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Prospects for the peat using as the basis of the soil-like substrate in mini-ecosystems modelling

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Abstract. Global urbanization is causing a constant decline in arable land as cities and associated industrial zones are "attacking" adjacent agricultural areas. One of the promising ways to solve the problem of increasing food production for the constantly growing population of the planet against the background of rapidly decreasing land resources is the development of fundamentally new alternative methods for the production of crop products, including in greenhouses. The fundamental basis for technological optimization of plant cultivation parameters and the output of the productive process of a particular crop to the maximum of its genetic capacities can be the development of artificial mini-ecosystems based on the reproduction of nature-like processes, implying the balance and combination in one volume of the processes of plant production and reduction of organic waste, initiated directly in the zone of the rhizosphere of plants due to the introduction of technological earthworms into the reduction zone. According to the results of model studies presented in this article, peat is an acceptable basis for the substrate of the root block of a mini-ecosystem, and the introduction of earthworms *Eisenia fetida* Sav. into the reduction zone does not have a negative effect on lettuce plants, provided that it is used as an energy substrate for cattle manure worms in quantities not exceeding 10 - 20% of the total volume of the substrate.

1. Introduction

Serious environmental problems that arose in the late 20th - early 21st centuries are aggravated by the protracted economic crisis, which, against the background of the constantly growing population of the Earth, causes an ever deeper social stratification of the planet's population both in the geographical aspect (rich north and poor south) and between urban and rural residents. According to UNDESA [1], by 2050 the share of urban dwellers in the total world population will exceed 66%. At the same time, with the growth of the population, the availability of the resources of the planet as a whole and of arable lands, in particular, naturally decreases [2], which inevitably poses a threat to food security on a global scale. Global urbanization leads to an even greater reduction in the area of arable land as a result of the "offensive" of cities and associated industrial zones on adjacent agricultural areas [3].

Climate change is also an additional problem, which is most acutely felt in the most densely populated regions with tropical and subtropical climates. The tendency towards constant climate aridization is responsible for a particularly rapid rate of decline in suitable arable land due to desertification and the continuous rise in sea level. Anthropogenic climate change exacerbates the above problems as many tropical and subtropical countries more vulnerable to global warming are experiencing rapid declines in usable arable land due to the effects of desertification and sea level rise [4].

One of the promising ways to solve the problem of increasing food production for the constantly growing population of the planet against the background of rapidly decreasing land resources is the development of fundamentally new methods of crop production, in particular the creation of CEA (Closed Environment Agriculture) - a wide range of alternative methods of crop production in a closed environment [5]. The food production in such closed systems allows one to control such important factors as the temperature and humidity of the soil and air, the gas composition of the atmosphere, the intensity of illumination and the spectral characteristics of light sources [6]. These technologies make it possible to expand the geography of crop production up to regions, in terms of their climatic conditions, in principle, unsuitable for solving these problems in open ground conditions.

The ability to control the growing environment of plants also allows producing crop products in the off-season, receiving several harvests per year. The introduction into the technological cycles of these systems of methods for recycling irrigation water and some organic waste simultaneously solves the problem of saving resources. In addition, this technology can provide alternative agricultural production for highly industrialized and urbanized regions, eliminating the problem of dependence on a seasonal agricultural labor force [7]. To date, very successful artificial small ecosystems have been developed, simplified as much as possible along the food chain. Initially, the main purpose of their creation is the development of life support systems for people in remote and / or extreme places, including the polar and circumpolar regions on Earth, as well as the conditions of space and lunar (Martian) stations [8, 9, 10].

