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Influence of fertilization regime on yield and quality of carrot (*Daucus carot*a L.) seeds

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Abstract

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The main aim of the present study was to determine the effect of different fertilization regimes on the yield and quality of carrot seeds. The experiments were conducted with the Tushon variety. The seed plants were grown using standard technology through stecklings. Three levels of NPK were tested, as follows N – 0, 50, 70, 90 kg.ha^{-1}, P – 0, 90, 140, 190 kg.ha^{-1} and K – 0, 100, 150, 200 kg.ha^{-1}, applied once and twice. The yield from different variants, seed germination and germination was established. The highest yields were found to occur with a once application of $N_{90}P_{90}K_{200}$ and twice fertilization with $N_{90}P_{90}K_{100}$. The better quality of seeds was established after once application of $N_{90}P_{90}K_{200}$ and twice one with $N_{50}P_{190}K_{100}$. From the two-factor analysis the strongest influence to the seed production has the factor fertilization. The polynomial regressions between evenly increasing levels in once and twice fertilization and yield on the one hand and germination on the other were found with high determination coefficient, for productivity $R^2 = 0.994$ and $R^2 = 0.808$ and for germination $R^2 = 0.833$ and $R^2 = 0.690$, for once and twice fertilization, respectively.

Keywords: seed production; yield; germination; two-way analysis of variance; regression

Introduction

Vegetable seed production is carried out under a strictly defined cultivation technology. The main element in it is the observance of the optimal nutrient regime. Both, the yield and the quality status of the reproduced seeds depend on the proper nutrition of the plants, and hence of the seeds. The deterioration of the nutrient reserve affects not only the number and size of the obtained seeds but also affects their vitality (Panayotov, 2005). According to Copeland & McDonalds (2001) fertilization with phosphorus is of particular importance for better seed formation with improved quality.

Applying of different fertilization levels with N – 0, 40, 60 and 80 kg.ha^{-1} and with P_2O_5 – 0, 20, 40 and 60 kg.ha^{-1} Ravinder & Kanwar (2002) indicate that the development of carrots seed plants, as well as seed yields, are significantly improved by increasing the amount of the fertilizers. The highest seed yield was reported in the application of N 80 kg.ha^{-1} and P 60 kg.ha^{-1} – 1527 kg.ha^{-1} and 1165 kg.ha^{-1}, respectively. Ahmed & Tanki (1989) also report of a similar conclusion, pointing out that the increase in N increases the seed yield of carrots. According to the authors, however, phosphorus has less influence on the amount of seed production.

Hooda et al. (2014) tested three fertilizer levels (60:30:30; 80:40:40; and 100: 50: 50 N: P: K kg.ha^{-1}) and established that the seed yields increased significantly at the high fertilizer rate – $N_{100}P_{50}K_{50}$. This combination also improves the seed quality and better germination energy and germination are observed. The researchers reported that the increase in seed yield at the highest fertilizer rate is due to the better growth of the plants, as well as the better development of the central umbel and the higher number of first and secondary umbels.

Studies by Kushwaha (2009) also indicate that by increasing the amount of nitrogen from 0 to 100 kg.ha^{-1}, seed yield increases, reaching its maximum at the highest fertilizer rate of 100 kg.ha^{-1}. Stepuro (2008) concludes that the highest carrot seed yield is obtained with the application of $N_{45}P_{55}K_{75}$ and $N_{55}P_{65}K_{90}$ kg.ha^{-1}, both with and without prior application of manure at a dose of 30 t.ha^{-1}. This productivity reached between 970 and 1000 kg.ha^{-1}. According to Rao & Maurya (1998) also the fertilizing with higher nitrogen and phosphorus increases carrot seed yield and seed quality.

The main aims of the study were on the one hand to investigate the influence of fertilization methods (once or twice application) with different rates of nitrogen, phosphorus and potassium on the yield and quality of seed production in carrots and on the other through a mathematical approach to analyze the significance and strength of the influence of the factors "fertilization regime and levels" and "year" on the yield of carrot seeds, as well as to establish the regression models that express dependences between fertilization levels and productivity.

