

# Modern Practices for the Cultivation of Leaf Vegetables in Hydroponics

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**Abstract**— Nowadays, vertical multilayer placement of plants on racks is rapidly gaining popularity alongside the classic horizontal cultivation practice. Comparison between plant cultivation methods in functioning units constitutes the basis of the present research. The work has revealed that plants undergo different development stages in accordance with their biological and genetic characteristics and practically do not differ as for time spent in growing compartments. In general, over the entire cycle of leaf vegetables production, it can be noticed that lettuce needs from 30 to 33 days for harvesting in horizontal units and about 27 days in vertical ones. As regards dill, its cultivation does not significantly differ in relation to the unit type and amounts to 34-41 days, while basil revealed quite a wide specter of cultivation both in different units and within complexes ranging from 32 to 48 days, which indicates the reaction of plants to the influence of changes in microclimate and nutrient solution. When analyzing the development stages of arugula and parsley, it should be noticed that harvesting occurs 6-9 days faster in a vertical unit in an experimental container, which allows adding one or two more complete cycles over the year. Thanks to the multilayer placement of plants and subsequently the sufficient lighting of each tier, the Cerera 1.0 container system has reduced the area occupied by 1 plant and increased the number of net pots; as a result, the yielding capacity has increased by 2-3 times per unit area.

**Keywords**—hydroponics, multilayer system, leaf vegetables.

## I. INTRODUCTION

The rapidly changing global economy dictates the conditions for the development of production and society. Cities are growing all over the world as people move from rural areas in search of work, opportunities to improve their living conditions and for a better future for their children. This raises the issue of growing large volumes of fresh organic products in the immediate vicinity or directly where people live. At this very moment a great part of the soil which is able to produce vegetables is involved in the process, and part of it is seriously damaged by improper methods of exploitation [1].

Thanks to the use of the latest technological and scientific achievements in vegetable farming, the hydroponic method has been developing at an incredible speed in recent years. As a consequence, vertical multilayer placement of plants on racks is rapidly gaining popularity alongside the classic horizontal cultivation practice. Comparison between plant cultivation methods in functioning units constitutes the basis of the present research.

## II. LITERATURE REVIEW

The global hydroponic market is estimated at about \$ 21.2 million. Europe, the Pacific Rim and North America are the largest producers and leading areas in the implementation of advanced technologies in the field of protected ground.

The Japanese company Mirai is completing a multi-unit agricultural complex equipped with pioneering hydroponic units in the industrial region of Khabarovsk. By putting this complex into operation, the region will be able to increase the self-sufficiency of vegetables and greens from 10 to 60% [2]. At the All-Russian Science and Research Institute of Vegetable Crop Breeding and Seed Production (VNISSOK), work has begun on the use of multilayer small-volume cultivation practices in vegetable farming on protected ground using a five-layer hydroponic system with narrow racks. The distribution of such practice in Russian greenhouses has been constrained until recently by the lack of a specific range of vegetable plants. Therefore, a program for the creation of new highly productive forms of vegetable plants adapted to the conditions of multilayer hydroponics with narrow racks (MHNr) has been developed and operating in the laboratory of new technologies at VNISSOK since 2010 [3].

## III. RESEARCH METHODS

Research was carried out at the Educational and Scientific-Production Laboratory 'Horticulture' of the Educational and Experimental Farm of Omsk State Agrarian University in an autonomous high-tech mobile complex (greenhouse) applying a vertical multilayer cultivation method on the basis of a 40-foot shipping container. For practice comparison data were also provided by the following enterprises: 'TPK-Agrokultura' LLC, based in the Omsk Region (Russian Federation), and 'Greenhouse Technologies of Kazakhstan' LLC, based in the Republic of Kazakhstan.

Vegetable production at 'TPK-Agrokultura' LLC and 'Greenhouse Technologies of Kazakhstan' LLC is carried out using a small-volume practice (small-volume hydroponics) with the application of a continuous flow plant nutrition system, a supplementary illumination system and automatic climate control; both greenhouse complexes use 4th-generation greenhouses. The production of lettuce and leaf vegetables is carried out following the method of continuous flow hydroponics. Plants are grown in rectangular plastic boxes arranged horizontally across the unit, along the bottom of which a nutrient solution flows in a thin layer [4, 5].

Research on the cultivation of vegetables with vertical practices has been carried out on the territory of Omsk State Agrarian University in a high-tech mobile complex Cerera 1.0 in cooperation with the industrial partner ‘Siberian Klondike’ Group Company LLC. Products are grown in a closed system with fully controlled microclimate parameters. Plants are grown on multilayer racks, with a main compartment of 2 racks, each one consisting of 4 tiers. The power system includes a pumping station, a solution coarse filtering system, an ultraviolet filter, a nutrient solution distribution system, and a drainage system. The nursery is composed of 2 equal racks, with a periodic flooding nutrition system. Each of the racks has 6 tiers [6].

