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Production Systems

Tolerance and own tolerance of wheat under conditions of permanent and long-term rotation

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Dobrudzha Agricultural Institute, 9520 General Toshevo, Bulgaria

Abstract. The investigations on the long-term growing of wheat without rotation as well as its two-field rotation with maize in Dobrudzha Agricultural Institute date back to 1957. In a stationary field trial carried out during 2011 – 2013, cultivar Enola was grown at planting density 500 germinating seeds/m². Four levels of nutrition regime were tested, which were formed by systematic introduction of the following fertilizer norms: N P K, N P K, N P K, N P K. The long-term growing of wheat in two-field crop rotation increased the productivity of the crop with 16.8% in comparison to its cultivation without rotation. The yield from cultivar Enola under long-term non-rotation growing was influenced to a much higher degree by the meteorological conditions of the year (1.6 times) as compared to two-field rotation with maize. The systematic mineral fertilization increased wheat productivity under the two forms of rotation. Under two-field crop rotation, the increase of yield according to the non-rotation growing was with 20.9%. Averaged for the investigated period, wheat had higher productivity after mineral fertilization with N P K (∑N:PK=1:0.8:0.5). The intensive nitrogen fertilization, even when preserving the ratio with the other main macro elements, led to lower productivity, especially of the wheat grown without rotation. The factor determining wheat productivity under two-field rotation was mineral fertilization; its strength of effect was 1.9 times higher than its effect on long-term growing without rotation. The meteorological conditions during wheat growing influenced the physical indices of grain, and were especially well expressed on test weight. Under low nutrition regime (the check variant and N P K), the grain in the monoculture was smaller in comparison to the two-field crop rotation. Under the higher levels of fertilization and in the monoculture a tendency was observed toward larger grain. The test weight in both crop rotations decreased with the higher fertilization norms. No significant correlations were found between productivity and the physical properties of grain under both types of growing. Under long-term growing of wheat in two-field rotation, there was a high positive correlation between absolute and test weight of grain.

Keywords: wheat, long-term crop rotation, non-rotation and 2-field crop rotation, fertilization

Introduction

The role of crop rotation for optimal yields with good quality characteristics is undisputable and the researches in this respect have always been topical for the agricultural science (Klochkov et al., 1988; Kasimov et al., 1999). The rotation of different agro cenoses, one of the major laws in agriculture, is at the basis of maintaining and enhancing soil fertility and the environment leading to respective adequate response on the part of the crops (Brussard, 1994). The foundations of this type of researches were laid in the first half of the 19th century in England at single trial stations established under private patronage. Thus the Rothamsted experimental station was founded with funding provided by the well known agriculturalist Sir J.B. Lawes, which later gained the reputation of the best research center in agriculture (Fisher, 1951; Tudge, 1983).

The last decades of the 20th century were marked by sharp increase of intensification of the agricultural production accompanied with large-scale concentration and specialization. This created a prerequisite for the increase of the percent of the short-term crop rotations and long-term monoculture growing (Stamboliev et al., 2001). In Bulgaria researches of this type of long-term crop rotations were also carried out and the results showed that at strict adherence to a series of agronomy practices, the self-tolerance of wheat can be enhanced by a number of indices (Dzhumalieva et al., 1976; Dzhonova et al., 1976; Dzhumalieva, 1980; Borisov et al., 1993; Mitova, 1997). The researches which continued during the 21st century in different agro meteorological regions of the country showed that cultivar Yantur, grown on leached smolnitsa soil (Haplic Vertisols) in short monoculture strictly adhering to the required agronomy practices, had productivity of 5.5 t/ha and good bread making properties of grain (Zarkov, 2002). Nankov (2005, 2008) has found out that the meteorological conditions and the proper combination of the main agronomy factors (soil tillage and fertilization) allowed the successful growing of wheat in short-term monoculture (3 – 4) years under conditions of typical chernozem soil.

Angelova et al. (2008) reported 2.3 times higher yields when growing wheat in monoculture with interruptions of 2 – 3 years and at fertilization with N P K. The investigations on wheat grown in short and long-term monoculture at Dobrudzha Agricultural Institute have 50-year history. In one of the first publications (Vassilev and Shtereva, 1973), based on results from field trials in Karnobat and General Toshevo, a mean decrease of yield under monoculture with 10 – 15% in comparison to the yield after previous crop grain maize was determined. Shtereva et al. (1998) have found out that averaged for 26 years (1961 – 1986) the negative effect of monoculture growing was 18.4%, reaching 45.5% in 1980. In subsequent investigations the own tolerance of wheat was analyzed also from the point of view of the changes occurring in the agro chemical characteristics of soil (Dzhonova et al., 1976; Nankova et al., 1994 and 1996), its biological activity (Taleva and Shtereva, 1977), the risk of basal and root rot (Petkov et al., 1989), the grain quality (Shtereva et al., 1988; Shtereva et al., 1998; Stoeva and Tonev, 2003). The research work of Assoc. Prof. Shtereva on the problems of the monoculture and the two-field rotation of wheat was...
continued with thorough investigations by Prof. Tonev till the end of his life (Tonev, 1995; Tonev and Gospodinov, 1995a, 1995b; Nankova et al., 1994; Nankova et al., 1996; Tonev, 1996; Tonev and Shitereva, 1996, 2006; Stoeva and Tonev, 2003; Tonev, 2001; Tonev 2007a, 2007b).

