposed solution as a source of heat in agricultural production, for the management of the above-mentioned post-production residues, translates into savings of 2000 MJ of heat. If we produced such amount of heat in a coal-fired boiler, the CO2 emission for primary energy would amount to 640 kg CO_2.

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