Onion yield and its dependence on plant density in vegetable crop rotations on Ergenin Upland chestnut soils

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Abstracts. The years of experiment were from 2016..2020 in a farm on the Ergenin Upland chestnut soils in Volgograd region. The experiments were placed in five fields of vegetable crop rotation with the total area of 165 ha. During the presented period, a competitive test was carried out to identify the most productive samples of onions. The objects of the study were samples - the zoned variety Volgodonets (control variety) of domestic selection, hybrids of foreign selection Pandero F1, Benefit F1, Valero F1, Manas F1. It was found that hybrids give more than twice the yield over the control variety in almost all the variants. But the most optimal and more productive in all cases proved to be option No. 2 hybrid Benefit F1 with the parameters: the seeding rate of 1,000,000 pcs of seeds per hectare with viability of 97.31%, which provided for harvesting 973,100 plants per hectare and achieved a yield of 143.41 t/ha on average for repetitions in 2020. Thus, we can conclude that the seeding rate is 1,000,000 pcs of seeds per hectare in the conditions of chestnut soils of the Ergenin Upland is optimal in the conditions of the existing agricultural technology.

1. Introduction

The production of onions in our country is subject to the spontaneous laws of the market and often fluctuates to such volumes that the country sometimes sells tens of thousands of tons of surplus onions abroad, then buys it to meet the needs of the population with hundreds of thousands of tons from abroad. This destabilizes the food security of our state [1, 2, 3].

In our country, more than ten regions are engaged in the industrial production of onions for food purposes, but the Volgograd region is considered to be the leader, where this crop is grown, both on the right bank of the Volga River and in the Zavolzhje region. At the same time, almost everywhere onions are grown in vegetable crop rotations irrigated by the Volga water, and irrigation from the Don River and the Tsimlyansk reservoir is less significant [4, 5, 6].

The Volgograd region accounts for about 34% of all-Russian onion production. The Volgograd region onion growers, among other regions of our country, have passed through three stages in the evolution of this crop production, which are associated with the most labor-intensive process – the method of irrigation: 1) furrow irrigation with one hundred percent manual labor, which provided a yield of 15-20 t/ha. The sowing was carried out by a scattered method with a grain planter with a seeding rate
of 15-17 kg of seeds per hectare; 2) irrigation by sprinkling with sowing with grain seeders with sowing seeds through coulters to the depth of 1...2 cm with the seeding rate of 10-12 kg/ha. With this technology, partial mechanization has already been applied to harvesting operations – the KIK-1.5 mower was used for mowing the tops of onions and various diggers, including potato ones for extracting bulbs from the soil. Such technologies provided a yield of 35-40 t/ha; 3) irrigation with the use of drip irrigation systems with the introduction of mineral fertilizers and plant protection products from soil pests by fertigation [7, 8].

The introduction of drip irrigation systems in the vast expanses of both the south of Russia and the Volgograd region also had its own evolution, until technologies were introduced that provide a sufficiently reliable intensity of irrigation water supply to the plant [9, 10].

Drip irrigation and introduced cultivation technologies have opened a wide path for mechanized complexes, including the use of GPS-technologies for sowing [11, 12, 13]. Gone are the days when this crop was grown by "hectares", and the production of onions was an ungrateful "obligation", which attracted hundreds and thousands of citizens to weeding and harvesting this crop as day laborers.

As it was previously noted, different technologies of crop care also assumed different seeding rates: manual watering of 15-17 kg/ha, i.e. 2.5...3.0 million pieces of seeds per hectare, sprinkling irrigation of 10-12 kg/ha, i.e. 1.8...2.0 million pieces of seeds per hectare and irrigation through a drip irrigation system, provided accurate seeding in practice ranged from 0.5...1.5 million pieces of seeds per hectare. Such a variation in the seeding rates of onion growers was justified by different approaches, mainly related to saving money on the purchase of expensive seeds and, especially, foreign hybrids. As the practice of the first decade of the beginning of the 21st century showed, such savings on the purchase of seeds or, conversely, excessive costs, negatively affected the yield of onions and, accordingly, the profitability of its production.

2. Materials and methods
The experiment was placed in a five-field vegetable crop rotation with a total area of 165 ha with an average field size of 32 ± 3 ha. The crop rotation scheme included:
1 field - onion;
2 field - autumn fallow;
3 field - winter rye for grain;
4 field - winter rye for green manure;
5 field - "reclamation field".

A similar crop rotation scheme for the production of onion was determined back in the late 2000s. At the same time, taking into account the land use of the farm, about 1000 hectares, in parallel with the mentioned crop rotation, crop rotations with dominant crops - carrots, melons and gourds - are successfully used.