The functioning of such small ecosystems is based on the principle of autonomy, which assumes a certain degree of stability of the system, optimization of the plant cultivation parameters, contributing to obtaining maximum yields with minimum use of the usable area, as well as a high degree of closure of the main biogenic elements cycles. As is known, all small ecosystems developed to date are based almost exclusively on hydroponic or aeroponic methods of growing plants. At the same time, the combination of production and reduction processes in space and time due to the introduction of waste directly into the root zone of plants simultaneously with the introduction of technological species of lumbricide into the substrate will allow the development of highly efficient nature-like technobiocenoses, characterized by the maximum attainable stability and autonomy for such systems, combining the possibility of obtaining a consistently high crop production with effective control of plant pathogens due to saturation of the soil substrate with elements of mineral nutrition of plants and useful symbiotic microorganisms.

One of the most important problems inevitably arising in the creation of such mini-ecosystems is the development of an algorithm for the organic waste transformation in the root zone of the production unit of the system, initiated by the introduction of technological earthworms into the substrate. At the same time, among the most pressing issues are the issues of choosing the optimal basis of the growth substrate for plants, the choice of the optimal organic waste dose introduced into the substrate, as well as the optimal density of the starting population of earthworms.

In most artificial ecosystems (usually modeled for space greenhouses), various fibrous ion-exchange soil substitutes (for example, Biona-B3 ion exchanger), granular ceramic media (for example, Turface), argoperlite are most often used as the basis of the growth substrate in the root block [11], various analogs of lunar soil (for example, anorthosite) [12], as well as Martian soil (mainly consisting of plagioclase and amorphous material with accessory minerals, including zeolite, hematite, and smectite clays) [13].

In our opinion, fibrous peat can be used as the base substrate for the root module, which also has a fibrous structure and high sorption capacity, which allows it to be saturated with nutrients for their subsequent gradual release as they are depleted in solution. In addition, peat can also become an excellent absorber of liquid and semi-liquid organic waste, providing optimal water-air conditions for the active course of microbiological bioconversion of waste. Peat will also create optimal conditions for the successful introduction of earthworms into the peat-based substrate.

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The main purpose of the research presented in this article was to assess the efficiency of using peat as a base of a substrate for the root module of a mini-ecosystem. To achieve this goal, a laboratory vegetation experiment was set up, in which the optimal concentration of organic waste (cattle manure) in the peat-manure substrate was determined, providing the best morphometric parameters of lettuce plants grown on the studied substrates, but, at the same time, not causing overly active reproduction of earthworms and the resulting injury to the roots of plants. If you don't wish to use the Word template provided, please use the following page setup measurements.

2. Objects and methods

To solve the problem of determining the optimal concentration of organic waste (cattle manure) in the peat-manure substrate, a laboratory model experiment was carried out according to the following scheme:

Variant 1. The ratio of the mass of peat and cattle manure = 50: 50%
Variant 2. The ratio of the mass of peat and cattle manure = 70: 30%
Variant 3. The ratio of the mass of peat and cattle manure = 80: 20%
Variant 4. The ratio of the mass of peat and cattle manure = 90: 10%

We used sphagnum oligotrophic peat with degree of decomposition 10-15 % to peat-manure substrate production.

The moisture content of peat and manure used to obtain the substrate is 80%. Substrate weight was 800 g, pot volume was 2 liters. After mixing the peat and manure, the substrate was kept for 7 days to homogenize the components and absorb the excess ammonia (from the manure) by peat. After a period of preliminary composting, the earthworms *Eisenia fetida*, Sav., in the amount of 10 individuals / pot, were introduced into the substrate.

Seeds of lettuce (*Lactuca sativa* L.) were planted in the substrate in the number of 6 seeds per pot 7 days after the introduction of the worms. After emergence, some of the plants were removed. The final number of plants per pot was 3. The experiment was repeated 3 times.

Lettuce plants were grown in a climatic chamber at an illumination intensity with fluorescent lamps - 6 kLq, PAR - 87 μmol quanta / (m2 s) with a 12-hour photoperiod at + 20 ... + 22 ° C (daytime temperatures) and + 15 ... + 17 ° C (night temperatures). The total duration of the experiment was 64 days (the duration of growing plants was 50 days).