Material and Methods

The experiments were carried out during the period 2017-2019 in the Experimental field and Laboratory of the Department of Horticulture at the Agricultural University-Plovdiv, Bulgaria. The Tushon carrots variety was used for caring out of these experiments. The standard, well-established technology for Bulgaria through steklings (Murtazov et al., 1984) for seed production of carrot was done. The sowing of the seeds for steklings production was done at the end of June and harvesting was in the middle of November. The steklings were placed in a pit for storage during the winter. The steklings were planted in the middle of March on furrows by the scheme 80 x 30 cm. Each variant is presented in four replicates with a plot size of 7 m^2 and a yield establishing area of 6 m^2 (Barov, 1982). Soil preparation involves deep autumn plowing and profiling of the furrows in spring.

Two regimes of fertilization were investigated: 1. Once fertilization by applying all the amount of phosphorus and potassium fertilizers in the autumn before deep plowing and nitrogen during planting; 2. Twice fertilization – half of the phosphorus and potassium fertilizers are applied before the autumn deep plowing, the other half in spring before planting, and the nitrogen fertilizer – half before planting and the other part during the growing season at the beginning of flowering. The following variants with different terms and fertilization levels in kg.ha^{-1} were studied: Once fertilization: 1.$N_0P_0K_0$ (control); 2.$N_{70}P_{140}K_{150}$ (recommended); 3.$N_{50}P_{90}K_{100}$; 4.$N_{50}P_{90}K_{200}$; 5.$N_{50}P_{190}K_{100}$; 6.$N_{50}P_{190}K_{200}$; 7.$N_{90}P_{90}K_{100}$; 8.$N_{90}P_{90}K_{200}$; 9.$N_{90}P_{190}K_{100}$; 10.$N_{90}P_{190}K_{200}$ and twice fertilization: 11.$N_{50}P_{90}K_{100}$; 12.$N_{50}P_{90}K_{200}$; 13.$N_{50}P_{190}K_{100}$; 14.$N_{50}P_{190}K_{200}$; 15.$N_{90}P_{90}K_{100}$; 16.$N_{90}P_{90}K_{200}$; 17.$N_{90}P_{190}K_{100}$; 18.$N_{90}P_{190}K_{200}$. The application of different fertilizer levels was arranged according to the recommended fertilization of carrot seed production by Madzharova (1968) and Kolev et al. (1977).

The following fertilizers were used: ammonium nitrate (N 34%), triple superphosphate (P_2O_5 46%) and potassium sulfate (K_2O 50%). During the growing season, all the necessary agrotechnological practices for the normal development of seed plants were conducted. Harvesting of the seed stalks was performed when 60-70% of the seeds were in the ripening stage and the rest were in waxy maturity. After harvest, the plants were placed for 10 days post-harvest maturation of the seeds. The seeds from the umbels of the individual orders – central I, II and III were extracted separately, after which the seed yield for the tested variants was determined. Germination energy and seed germination were determined according to the requirements of ISTA (2013).

The study data were analyzed for variance and the least significant differences between the variants (ANOVA) were calculated using the Fisher test at p = 0.05 and also for regression analysis. These methods are described in Fowel & Cohen (1992)

The obtained experimental data for the yield were statistically processed by computer software MS Excel. The assessment of the strength of the influence of factors was calculated by the method of Plohinski (Lakin, 1980). It is defined as part of the intergroup variation in the total variation. The sum of the squares was applied and calculates by the formula:

$$h_x^2 = \frac{D_x}{D_y},$$

where D_x – sum of the squares of the factor *x*, D_y – total sum of squares (SS). The influence of both the factor of fertilization with mineral fertilizers and the year and their interaction on the carrot seeds productivity has been established.