Observation and measuring were carried out according to the methodology of State Crop Variety Testing.

#### IV. RESULTS

##### A. Microclimate

Microclimate is one of the decisive factors when growing plants in greenhouse complexes and is created by the action of all the systems of technological equipment. Plants themselves have a great influence on microclimate. The level of illumination, temperature, humidity, and CO<sub>2</sub> concentration vary along tiers within the plant cenosis. Table 1 presents data about greenhouse microclimate in different climatic zones [7, 8].

TABLE I. MICROCLIMATE ON PROTECTED GROUND FOR THE CULTIVATION OF LEAF VEGETABLES

| Culture type                                | Nursery        |                          |                            |         | Cultivation compartment |                          |                            |         |
|---|----------------|--------------------------|----------------------------|---------|-------------------------|--------------------------|----------------------------|---------|
|   | Quantity, days | Temperature, day / night | Supplementary illumination |         | Quantity, days          | Temperature, day / night | Supplementary illumination |         |
|   |                |                          | W/m²                       | Time, h |                         |                          | W/m²                       | Time, h |
| ‘Greenhouse Technologies of Kazakhstan’ LLC |                |                          |                            |         |                         |                          |                            |         |
| Lettuce                                     | 10             | 18-20 / 16-18            | 85                         | 12-16   | 18-20                   | 16-18 / 15-16            | 85-125                     | 16      |
| Dill  | 12             | 18-20 / 16-18            | up to 250                  | 12-16   | 22-28                   | 16-18 / 15-16            | 125-130                    | 16      |
| Basil                                       | 14             | 16/18                    |                            | 16-20   | 25-35                   | 21-22/16-18              | 125-150                    | >11     |
| Arugula                                     | 8              |                          |                            |         | 21                      | 16-18                    | 100                        | 12-14   |
| Parsley                                     | 14             | 18-20/16-18              | 85                         | 12-16   | 36-38                   | 16-18/15-16              | 100-125                    | 16      |
| ‘TPK-Agrokultura’ LLC, Omsk Region          |                |                          |                            |         |                         |                          |                            |         |
| Lettuce                                     | 10             | 22/20                    | 90                         | 20      | 18-20                   | 20/18                    | 90                         | 18      |
| Dill  | 12             | 22/20                    | 90                         | 20      | 22-28                   | 20/18                    | 90                         | 18      |
| Basil                                       | 10             | 22/20                    | 90                         | 20      | 27-33                   | 20/18                    | 90                         | 18      |
| Arugula                                     | 10             | 22/20                    | 90                         | 20      | 21                      | 20/18                    | 90                         | 18      |
| Parsley                                     | 12             | 22/20                    | 90                         | 20      | 36-40                   | 20/18                    | 90                         | 18      |
| Cerera, Omsk                                |                |                          |                            |         |                         |                          |                            |         |
| Lettuce                                     | 9              | 24-26/20-22              | 125                        | 16      | 18                      | 20-22/16-18              | 125                        | 14      |
| Dill  | 11             | 24-26/20-22              | 125                        | 16      | 25-28                   | 20-22/16-18              | 125                        | 14      |
| Basil                                       | 10             | 24-26/20-22              | 125                        | 16      | 25-35                   | 20-22/16-18              | 125                        | 14      |
| Arugula                                     | 10             | 24-26/20-22              | 125                        | 16      | 20-22                   | 20-22/16-18              | 125                        | 14      |
| Parsley                                     | 13             | 24-26/20-22              | 125                        | 16      | 35-40                   | 20-22/16-18              | 125                        | 14      |

Comparing leaf vegetables cultivation practices at ‘Greenhouse Technologies of Kazakhstan’ LLC and ‘TPK-Agrokultura’ LLC, no significant deviations have been observed as for temperature regime and supplementary illumination in the nursery and the cultivation compartment. The temperature difference is about 2-4 °C.

When cultivating leaf vegetables in container-type vertical greenhouses, the difference is represented by direct sowing of seeds into the nursery, bypassing the germination chamber. In addition, the air temperature in the nursery and in the cultivation compartment is increased by 4-6 °C and the intensity of additional illumination is boosted to 40 W/m<sup>2</sup>. In general, this contributes to obtaining standard products 4-6 days earlier if compared to horizontal greenhouses.

##### B. Phenological observations

Phenological observations are necessary to track the entry of plants into a particular phase, as well as its completion. This allows us to promptly change, depending on the crop age, all the parameters of cultivation: temperature, humidity, nutrient solution, etc. [9].