To ensure a uniform character of illumination of plants in different variants of the experiment, the pots were rotated clockwise in the growth chamber every 2 days. In addition, the pots located on the upper shelf were moved to the lower one and vice versa.

Every 2 weeks from the moment of planting, the height of the plants and the area of the leaf blade were recorded. At the end of the experiment, the height, the area of the leaf plate of the 1st, 2nd, 3rd, 7th and 8th leaves, and the weight of each plant were measured. At the end of the experiment, the structure of the earthworm population was also analyzed, namely: the number of adults and juveniles, the number of cocoons, and the weight of adult worms.

3. Results

The results of the vegetation experiment showed that peat is a promising material as a substrate base for the root block of the mini-ecosystem being developed. The physical properties of peat (fibrous structure, high moisture capacity and high sorption capacity in relation to ammonia) provided the used peat-manure substrate with the properties of a comfortable habitat for introduced earthworms and for the growth and development of lettuce plants in one volume.

Measurements of the morphometric parameters of lettuce plants carried out 3 weeks after the start of the experiment showed that growth of lettuce plants was observed in all variants of the experiment. Plants with 10% and 20% manure were distinguished by the most active growth. In the variant with 50% manure, inhibition of plant growth was even visually observed (figure 1).

Figure 1. Visual comparison of the volumes of lettuce green mass in different variants.

After 1.5 months from the beginning of the experiment, the variant with 50% manure in the substrate was still distinguished by significantly less active growth of lettuce plants. Thus, the number of leaves in plants in this variant was almost 2 times less than in plants in variants with 20% and 10% manure. All variants where manure doses of less than 50% were applied did not statistically differ among themselves in the number of leaves, but all together significantly differed from the variant with 50% manure (figure 2). At the same time, the largest number of leaves was observed in plants grown in a substrate with 10% and 20% manure.

Measurement of the area of the third leaf of plants showed that in the variant with 50% manure, lettuce leaves were more than 5 times smaller than in the variant with 20% manure, where the maximum values of this indicator were observed. The values of the area of the 3rd leaf of plants grown on a substrate with 20% manure statistically significantly differed from plants grown in variants with 30% and 50% manure. At the same time, the plants in the variants with 20% and 10% manure in the area of the third leaf did not statistically differ from each other (figure 3).

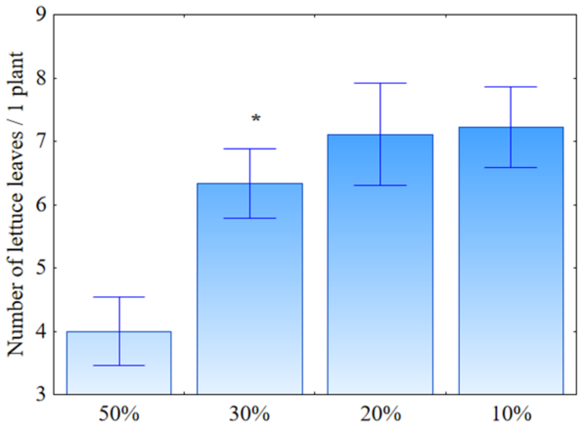

Figure 2. The effect of the manure dose on the number of leaves in lettuce plants after 1.5 months from the beginning of the experiment.

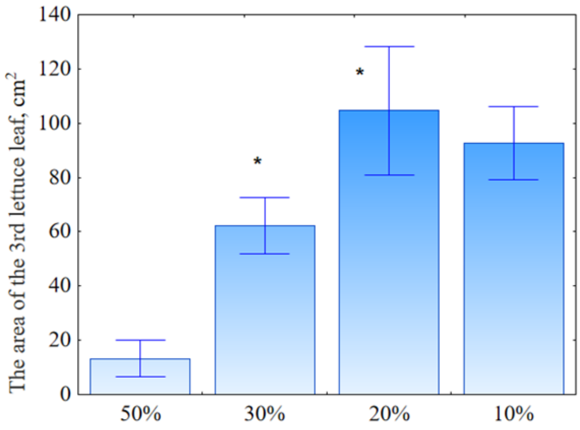

Figure 3. The effect of the manure dose on the area of the 3rd leaf of lettuce plants after 1.5 months from the beginning of the experiment.