Results and Discussion

The fertilization regime has a significant effect on the seed yield of carrots. Panayotov (2005) also points out that mineral nutrition is very important about the increasing of the carrot seeds yield. Some differences between experimental years were established. In 2017 the highest yield (Table 1) was obtained from the plants by once fertilization with $N_{90}P_{90}K_{200}$ – 774.90 kg.ha^{-1} , which is 38.7% more than the not fertilized control and 27.2% of the recommended one. In twice fertilization with the highest yield is distinguished the variant $N_{90}P_{90}K_{100}$ – 796.76 kg.ha^{-1}. The differences here are higher compared to the fertilized and non-fertilized controls, 42.6% and 30.8%, respectively. Twice application of $N_{50}P_{190}K_{100}$ results in maximum seed yield in the second year – 808.50 kg.ha^{-1}. With the once application of fertilizers the highest seed productivity from 756.48 kg.ha^{-1} was established for the $N_{90}P_{90}K_{200}$. The difference between the best variants ($N_{50}P_{190}K_{100}$ and $N_{90}P_{90}K_{200}$) for the two types of application is 52.02 kg.ha^{-1} or 6.88% more for the combination of twice regime. The highest seed yield in 2019 was obtained from plants fertilized twice with $N_{90}P_{90}K_{100}$ – 781.96 kg.ha^{-1}. In the first fertilization period, the highest yields were reported for variants $N_{90}P_{190}K_{100}$ and $N_{90}P_{90}K_{200}$, 746.12 kg.ha^{-1} and 708.00 kg.ha^{-1}, respectively. In most of the variants, the differences are with statistical significance.

Throughout the whole study period, the average seed yield was highest in the variant $N_{90}P_{90}K_{100}$ twice fertilization – 786.19 kg.ha^{-1}. The differences between the two fertilizer regimes are small. There are contradictory views about the effect of nitrogen on carrot seed production. Szafirowska et al. (1996) emphasizing that these fertilizers have a weaker effect while according Satyaveer et al. (1994) by increasing nitrogen fertilization the productivity of carrot seeds as well as their quality also increase. In implement these experiments, it may be noted that combining the higher levels of N with P_{90-190} and $K_{100-200}$ is essential for obtaining higher seed production, which corresponds with the results of other studies (Ravinder & Kanwar, 2002; Hooda et al., 2014).

The influence of the factors year, fertilization regime and their interaction on the indicator “yield” is established. The analysis of variance is considered at different levels and regimes of fertilization: once, twice and

Table 1.Effect of fertilization regime on the seed yield of carrot, kg.ha^{-1}

Variant	2017	2018	2019	Average
Once fertilization				
1.$N_0P_0K_0$ (control)	558.62	595.72	572.48	575.60
2.$N_{70}P_{140}K_{150}$ (recomended)	608.88	627.72	618.64	618.41
3.$N_{50}P_{90}K_{100}$	622.66	639.50	622.76	628.30
4.$N_{50}P_{90}K_{200}$	671.62	682.00	644.62	666.08
5.$N_{50}P_{190}K_{100}$	701.24	668.00	683.56	684.26
6.$N_{50}P_{190}K_{200}$	653.70	704.00	664.24	673.98
7.$N_{90}P_{90}K_{100}$	647.74	650.36	631.00	643.03
8.$N_{90}P_{90}K_{200}$	774.90	756.48	708.00	746.46
9.$N_{90}P_{190}K_{100}$	629.66	682.58	746.12	686.12
10.$N_{90}P_{190}K_{200}$	662.88	640.00	658.72	653.86
Twice fertilization				
11.$N_{50}P_{90}K_{100}$	636.68	639.56	631.20	635.81
12.$N_{50}P_{90}K_{200}$	656.92	652.00	678.88	662.60
13.$N_{50}P_{190}K_{100}$	678.98	808.50	697.78	728.42
14.$N_{50}P_{190}K_{200}$	760.62	672.00	631.88	688.16
15.$N_{90}P_{90}K_{100}$	796.76	789.86	781.96	786.19
16.$N_{90}P_{90}K_{200}$	746.52	723.86	660.40	710.26
17.$N_{90}P_{190}K_{100}$	644.32	679.72	708.70	677.58
18.$N_{90}P_{190}K_{200}$	730.80	719.20	658.56	702.85

common to both regimes. From the obtained results for the indicator "total yield" in case of once fertilization the strongest influence of the factor (B) is observed – fertilization regime with dominant influence of 49% and clear reliability p≤0.001 on the change of the indicator. And the unexplained influence due to random factors (errors) is in second place with an influence of 40% (Table 2). The studied indicator "yield" in the regime of twice fertilization has the strongest influence of the interaction of the two factors (AxB) of 36% on the change of the indicator. In second place is again the influence of random factors with an influence of 43%, followed by the factor fertilization regime with an influence of 17% (Table 3). In case of once and twice fertilization for the indicator "yield" with a dominant influence of 42% is the factor fertilization (B) and with a clear reliability p≤0.001 on the change of the indicator. The interaction between the two factors (AxB) has an influence of 20%. The unexplained influence due to random factors is 37% (Table 4).