The aim of the present investigation was to study the response of cultivar Enola with regard to productivity and the physical properties of grain to growing under long-term monoculture in comparison to its growing under long-term two-field crop rotation.

**Material and methods**

The investigation was carried out in a permanent field experiment at the trial field of Dobrudzha Agricultural Institute (DAI), General Toshevo (Haplic Chernozems), which included non-rotation and two-field growing of wheat. The two-field rotation of wheat was with grain maize and was initiated in 1957, playing the role of a check variant for the two crop rotations. In harvest year 1960 the testing of two monocultures of wheat and maize began. From the mid-1960’s till the end of the 90’s, two levels of mineral fertilization were tested: N(K)P and N(K)P (kg/ha) for the two-field crop rotation, combining them with 40 and 80 K O in the non-rotation growing. In the new millennium, the trial underwent two corrections with regard to the tested fertilizer norms, maintaining the same ratio between the main macro elements – N:P:K = 1:0.8:0.5 (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Tested fertilizer norms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoculture</td>
</tr>
<tr>
<td>2000 – 2008</td>
</tr>
<tr>
<td>N&lt;sub&gt;p&lt;/sub&gt; K&lt;sub&gt;0&lt;/sub&gt;</td>
</tr>
<tr>
<td>N&lt;sub&gt;p&lt;/sub&gt; K&lt;sub&gt;10&lt;/sub&gt;</td>
</tr>
<tr>
<td>N&lt;sub&gt;p&lt;/sub&gt; P&lt;sub&gt;100&lt;/sub&gt; K&lt;sub&gt;0&lt;/sub&gt;</td>
</tr>
<tr>
<td>2009 – 2013</td>
</tr>
<tr>
<td>N&lt;sub&gt;p&lt;/sub&gt; K&lt;sub&gt;0&lt;/sub&gt;</td>
</tr>
<tr>
<td>N&lt;sub&gt;p&lt;/sub&gt; K&lt;sub&gt;10&lt;/sub&gt;</td>
</tr>
<tr>
<td>N&lt;sub&gt;p&lt;/sub&gt; P&lt;sub&gt;100&lt;/sub&gt; K&lt;sub&gt;0&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

The introduction of mineral fertilizers was done according to the accepted technology for growing of this crop. The phosphorus and potassium fertilizers in the monoculture were introduced prior to permanent plowing, and in the two-field rotation – prior to the first disking. The tested nitrogen norms were applied manually before permanent spring vegetation of wheat.

The data were processed by analysis of the variances (ANOVA), using SPSS 13 (Waller –Duncan Test) at the 0.05 level of significance.

The main elements from the meteorological characteristics of the investigated period had significant deviations from the mean values for the period 1953 – 2013 (Figure 1). The precipitation sum during the growing season of wheat in 2009, 2010 and 2012 exceeded the long-term values with 13.7%, 34.2% and 2.7%, respectively. In harvest years 2011 and 2013, lower respective amounts of rainfalls were recorded – 10.4% and 7.8%.

The distribution of the rainfalls by months during the autumn and winter vegetation of harvest years 2009 and 2011 was below the mean values for the 60-year period, while in 2010 their values were 1.8 times higher. At the beginning of permanent spring vegetation in 2010 (April) there were lower amounts of rainfalls than in the other years; however, the extremely high sum of autumn and winter precipitation in combination with the rainfalls in May, June and July made this year the most humid for the 1953 – 2013 period.

During the 5-year period of the investigation, only year 2011 had mean annual temperature approximating the mean value for the 60-year period (10.6°C). The other years were characterized with mean annual temperatures within 11.6 – 12.0°C. The mean temperatures during the growing season of wheat varied in this situation from 8.5°C (2011) to 10.4°C (2013), the level of the mean long-term temperatures being 8.9°C. Early spring vegetation, intensive dry matter accumulation and especially grain filling occurred under higher temperatures in 2012 and 2013.

**Results**

The results obtained from the investigation were marked by a high level of statistical significance in both types of growing of the crop (Table 2). The analysis of the variances showed high effect of the meteorological conditions and the mineral fertilization not only on productivity but also on the values of the physical properties of grain.