Important indicators of plant phenology in hydroponics are the number of days spent in the germination chamber, the nursery and the cultivation (main) compartment, as well as the entire growing period. Comparison between the phases of development of the main leaf vegetables in case of vertical and horizontal practices at the units of ‘TPK-Agrokultura’ LLC, ‘Greenhouse Technologies of Kazakhstan’ LLP and at the Cerera experimental unit (‘Siberian Klondike’ Company Group LLC and Omsk State Agrarian University) is presented in Table 2.

TABLE II. DEVELOPMENT STAGES OF MAIN LEAF VEGETABLES IN VERTICAL AND HORIZONTAL HYDROPONIC UNITS

| Crop type | Greenhouse complex and cultivation practice |  |                   |                                    |  |                   |                                    |  |                   |
|-----------|---|--|-------------------|------------------------------------|--|-------------------|------------------------------------|--|-------------------|
|           | 'TPK-Agrokultura' LLC (horizontal)          | 'Greenhouse technologies of Kazakhstan' LLC (horizontal) | Cerera (vertical) | 'TPK-Agrokultura' LLC (horizontal) | 'Greenhouse technologies of Kazakhstan' LLC (horizontal) | Cerera (vertical) | 'TPK-Agrokultura' LLC (horizontal) | 'Greenhouse technologies of Kazakhstan' LLC (horizontal) | Cerera (vertical) |
|           | Plant development stages                    |  |                   |                                    |  |                   |                                    |  |                   |
|           | Germination chamber                         |  |                   | Nursery                            |  |                   | Cultivation (main) compartment     |  |                   |
| Lettuce   | 2   | 2-3  | -                 | 10                                 | 10   | 9                 | 18-20                              | 18-20  | 18                |
| Dill      | 4   | 2-3  | -                 | 12                                 | 10   | 11                | 22-28                              | 22-28  | 25-28             |
| Basil     | 3   | 3  | -                 | 10                                 | 5-10   | 9                 | 27-33                              | 25-35  | 23-33             |
| Arugula   | 5   | 2  | -                 | 10                                 | 5-10   | 10                | 21                                 | 21   | 20-22             |
| Parsley   | 6   | 4-6  | -                 | 12                                 | 12   | 13                | 36-40                              | 36-48  | 35-40             |

The reduction of the cultivation period and, accordingly, the harvesting of finished products depends on the time spent by plants in the compartments. All large greenhouse complexes are equipped with germination chambers, in which, depending on the crop, the seeds are kept from 2 to 6 days. The Cerera 1.0 unit does not provide for separate germination in its cycle, and immediately after sowing the cassettes are installed in the nursery (for preservation in the nursery, the climatic conditions are close to ideal as regards temperature, humidity and illumination), which practically does not affect the development of plants, since variation amounts to one single day. After the root system grows out of the net pot, the plants are moved to the cultivation compartment. For crops such as lettuce, dill and arugula, differences in cultivation time have not been observed among complexes. Parsley and basil are ready for sale 1-8 days earlier in case of a multilayer system. To sum up, the comparison of horizontal and vertical cultivation systems has shown that the plants go through development stages in accordance with the biological and genetic characteristics of the single crop, and there are practically no differences among complexes, except for parsley and basil.

It is important to notice not only the main phases of plant development, but also the entire cultivation period (tab. 3).

TABLE III. THE CULTIVATION PERIOD OF MAIN LEAF VEGETABLES IN VERTICAL AND HORIZONTAL HYDROPONIC UNITS, IN DAYS

| Crop type | Greenhouse complex and cultivation practice |  |                   |
|-----------|---|--|-------------------|
|           | 'TPK-Agrokultura' LLC (horizontal)          | 'Greenhouse technologies of Kazakhstan' LLC (horizontal) | Cerera (vertical) |
| Lettuce   | 30-32                                       | 30-33  | 27                |
| Dill      | 38-40                                       | 34-41  | 36-39             |
| Basil     | 40-46                                       | 35-48  | 32-42             |
| Arugula   | 36  | 33-38  | 30-32             |
| Parsley   | 54-58                                       | 52-64  | 48-53             |

Analyzing the cultivation of leaf vegetables on hydroponics, it can be noticed that lettuce needs from 30 to 33 days for harvesting in horizontal systems and about 27 days in vertical ones. As regards dill, its cultivation does not significantly differ in relation to the unit type and amounts to 34-41 days, while basil revealed quite a wide specter of cultivation both in different units and within complexes ranging from 32 to 48 days, which indicates the reaction of plants to the influence of changes in microclimate and nutrient solution. When analyzing the cultivation periods of arugula and parsley, it should be noticed that harvesting occurs 6-9 days earlier in the vertical unit of the experimental container, which allows adding one or two complete cycles over the year.