On the Figures 1 and 2 are shown the regression lines that reflect the changes in seed productivity of carrots depending on the evenly increasing of fertilization levels. The correlation coefficient squared – R^2 (R Square) is called the coefficient of determination. It shows what percentage of the dispersion of the resultant variable is explained by the action of the factor variable. The regression is of polynomial type, as the determination coefficients are high $R^2 = 0.9946$ – for once fertilization and $R^2 = 0.8082$ – for twice the application of mineral fertilizers. This shows that in 99% and 80% of cases, respectively, depending on whether it is a once or twice fertilization, changes in the amount of mineral fertilizers will provoke the observed changes in the yield.

Seed quality is determined by several indicators, of which germination energy and germination are among the most important (Copeland & McDonald, 2001; Panayotov, 2015). The different nutrient regimes in which carrot seed plants are grown have a significant impact on the quality of the obtained seed (Table 5).

In the first two years, the germination energy of the seeds was highest in the once fertilization in $N_{90}P_{90}K_{200}$ – 82.66% and 78.66%, respectively. In comparison to the fertilizer control, the increase is by 18.08% and 20.04% respectively, while for not fertilization plants this difference is even higher, reaching to 37.76% and to 16.66%. The highest germination energy in 2019 distinguishes

Table 2. Two-factor analysis of variance of the factors: A – year and B – fertilization regime on seed yield (once fertilization)

ANOVA							Strength of influence
Source of Variation	SS	df	MS	F	P-value	F crit	
Year (A) n.s.	16.42	2	8.21	0.37	0.694	3.15	0%
Regime of fertlization (B)***	1646.21	9	182.91	8.18	0.000	2.04	49%
Interaction (AxB) n.s.	383.87	18	21.33	0.95	0.521	1.78	11%
Errors	1341.17	60	22.35				40%

***, **, * – proved respectively at p ≤ 0.001, p ≤ 0.01 и p ≤ 0.05; n.s. – unproven

Table 3. Two-factor analysis of variance of factors: A – year and B – fertilization regime on seed yield (twice fertilization)

ANOVA							Strength of influence
Source of Variation	SS	df	MS	F	P-value	F crit	
Year (A) n.s.	98.22	2	49.11	2.33	0.108	3.19	4%
Regime of fertlization (B)***	397.90	7	56.84	2.70	0.019	2.21	17%
Interaction (AxB) n.s.	835.53	14	59.68	2.84	0.004	1.90	36%
Errors	1009.70	48	21.04				43%

Table 4. Two-factor analysis of variance of the factors: A – year and B – fertilization regime on seed yield (once and twice fertilization (total)

ANOVA							Strength of influence
Source of Variation	SS	df	MS	F	P-value	F crit	
Year (A) n.s.	71.99	2	35.99	1.65	0.196	3.08	1%
Regime of fertlization (B)***	2665.38	17	156.79	7.20	0.000	1.72	42%
Interaction (AxB) n.s.	1262.06	34	37.12	1.71	0.021	1.54	20%
Errors	2350.87	108	21.77				37%

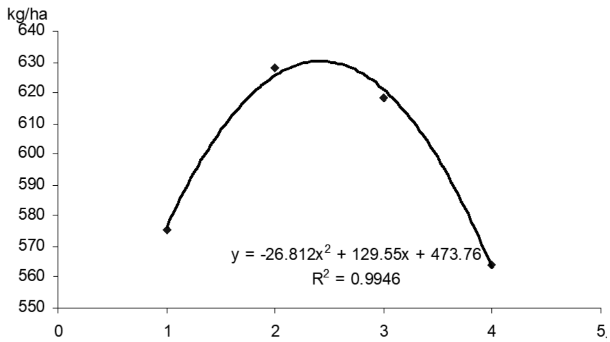

Fig. 1. Regression dependence between evenly increasing levels in once fertilization and yield (kg.ha-1) 1. $N_0P_0K_0$; 2. $N_{50}P_{90}K_{100}$; 3. $N_{70}P_{140}K_{150}$; 4. $N_{90}P_{190}K_{200}$