Note. * – the differences with the previous variant are statistically significant according to Mann-Whitney, $p<0.05$.

At the end of the observation period (after 2 months of cultivation), according to the sum of indicators, the plants grown in substrates containing 10% and 20% manure were characterized by the best morphometric parameters. In the variant with 20% manure, the plants were distinguished by the highest height and the maximum, according to the experience, indicators of the total area of the largest 7th and 8th leaves. In the variant with 30% manure, the height of plants slightly differed from those of plants grown on a substrate with 50% manure, but in terms of leaf area, the variant with 30% was statistically different from the variant with 50% for the better (figure 4, 5).

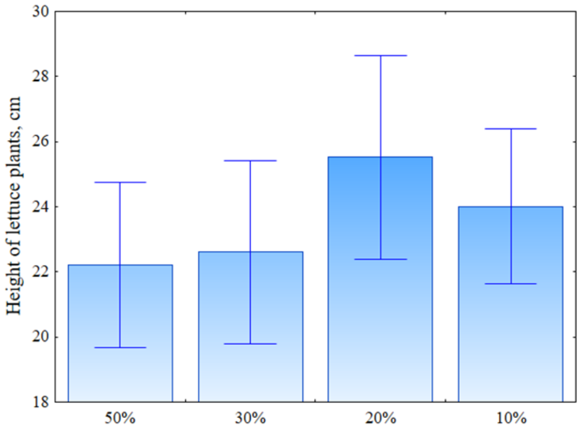

Figure 4. The effect of the manure dose on the height of lettuce plants after 2 months of cultivation.

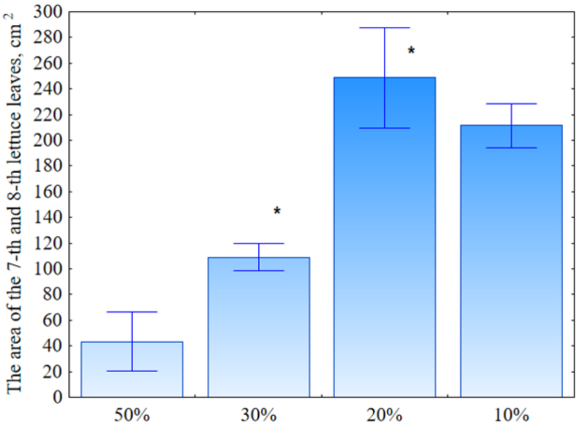

Figure 5. Influence of the manure dose on the area of 7 and 8 leaves of lettuce plants after 2 months of cultivation.

Note. * – the differences with the previous variant are statistically significant according to Mann-Whitney, $p<0.05$.

The significant inhibition of plant growth in the variant with 50% manure in the substrate is most clearly evidenced by the fact that the total area of the 7th and 8th leaves of plants in the variant with 20% and 10% manure is 5-fold higher than in the variant with 50% manure. At the same time, the differences between the variants with 20 and 10% manure are statistically insignificant.

Since the most reliable indicator of the lettuce yield is the green mass, we have to admit that the most optimal amount of manure in the substrate is 10%. In this variant, the total green mass of plants turned out to be the maximum according to the experience. In general, as can be seen from figure 6, there is an inverse relationship between the dose of manure in the substrate and the yield of green mass of lettuce plants. It is also noteworthy that, in comparison with the variant with 50% manure, in the variants with lower doses of manure, the proportion of the mass of leaves, as the most edible part of the plant, increases in comparison with the mass of stems (figure 6).