Our experience was laid on field No. 1, plot No. 4, in four repetitions with the following options for seeding rates: B1 - 1.1 million pcs/ha; B2 - 1.0 million pcs/ha; B3 - 0.9 million pcs/ha; B4 - 0.8 million pcs/ha; B5 - 0.7 million pcs/ha. In time, the experiment was divided into 2 stages according to the number of samples - varieties and hybrids of onions participating in the experiment. At the first stage 2011-2015 as the result of a competitive trial, one cultivar Volgodonets was selected as the control variety and two of the most productive hybrids, Pandero F1 and Benefit F1, with which the experiment was continued in the period 2016-2020.

Section 4 has a run length of 400 m, which are divided into 4 sections, 100 m each. Section 1 was assigned to us (this scheme was maintained throughout the years of the study). Taking into account that our experiment was carried out under conditions of nearby production crops, the selected variety and hybrids in all the variants were sown to the full length of the runs, i.e., 400 m.

One pass of the tractor along the centers of the impellers has a distance of 1.70 m. This is the width of the experimental section with four repetitions placed on it; the given accounting area is taken at 10.00 m² i.e. has the following parameters: the width is 1.70 m, the length is 5.88 m. The total area of 4 repetitions is 40.00 m² with a total length of counting sites of 23.52 m. The total area under one variant
is 120.00 m² (40.00 m² × 3); total area under the experiment of the 5 variants is 600.00 m² (120.00 m² × 5). The sowing was carried out by a twelve-row seeder on the prepared arable land, plowed in the fall of the previous year, "reclamation field" to the depth of 0.22...0.25 m. The seeds are sown in the process lane of 1.30 m wide by a twelve-row seeder. It should be noted that from the given seeding rates for harvesting, not all plants survived for various reasons, which is reflected in the corresponding Tables 1, 2, 3, that is, the safety ranged from 94.17% to 97.21% for options and samples. For the processing of samples, we used Dospekho’s experimental field plots [14], as well as scientific publications of Russian scientists on the topic under discussion.

The aim of the study was to experimentally prove the effect of the optimal seeding rates levels on the yield of onions on the chestnut soils of the Ergenin Upland, which ensure maximum productivity with the existing technologies of soil preparation, sowing, and plant care.

3. Results and discussion
In the course of this work, we made an attempt to experimentally prove the influence of the levels of optimal seeding rates for onion seeds on chestnut soils, which ensure maximum productivity with the existing technologies [2], soil preparation, sowing, plant care. For this, many years of experience from 2016...2020 were laid in the farm on land holdings in the Gorodishchensky district of the Volgograd region.

Land management of the farm was implemented 35-40 years ago, even during the period of widely used public production, the fields were surrounded by forest belts, and with the launch of the Gorodishchenskaya irrigation system, a wide network of metal pipelines was placed in the fields, which in the past served as water conduits for sprinkling, and now successfully are used as main and field pipelines that ensure the operation of drip irrigation systems.

Consider the indicators obtained during the observation period a significant difference in the yield data between the control variety Volgodonets and two hybrids Pandero F₁ and Benefit F₁ was noted. So, the control variant during the observations in 2016...2020 practically did not differ in the yields obtained, and the excess or decrease in yields is tied, rather, to such a concept as a "favorable or not favorable" year for growing a particular crop, including onions. So, in option 1, the average yield of the Volgodonets variety in 2016 was 67.18 t/ha, and in 2020 - 66.83 t/ha, i.e., the difference was 0.35 t/ha, while Lowest Significant Difference (LSDₜₜ) was 3.34 t/ha. The difference in yield between option 1 and option 2 is more voluminous and amounted to 5.91 t/ha in 2016 with LSDₜₜ of 3.65 t/ha, and in 2020 the difference was already 7.26 t/ha, at LSDₜₜ of 3.70 t/ha. If we compare the indicators of option 2 with option 4 and 5, then the difference in the direction of reducing the yield was even more significant and amounted to 14.02 t/ha in 2016 (between options 2 and 5), and in 2020 - 14.72 t/ha at LSDₜₜ according to options 3.33 t/ha and 3.34t/ha, respectively.