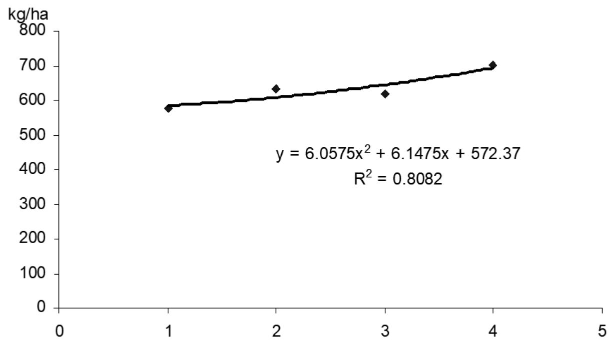

Fig. 2. Regression dependence between evenly increasing levels in twice fertilization and yield (kg.ha-1) 1. $N_0P_0K_0$; 2. $N_{50}P_{90}K_{100}$; 3. $N_{70}P_{140}K_{150}$; 4. $N_{90}P_{190}K_{200}$

Table 5. Effect of fertilization regime on the quality on carrot seed

Variant	Germination energy, %				Germination, %			
	2017	2018	2019	average	2017	2018	2019	average
Once fertilization								
1	60.00	62.00	55.66	59.22	60.00	63.33	59.33	60.88
2	70.00	65.33	58.33	64.55	71.33	70.00	62.33	67.88
3	64.00	63.33	60.66	62.66	72.66	74.00	62.00	69.55
4	73.33	66.00	68.33	69.22	76.66	69.33	73.33	73.10
5	72.00	66.00	67.33	68.44	72.66	70.00	68.66	70.44
6	64.00	66.66	70.00	66.88	68.00	72.00	71.33	70.44
7	60.66	56.00	68.66	61.77	72.66	72.66	71.33	72.21
8	82.66	78.66	75.33	78.88	84.66	80.00	78.00	80.88
9	75.33	74.66	72.00	73.99	78.00	78.66	73.33	76.66
10	61.33	64.00	65.33	63.55	65.33	72.00	67.33	68.22
Twice fertilization								
11	70.66	68.66	68.66	69.32	76.00	74.00	73.66	74.55
12	77.33	66.00	65.00	69.44	85.33	73.33	70.00	76.22
13	66.00	68.66	66.66	67.10	77.33	84.00	78.00	79.77
14	56.66	65.33	73.33	65.10	60.00	70.66	76.66	69.10
15	68.00	62.66	68.66	66.44	73.33	66.66	71.33	70.44
16	75.33	60.00	71.33	68.88	76.66	70.66	79.66	75.66
17	65.33	66.00	67.00	66.11	66.66	72.00	74.66	71.10
18	59.00	62.00	65.33	62.11	61.00	67.33	68.00	65.44
LSDp = 0.05	15.87	17.11	7.20	7.24	15.12	17.36	6.22	7.34

the seeds from the twice fertilization with $N_{50}P_{190}K_{200}$ – 73.33%.

In the first year of the experiment, the highest germination was established for the twice fertilization variant with $N_{50}P_{90}K_{200}$ – 85.33%. This, twice fertilization with different levels provokes an increase of seed germination in the other two years and it reaching maximum values in the combination $N_{50}P_{190}K_{100}$ – 84.00% and 78.00%, respectively for 2018 and 2019 and also it is the same in the last year for once fertilization with $N_{90}P_{90}K_{200}$ – 78.00%.