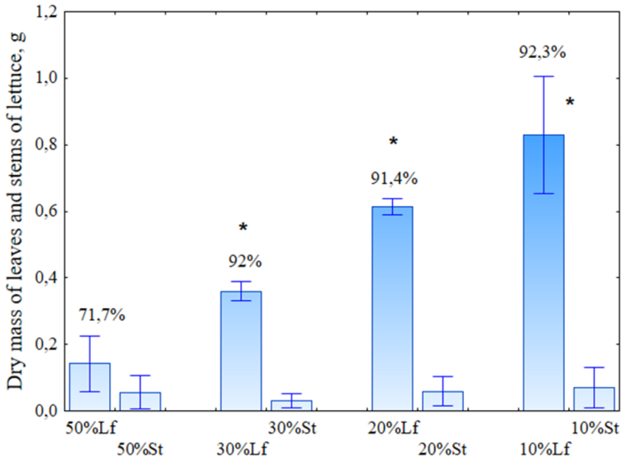

Figure 6. Influence of the manure dose on the dry weight of leaves and stems of lettuce plants after 2 months of cultivation: Lf - mass of leaves, St - mass of stems.

Note. * – the differences with the previous variant are statistically significant according to Mann-Whitney, $p<0.05$.

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Analysis of the population of earthworms in the substrate at the end of the experiment showed that the survival rate of adults introduced into the peat-manure substrate at the beginning of the experiment naturally increases with an increase in the amount of manure in the substrate (Table 1). In the variant with the maximum amount of manure, the largest increase in the weight of one adult worm is naturally observed. It is interesting that in the variant with a minimum 10% dose of manure, the weight gain of one adult worm turned out to be significantly higher than in the variants with average doses of manure (20% and 30%), which, most likely, was due to the fact that in these variants the worms were more focused on reproduction than in the variant with 10% manure. In the variant with the lowest dose of manure, due to a clear lack of nutrition, adult earthworms were guided not so much by the reproduction strategy as by the maintenance of their own viability (Table 1).

Table 1. Influence of manure dose on the earthworm population characteristics.

	Number of adult worms	Survival of worms, %	Weight gain of the 1st worm, %	Number of juveniles	Number of worm cocoons	Number of cocoons per 1 adult worm
50% manure	10,0±0,7	100,0	81,5	260,7±15,8	157,0±3,6	15,7±1,3
30% manure	9,7±0,3	97,0	12,7	67,3±20,3	62,3±5,0	6,4±1,0
20% manure	6,0±1,0	60,0	12,9	11,2±0,7	41,6±3,2	6,9±0,6
10% manure	5,0±2,0	50,0	52,7	0,2±0,1	0,3 ± 0,1	0,06±0,01

The number of juveniles and deposited cocoons also naturally increases with an increase in the amount of manure in the substrate. The maximum reproduction rate of worms, expressed as the number of cocoons per mature worm at the end of the experiment, was characteristic of lumbricids introduced into the variant with the maximum (50%) amount of manure. It is noteworthy that the differences in 20% and 30% of manure in the substrate had practically no effect on the reproduction rate of worms in the corresponding variants of the experiment (Table 1).

4. Discussion

Manure, used as a source of nutrients for lettuce plants and, at the same time, as the main energy substrate for the earthworms *E. fetida* Sav. introduced into the substrate, undoubtedly turned out to be a decisive factor that determined both the morphometric parameters of lettuce plants and its yield, as well as the main population characteristics of earthworms. In accordance with the data obtained, the most optimal dose of manure in the composition of the peat-manure substrate should be recognized as 10%. It was in this variant of the experiment that the maximum mass of the aboveground part of the plants was obtained by the end of plant cultivation. At the same time, the plant habit was distinguished by optimal parameters, at which more than 92% of the total plant mass is the mass of leaves, as the most suitable part of the plant as food.