Summing up the results of five-year studies of the relationship between the number of sown seeds, preserved plants for harvesting and safety in percents, we note that over the years, regardless of the seeding rates [3, 6, 10], the yield of the Volgodonets variety (Table 1) is practically stable and, apparently, the maximum, since the variety, most likely, has exhausted its biological potential for yield growth [4, 7, 8], but it actively responds to the dynamics of crop density. Thus, the variety significantly reduced the yield at the planting density of 1,100,000 pcs of seeds per hectare; provided the maximum yield at the crop density of 1,000,000 pieces of seeds per hectare and showed a noticeable decrease in yield with the decrease in the density of crops, as evidenced by the data of mathematical analysis.
Table 1. Dependence of yield on plant Volgodonets varieties density.

| Number of seeds, plants | Safety, % | Repetition | Productivity, t/ha |
|-------------------------|-----------|------------|-------------------|
|                         | sowing, pcs/ha | harvesting, pcs/ha | 2016 | 2017 | 2018 | 2019 | 2020 |
| 1,100,000               | 1,042,910   | 94.81      | 1   | 67.07 | 70.54 | 71.34 | 64.62 | 67.60 |
|                         |            |            | 2   | 66.98 | 68.07 | 71.13 | 65.19 | 66.71 |
|                         |            |            | 3   | 66.54 | 70.31 | 72.27 | 64.54 | 65.93 |
|                         |            |            | 4   | 68.13 | 68.72 | 70.54 | 66.01 | 67.08 |
| Average                 |            |            |     | 67.18 | 69.41 | 71.32 | 65.09 | 66.83 |
| LSD05                  |            |            |     | 3.36 | 3.47 | 3.57 | 3.45 | 3.34 |
| 1,000,000               | 967,200    | 96.72      | 1   | 73.19 | 75.13 | 81.70 | 71.15 | 73.74 |
|                         |            |            | 2   | 72.91 | 74.98 | 82.09 | 72.21 | 73.81 |
|                         |            |            | 3   | 72.09 | 76.32 | 81.82 | 73.49 | 73.64 |
|                         |            |            | 4   | 74.17 | 74.41 | 83.07 | 71.63 | 75.17 |
| Average                 |            |            |     | 73.09 | 75.21 | 82.17 | 72.12 | 74.09 |
| LSD05                  |            |            |     | 3.65 | 3.76 | 4.11 | 3.61 | 3.70 |
| 900,000                 | 869,670    | 96.63      | 1   | 70.45 | 73.41 | 80.25 | 68.55 | 71.70 |
|                         |            |            | 2   | 71.44 | 73.37 | 78.41 | 68.32 | 70.97 |
|                         |            |            | 3   | 72.18 | 72.83 | 77.18 | 67.49 | 70.48 |
|                         |            |            | 4   | 70.41 | 74.07 | 80.64 | 69.32 | 72.09 |
| Average                 |            |            |     | 71.12 | 73.42 | 78.97 | 68.42 | 71.31 |
| LSD05                  |            |            |     | 3.56 | 3.67 | 3.95 | 3.42 | 3.57 |
| 800,000                 | 772,160    | 96.52      | 1   | 62.49 | 66.45 | 70.42 | 60.68 | 62.99 |
|                         |            |            | 2   | 61.97 | 67.21 | 69.04 | 59.72 | 61.83 |
|                         |            |            | 3   | 63.07 | 66.39 | 67.19 | 58.91 | 62.17 |
|                         |            |            | 4   | 61.83 | 68.03 | 69.23 | 60.17 | 61.37 |
| Average                 |            |            |     | 62.34 | 67.02 | 68.97 | 59.87 | 62.09 |
| LSD05                  |            |            |     | 3.12 | 3.35 | 3.45 | 2.99 | 3.10 |
| 700,000                 | 667,170    | 95.31      | 1   | 58.67 | 60.87 | 64.83 | 59.31 | 59.60 |
|                         |            |            | 2   | 59.13 | 61.82 | 63.79 | 58.17 | 59.18 |
|                         |            |            | 3   | 58.17 | 60.18 | 62.87 | 57.61 | 58.63 |
|                         |            |            | 4   | 60.31 | 62.41 | 64.07 | 59.43 | 60.07 |
| Average                 |            |            |     | 59.07 | 61.32 | 63.89 | 58.13 | 59.37 |
| LSD05                  |            |            |     | 2.95 | 3.07 | 3.19 | 2.91 | 2.97 |