The productivity of cultivar Enola under non-rotation growing varied over the years according to the level of mineral fertilization. Highest effect from the use of different fertilizer norms in comparison
Table 2. Analysis of variances

<table>
<thead>
<tr>
<th>Source</th>
<th>Dependent Variable</th>
<th>df</th>
<th>Non-rotation (Monoculture)</th>
<th>Two-field rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td>Years (1)</td>
<td>Yields</td>
<td>4</td>
<td>19.576</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Mass</td>
<td>4</td>
<td>212.884</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>HW</td>
<td>4</td>
<td>252.430</td>
<td>.000</td>
</tr>
<tr>
<td>Fertilization (2)</td>
<td>Yields</td>
<td>3</td>
<td>29.293</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Mass</td>
<td>3</td>
<td>61.134</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>HW</td>
<td>3</td>
<td>47.737</td>
<td>.000</td>
</tr>
<tr>
<td>1 x 2</td>
<td>Yields</td>
<td>12</td>
<td>4.657</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Mass</td>
<td>12</td>
<td>23.465</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>HW</td>
<td>12</td>
<td>3.580</td>
<td>.000</td>
</tr>
</tbody>
</table>

Table 3. Productivity of cultivar Enola under long-term non-rotation growing (Waller-Duncan test, p ≤ 0.05)

<table>
<thead>
<tr>
<th>Fertilization</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{0}$P$<em>{0}$K$</em>{0}$</td>
<td>1911.0</td>
<td>2311.0</td>
<td>3710.0</td>
<td>1811.0</td>
<td>3822.3</td>
</tr>
<tr>
<td>$N_{0}$P$<em>{0}$K$</em>{0}$</td>
<td>3183.0</td>
<td>3633.5</td>
<td>4720.0</td>
<td>2952.0</td>
<td>4933.3</td>
</tr>
<tr>
<td>$N_{120}$P$<em>{0}$K$</em>{0}$</td>
<td>4661.0</td>
<td>4078.0</td>
<td>3881.0</td>
<td>3606.0</td>
<td>5827.8</td>
</tr>
<tr>
<td>$N_{120}$P$<em>{120}$K$</em>{0}$</td>
<td>5106.0</td>
<td>4200.0</td>
<td>2940.0</td>
<td>4078.0</td>
<td>5677.8</td>
</tr>
</tbody>
</table>

Table 4. Productivity of cultivar Enola under long-term two-field rotation (wheat-maize), kg/ha (Waller-Duncan test, p ≤ 0.05)

<table>
<thead>
<tr>
<th>Fertilization</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{0}$P$<em>{0}$K$</em>{0}$</td>
<td>2444.0</td>
<td>1859.3</td>
<td>3000.0</td>
<td>2684.0</td>
<td>3249.0</td>
</tr>
<tr>
<td>$N_{120}$P$<em>{0}$K$</em>{0}$</td>
<td>4622.0</td>
<td>4348.3</td>
<td>3760.0</td>
<td>4740.0</td>
<td>5874.0</td>
</tr>
<tr>
<td>$N_{120}$P$<em>{120}$K$</em>{0}$</td>
<td>4659.0</td>
<td>5385.0</td>
<td>5290.0</td>
<td>5180.0</td>
<td>6852.0</td>
</tr>
<tr>
<td>$N_{120}$P$<em>{120}$K$</em>{0}$</td>
<td>4571.0</td>
<td>4503.7</td>
<td>4740.0</td>
<td>5572.0</td>
<td>6630.0</td>
</tr>
</tbody>
</table>

Discussion

The agro meteorological variability during the investigated period caused significant variation of the cultivar’s mean productivity depending on the nutrition regime level. The worsened ecological plasticity of the cultivar grown on an area where wheat has been grown annually for 53 years led to formation of maximum mean productivity of approximately 4400 kg/ha (Figure 2). In the two-field crop rotation, a well expressed tendency toward higher production potential of the cultivar was observed. Tonev and Shtereva (1998), analyzing 10-year results from this trial for the period 1983 – 1992, determined that the mean productivity of cultivar Pliska grown in two-field crop rotation at two levels of fertilization was with 9.3% higher in comparison to its non-rotation growing.