However, despite the fact that the mass of the aboveground part of lettuce plants in the variant with 20% manure turned out to be 21% less than in the variant with 10% manure, if it is necessary to accelerate the processing of large volumes of organic waste in the mini-ecosystem, the variant with 20% manure can also be highly recommended for practical use. Perhaps, to reduce the negative impact of too high a dose of manure on lettuce plants, a slightly longer than 1 week period of preliminary vermicomposting of the peat-manure substrate, preceding planting, can be used. Earthworms, transforming the organic matter of manure in the process of preliminary vermicomposting, thereby ensure its partial stabilization and reduce the amount of mobile water-soluble salts in the substrate, which have a suppressive effect on the root system of plants, converting them into humic compounds and other high-molecular organic complexes. Such stabilization of the organic matter of the substrate will also provide its prolonged effect on plants.

The strong inhibitory effect on lettuce plants of the maximum 50% of the manure dose was probably also due to the higher population density of earthworms, especially the most active juveniles, compared to other options. The high locomotor activity of young earthworms could have a traumatic effect on the root system of the lettuce, especially on the thinnest roots. Similar traumatic effects of earthworms on young weak plant roots that have not yet formed protective layers, and therefore are especially susceptible to physical stress, were noted in the work of Zhang Yu et al. [14], as well as in a review article by Scheu S. et al. [15], who indicated that 9% of the 67 publications reviewed by them provide information on the possible indirect negative impact on plants of the bioturbation processes of the substrate caused by earthworms, especially in the case of their high abundance and in conditions of a limited volume of pots.

In general, it should be noted that in a number of works devoted to modelling partially closed mini-ecosystems and microcosms of various contents, information is provided on the positive effect of receiving the introduction of earthworms into the composition of the substrate of the root block. For example, Lu Liu et al. [16], who investigated the efficiency of growing eight species of plants of the Poaceae family in a microcosm with two species of earthworms differing in their ecological strategy (the epigeic red worm *E. fetida* Sav. and the anecic gray worm *Metaphire guillelmi*, M.) noted a significant stimulation of plant growth and development by earthworm metabolites. Metabolites of earthworms contributed to an increase in the yield of some types of cereals by 110% compared to the control (without worms). In microcosms modeled by Ulrike Jana et al. [17], the introduction of the earthworm *Aporrectodea caliginosa* into the soil substrate also stimulated the growth and development of Arabidopsis plants.

In our experiment, the presence of an energetic substrate became the main factor not only for mass gain by adult worms, initially introduced into the substrate, but also for their subsequent reproduction. As can be seen from the table, the number of juveniles and the number of cocoons deposited by worms are in direct proportion to the amount of manure introduced into the substrate. Thus, by regulating the amount of manure in the composition of the peat-manure substrate, it is possible to successfully regulate the number of earthworms in the root block, preventing their excessive reproduction and the resulting traumatic effect on plant roots. At the rate of launching adult worms - 10 worms per 800 g of substrate and in the absence of a period of preliminary vermicomposting of manure, the dose of manure corresponding to 10% of the weight of the peat substrate should be considered optimal, and the dose corresponding to 20% of manure - the maximum allowable, at which there is no noticeable decrease in the growth and development of lettuce plants.

5. Conclusion

The results of a vegetation experiment aimed at modelling a mini-ecosystem based on growing lettuce plants on a peat-manure substrate with the addition of different amounts of cattle manure and the introduction of earthworms *E. fetida* into the substrate showed that fibrous peat is a quite acceptable basis for the substrate of the root block of a mini-ecosystem. Fibrous peat with a low degree of decomposition (less than 20 %) is most preferable for the formation of the root block for a mini-ecosystem. The presence of earthworms in the composition of the peat-manure substrate and directly in its root layer, in principle, does not have a negative effect on lettuce plants, provided that 10-20% of manure from the total volume of the substrate is used.

Acknowledgments

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