By variants: LSD05 3.33, 3.46, 3.95, 3.24, 3.34

Hybrid Padero F1 was markedly different from its productive Volgodonets varieties. Over the years of the study, the increase in yield for option 1 was 115.34%, for option 2 - 121.10%, and even in options 3...5 there is a slight increase in yield over the years (Table 2). This suggests that the Padero F1 hybrid responds with the increase in yield to the increase in the general crop culture in the studied area, and to the increasing perfection of plant protection from weeds, diseases and pests. However, hybrid Padero F1 reacts sharply to one or another seed rate and the viability of plants for harvesting. In option 1 in 2016, the seeding rate the increase to 1100000 pcs of seeds per hectare led to a drop in yield of 10.90 t/ha compared to 1000000 pcs of seeds per hectare at LSD05 of 4.56 t/ha, and in 2020 this gap was already 17.81 t/ha at LSD05 of 5.51 t/ha. The decrease in the density of crops in options 3...5 has an even more detrimental effect on the yield, which systematically decreases and reached a fall in 2016 - between options 2 and 5 - 26.96 t/ha at LSD05 of 3.88 t/ha and even 40.09 t/ha in 2020 at LSD05 of 4.43 t/ha.
### Table 2. Dependence of yield on hybrid Pandero F<sub>1</sub> plant density.

| Number of seeds, plants | Viability, % | Repetition | Productivity, t/ha |
|-------------------------|--------------|------------|-------------------|
| sowing, pcs/ha | harvesting, pcs/ha | 2016 | 2017 | 2018 | 2019 | 2020 |
| 1,100,000 | 1,035,870 | 94.17 | 1 | 79.61 | 91.97 | 91.41 | 89.80 | 91.71 |
| 2 | 79.91 | 89.83 | 88.67 | 92.03 | 92.81 |
| 3 | 79.43 | 90.13 | 87.49 | 90.71 | 93.07 |
| 4 | 81.17 | 91.07 | 90.07 | 92.14 | 91.65 |
| Average | 80.03 | 90.75 | 89.41 | 91.17 | 92.31 |
| LSD<sub>0.05</sub> | 4.00 | 4.54 | 4.47 | 4.56 | 4.62 |
| 1,000,000 | 972,100 | 97.21 | 1 | 92.45 | 111.28 | 106.06 | 108.82 | 110.13 |
| 2 | 90.41 | 109.19 | 104.01 | 108.13 | 108.97 |
| 3 | 89.73 | 108.64 | 102.83 | 106.32 | 109.21 |
| 4 | 91.13 | 110.17 | 104.06 | 108.09 | 112.17 |
| Average | 90.93 | 109.82 | 103.71 | 107.84 | 110.12 |
| LSD<sub>0.05</sub> | 4.56 | 5.49 | 5.19 | 5.39 | 5.51 |
| 900,000 | 864,630 | 96.07 | 1 | 82.95 | 90.97 | 90.01 | 91.06 | 94.13 |
| 2 | 82.19 | 89.73 | 88.93 | 90.87 | 92.67 |
| 3 | 83.61 | 88.18 | 88.61 | 90.04 | 91.85 |
| 4 | 81.17 | 91.32 | 90.09 | 92.31 | 93.07 |
| Average | 82.48 | 90.05 | 89.41 | 91.07 | 92.93 |
| LSD<sub>0.05</sub> | 4.12 | 4.50 | 4.47 | 4.55 | 4.65 |
| 800,000 | 765,040 | 95.63 | 1 | 70.26 | 69.58 | 70.55 | 74.81 | 77.28 |
| 2 | 69.79 | 69.13 | 73.11 | 75.07 | 78.42 |
| 3 | 69.48 | 68.73 | 71.39 | 74.67 | 77.83 |
| 4 | 71.31 | 70.04 | 73.07 | 73.09 | 79.31 |
| Average | 70.21 | 69.37 | 72.03 | 74.41 | 78.21 |
| LSD<sub>0.05</sub> | 3.51 | 3.47 | 3.60 | 3.72 | 3.91 |
| 700,000 | 660,870 | 94.41 | 1 | 64.69 | 64.34 | 65.93 | 67.59 | 70.61 |
| 2 | 64.11 | 64.91 | 65.04 | 68.31 | 70.32 |
| 3 | 63.01 | 64.83 | 63.78 | 67.81 | 69.87 |
| 4 | 64.07 | 66.12 | 65.13 | 69.13 | 69.32 |
| Average | 63.97 | 65.05 | 64.97 | 68.21 | 70.03 |
| LSD<sub>0.05</sub> | 3.20 | 3.25 | 3.25 | 3.41 | 3.50 |
| By variants: LSD<sub>0.05</sub> | 3.88 | 4.25 | 4.19 | 4.33 | 4.43 |