### C. Yielding capacity

The main goal of studying and implementing advanced practices is to increase the production of quality vegetable products. The yielding capacity of the main leaf vegetables in the complexes and units at study is presented in Table 4.

TABLE IV. YIELDING ELEMENTS OF MAIN LEAF VEGETABLES IN VERTICAL AND HORIZONTAL HYDROPONIC UNITS

| Greenhouse complex and cultivation practice | 'TPK-Agrokultura' LLC (horizontal) | 'Greenhouse Technologies of Kazakhstan' LLP (horizontal) | Cerera (vertical) | 'TPK-Agrokultura' LLC (horizontal)    | 'Greenhouse Technologies of Kazakhstan' LLP (horizontal) | Cerera (vertical) | 'TPK-Agrokultura' LLC (horizontal)              | 'Greenhouse Technologies of Kazakhstan' LLP (horizontal) | Cerera (vertical) |
|---|------------------------------------|--|-------------------|---------------------------------------|--|-------------------|---|--|-------------------|
| Plant development periods                   | Arrangement, pcs/m <sup>2</sup>    |  |                   | Weight of 1 plant with the net pot, g |  |                   | Yielding capacity, kg/m <sup>2</sup> (per year) |  |                   |
| Lettuce                                     | 32                                 | 32   | 50                | 200-220                               | 200-220  | 180-200           | 76.8  | 76.8   | 120.0             |
| Dill  | 60-64                              | 60-64  | 200               | 100-140                               | 100-140  | 100-120           | 54.0  | 54.0   | 180.0             |
| Basil                                       | 60-64                              | 60-64  | 144               | 100-140                               | 100-140  | 110-120           | 48.0  | 48.0   | 115.2             |
| Arugula                                     | 60-64                              | 60-64  | 144               | 100-140                               | 100-140  | 110-120           | 60.0  | 60.0   | 158.4             |
| Parsley                                     | 60-64                              | 60-64  | 200               | 100-140                               | 100-140  | 110-120           | 36.0  | 36.0   | 140.0             |

By observing optimal microclimate parameters in greenhouse complexes, a stable yield of quality products is obtained. The yielding capacity depends on the weight and number of plants over a specific surface. 'TPK-Agrokultura' LLC and 'Greenhouse Technologies of Kazakhstan' LLC adhere to the generally accepted practice and subsequently the standard arrangement of plants per  $m^2$ . The weight of each plant with its pot is regulated by normative acts, so it is not advisable to increase this parameter. Thanks to the multilayer placement of plants and subsequently the sufficient illumination of each tier, the Cerera 1.0 container unit reduces the area occupied by 1 plant and increases the number of net pots by 2-3 times; as a result, the yielding capacity has proportionally increased.

Thus, based on the data in Table 4, it can be noticed that the yield of lettuce with classical horizontal practices amounts to  $76.8 \text{ kg/m}^2$ , for dill – to  $54.0 \text{ kg/m}^2$ , for basil –  $48.0 \text{ kg/m}^2$ , for arugula –  $60 \text{ kg/m}^2$ , for parsley –  $36 \text{ kg/m}^2$ , while in multilayer systems, for lettuce –  $120.0 \text{ kg/m}^2$ , for dill –  $180.0 \text{ kg/m}^2$ , for basil –  $115.2 \text{ kg/m}^2$ , for arugula –  $158.4 \text{ kg/m}^2$ , for parsley –  $140 \text{ kg/m}^2$ , which is 2–3 times higher than in horizontal cultivation.

#### V. PRACTICAL SIGNIFICANCE

In order to increase the output of high-quality, environmentally friendly leaf vegetables without expanding the surface under the conditions of greenhouse complexes, it is recommended that the racks be gradually converted to multilayer units.

#### VI. CONCLUSION

When comparing horizontal and vertical practices, it should be noticed that plants go through different development stages in accordance with their biological and genetic characteristics and practically do not differ in the time spent in the growing compartments. In general, over the entire cycle of leaf vegetables production, it can be noticed that lettuce needs from 30 to 33 days for harvesting in horizontal units and about 27 days in a vertical one. As regards dill, its cultivation does not significantly differ in relation to the unit type and amounts to 34-41 days, while basil revealed quite a wide specter of cultivation both in different units and within complexes, which indicates the reaction of plants to the influence of changes in microclimate and nutrient solution.

When analyzing the periods of arugula and parsley, it should be noticed that harvesting occurs 6-9 days faster in a vertical unit in an experimental container, which allows adding one or two more complete cycles over the year.

Thanks to the multilayer placement of plants and subsequently the sufficient illumination of each tier, the Cerera 1.0 container unit reduces the area occupied by 1 plant and increases the number of net pots by 2-3 times; as a result, the yielding capacity is proportionally increased as well.

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