In once application average over the reporting period, the values of both indicators are maximum for $N_{90}P_{90}K_{200}$ – 78.88% about germination energy and 80.88% about germination. For twice fertilization, the $N_{50}P_{90}K_{200}$ combination determines the highest germination energy of the seeds – 69.44%, while for germination the highest values from 79.99% were established in $N_{50}P_{190}K_{100}$. The statistical significance of the differences between the variants compared

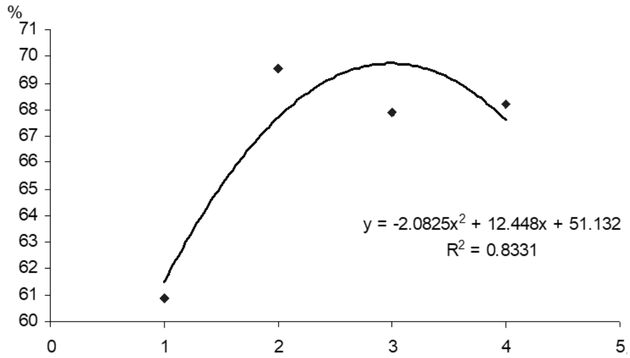

Fig. 3. Regression dependence between evenly increasing levels in once fertilization and germination (%) 1. $N_0P_0K_0$; 2. $N_{50}P_{90}K_{100}$; 3. $N_{70}P_{140}K_{150}$; 4. $N_{90}P_{190}K_{200}$

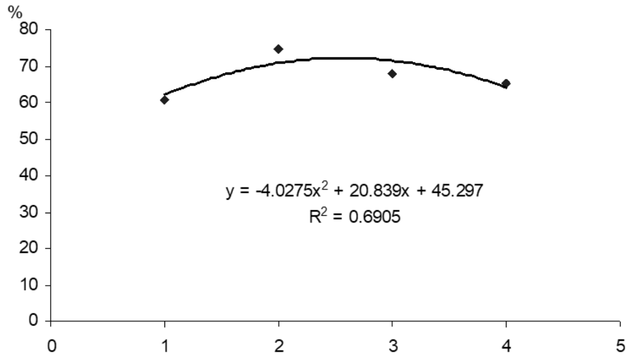

Fig. 4. Regression dependence between evenly increasing levels in twice fertilization and germination (%) 1. $N_0P_0K_0$; 2. $N_{50}P_{90}K_{100}$; 3. $N_{70}P_{140}K_{150}$; 4. $N_{90}P_{190}K_{200}$

to non- fertilized control was established. It can be summarized that the application of higher levels of P and K improves the vitality of carrot seeds. A similar conclusion is reached by Rao & Maurya (1998) and Hooda et al. (2014).

The regression dependences between uniformly increasing fertilization levels and the germination of carrot seeds are shown in Figures 3 and 4. They are also with a polynomial character, like for productivity. The coefficients of determination are again high, as for once application it is $R^2 = 0.8331$, and for twice fertilization, it is $R^2 = 0.6905$. It can be argued that in 83% and 69% of cases, respectively, in once and twice fertilization, changes in the amount of mineral fertilizers will lead to the founded trends of seed germination.

Conclusion

The different fertilizer levels as well as the term of their application are essential for the quantity and quality of carrot seed. The highest seed yield for each tested regimes and levels was established for twice fertilization with $N_{90}P_{90}K_{100}$ – 786.19 kg.ha^{-1} that is recommended to apply in practice. For once application it was observed in variant $N_{90}P_{90}K_{200}$ – 746.46 kg.ha^{-1}.

According to the two-factor analysis of variance the strongest influence on the variation of seed yield is exerted by the factor fertilization regime (49%) in case of once and total (once and twice) fertilization, while in case only of twice fertilization there is the interaction between them (36%). The dependence of the factor – year (A) on the considered indicator "yield" has not been statistically proven.

Applying higher levels of P_2O_5 and K_2O improves seed viability, with the highest germination energy and germination was counted at $N_{90}P_{90}K_{200}$ for once application and for twice one it was observed for $N_{90}P_{90}K_{200}$ and $N_{50}P_{190}K_{100}$.

The quantity and quality of carrots seed production in most of the investigated combinations increase after twice application of mineral fertilizers.

The established regression dependences, with a high coefficient of determination, itemized and confirmed the significant influence of the different regimes and evenly increasing levels of fertilization on the yield and quality of carrot seeds.

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