Hybrid Benefit F<sub>1</sub> for all the years of research and during the period of competitive trials in 2011...2015 and the period of setting the experiment in 2016...2020 showed the highest yield in experiments, which in 2020 reached 143.41 t/ha at the sowing density of 1,000,000 pieces of seeds per hectare. It should be noted that for all the variants of plant density (option 1...5), there is a noticeable increase in yield over the years, which was 107.43% in option 1, 118.12% in option 2, and fluctuated in options 3...5 from 133.99% to 126.83%. At the same time, the decrease in the yield in 2016 in option 5 compared to option 2 amounted to 63.09 t/ha, i.e., more than a twofold drop in yield. The same tendency continued in 2020: the drop in yield amounted to 69.44 t/ha with LSD<sub>0.05</sub> of 5.49 t/ha.
Table 3. Dependence of yield on hybrid Benefit F₁ plant density.

| Number of seeds, plants | Viability, % | Repetition | Productivity, t/ha |
|-------------------------|-------------|------------|--------------------|
| sowing, pcs/ha          | harvesting, pcs/ha | 2016 | 2017 | 2018 | 2019 | 2020 |
| 1,100,000               | 1,043,020   | 94.82     | 111.01            | 110.75            | 115.15            | 117.26            | 118.69            |
|                         |             |           | 2                   | 107.82            | 112.11            | 113.41            | 114.97            | 115.89            |
|                         |             |           | 3                   | 107.69            | 110.31            | 111.87            | 114.89            | 116.61            |
|                         |             |           | 4                   | 110.32            | 112.07            | 114.09            | 116.12            | 118.09            |
| Average                 |             |           | LSD₆₅              | 5.46              | 5.57              | 5.68              | 5.79              | 5.87              |
| 1,000,000               | 973,100     | 97.31     | 1                   | 120.59            | 128.27            | 134.70            | 136.31            | 143.75            |
|                         |             |           | 2                   | 121.91            | 126.87            | 130.91            | 135.41            | 143.21            |
|                         |             |           | 3                   | 120.83            | 126.64            | 130.18            | 136.75            | 142.61            |
|                         |             |           | 4                   | 122.31            | 128.13            | 132.09            | 135.81            | 144.07            |
| Average                 |             |           | LSD₆₅              | 6.07              | 6.37              | 6.59              | 6.80              | 7.17              |
| 900,000                 | 868,400     | 96.49     | 1                   | 96.67             | 100.45            | 112.99            | 130.80            |
|                         |             |           | 2                   | 96.83             | 97.63             | 102.89            | 112.09            | 129.73            |
|                         |             |           | 3                   | 96.47             | 98.17             | 102.32            | 110.97            | 128.64            |
|                         |             |           | 4                   | 98.31             | 99.07             | 104.12            | 112.63            | 131.11            |
| Average                 |             |           | LSD₆₅              | 4.85              | 4.94              | 5.16              | 5.61              | 6.50              |
| 800,000                 | 769,040     | 96.18     | 1                   | 70.26             | 74.39             | 81.58             | 81.54             | 83.23             |
|                         |             |           | 2                   | 69.21             | 75.09             | 75.98             | 80.87             | 85.07             |
|                         |             |           | 3                   | 68.37             | 74.63             | 75.69             | 80.31             | 84.59             |
|                         |             |           | 4                   | 70.04             | 75.13             | 78.07             | 82.12             | 83.67             |
| Average                 |             |           | LSD₆₅              | 3.47              | 3.74              | 3.89              | 4.06              | 4.21              |
| 700,000                 | 670,010     | 95.73     | 1                   | 57.67             | 62.54             | 65.03             | 70.23             | 74.43             |
|                         |             |           | 2                   | 58.47             | 62.04             | 64.81             | 70.91             | 74.08             |
|                         |             |           | 3                   | 57.73             | 62.31             | 64.41             | 70.83             | 74.31             |
|                         |             |           | 4                   | 59.41             | 61.39             | 65.07             | 72.31             | 73.06             |
| Average                 |             |           | LSD₆₅              | 5.32              | 3.10              | 3.24              | 3.55              | 3.71              |

By variants: LSD₆₅ 4.56 4.75 4.91 5.16 5.49

4. Conclusion

It was revealed that the hybrids give an excess of yield over the variety by more than two times in almost all the variants, comparing the results of the experiment on the example of the Pandero F₁ and Benefit F₁ hybrids with the achieved indicators of the Volgodonets variety. But the most optimal and most productive in all cases proved to be option No. 2 hybrid Benefit F₁ with a seeding rate of 1,000,000 pieces of seeds per hectare with 97.31% viability, which provided 973100 seeds for harvesting plants per hectare and the achieved yield of 143.41 t/ha on average for repetitions in 2020. Thus, we can conclude that the seeding rate of 1,000,000 pieces of seeds per hectare under the conditions of the chestnut soils of the Ergenin Upland is optimal under the conditions of the existing agricultural technology, both for the commodity producer and during the experiment on the experimental field.
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