Analyzing our results obtained after correction of the fertilizer norms of phosphorus (lower) and the involvement of potassium fertilization in the two-field crop rotation, too, a tendency was observed toward significant increase of the crop’s productivity and higher ecological plasticity of cultivar Enola in comparison to cultivar Pliska. The response of cultivar Enola to the applied norms of...
mineral fertilization in both ways of growing of the crop was very well expressed (Figure 3). By mean yields averaged for the investigated period, the productivity of cultivar Enola in the check variants was with 2.43% lower under two-field growing in comparison to monoculture. During 2009 and 2011 the positive effect from the two-field rotation without mineral fertilization was very well expressed. Under non-rotation growing, the mean productivity of cultivar was lower and was between 80.5% and 85.0% from the yields obtained from the check variants without crop rotation. The main reasons for this phenomenon are the worse conditions for quality performance of all activities related to planting and the biological immobilization of nitrogen as a result from the decomposition of the plant residues from maize. In both crop rotations the effect from the three fertilizer combinations was very well expressed. Under non-rotation growing, the mean productivity of cultivar Enola increased with averagely 51.1%, and under two-field rotation – with 73.3% in comparison to the respective checks. In both crop rotation, the nitrogen norm 120 kg/ha at phosphorus and potassium ratio 1:0.8:0.5 was definitely agronomically and economically most advantageous. The further increase of the nitrogen norm, even if keeping the same the ratio with the other main macro elements, led to an effect variable over years, which was better expressed under non-rotation growing of wheat. The strength of the effect of the tested factors on the productivity of cultivar Enola, averaged for the 5-year period of investigation, showed high dependence on the crop rotation (Figure 4). Under non-rotation growing, the productivity was almost equally determined by the independent action of the two factors. Furthermore, the effect of their interaction was very high – 25.16%.

The term “interaction of factors” was introduced in biology and agricultural science in 1918 by the mathematician Fisher who worked at the Rothamsted experimentation station in England when developing 2-factor dispersion analysis. In the two-field crop rotation the yields were dependent to a significantly higher degree on the mineral fertilization (73.5%) and only to 21.6% on the meteorological conditions of the investigated years. Although the
combined interaction of the two factors was statistically significant, its strength decreased almost five times in comparison to growing without rotation.

Absolute grain weight varied within rather wide range under the conditions of the trial and the period of analysis of the results (Table 5). Within the cultivar, this variation was from 36.50 g to 47.20 g. The high level of significance of the obtained results was already discussed; it showed that the agronomy factors are a powerful tool for influencing the size of the grain. Averaged for the period of investigation, the variations in grain size under non-rotation (41.21 g) and two-field rotation (41.46 g) growing were insignificant. The cultivar formed largest grain under two-field growing in 2012 and 2013 both in the checks and averaged for the fertilization variants (Figure 5). Under non-rotation growing, this tendency was confirmed in 2012 followed by 2009. Over years, averaged for the period, under two-field crop rotation without mineral fertilization, the cultivar formed larger grain in comparison to its monoculture growing with averagely 4.6%. This tendency was confirmed and equally well expressed at the lower mineral fertilization levels (N1P1K1), where the mean increase of the values of absolute grain weight was with 7.5%, as compared to non-rotation growing. The further increase of the fertilization norms in the long term monoculture had positive effect on the values of the index, while in the two-field crop rotation a significant decrease of its values was observed, especially well expressed at systematic fertilization with N6P3K3.

The tested factors had variable effect on the values of the grain size depending on the crop rotation (Figure 6). Highest variations in the independent effects of the factors were determined with regard to the meteorological conditions of the years of investigation. The strength of the effect of this factor on the grain size was determining under monoculture growing of wheat. In the two-field crop rotation, the strength of the effect of the two factors was comparatively

**Table 5.** Absolute grain weight over years and mineral fertilization norms depending on crop rotation, g (Waller-Duncan test, \( p \leq 0.05 \))

<table>
<thead>
<tr>
<th>Crop rotation</th>
<th>Fertilization</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoculture</td>
<td>N0P0K0</td>
<td>43.17</td>
<td>38.78</td>
<td>41.00</td>
<td>41.00</td>
<td>44.67</td>
</tr>
<tr>
<td></td>
<td>N0P0K3</td>
<td>44.63</td>
<td>42.98</td>
<td>39.67</td>
<td>46.67</td>
<td>47.20</td>
</tr>
<tr>
<td></td>
<td>N0P0K6</td>
<td>38.28</td>
<td>41.52</td>
<td>38.50</td>
<td>43.00</td>
<td>42.27</td>
</tr>
<tr>
<td></td>
<td>N0P0K9</td>
<td>34.87</td>
<td>37.27</td>
<td>38.50</td>
<td>44.17</td>
<td>41.07</td>
</tr>
<tr>
<td>Two-field rotation</td>
<td>N0P0K3</td>
<td>43.17</td>
<td>38.78</td>
<td>41.00</td>
<td>41.00</td>
<td>44.67</td>
</tr>
<tr>
<td></td>
<td>N0P0K6</td>
<td>44.63</td>
<td>42.98</td>
<td>39.67</td>
<td>46.67</td>
<td>47.20</td>
</tr>
<tr>
<td></td>
<td>N0P0K9</td>
<td>38.28</td>
<td>41.52</td>
<td>38.50</td>
<td>43.00</td>
<td>42.27</td>
</tr>
<tr>
<td></td>
<td>N0P0K12</td>
<td>34.87</td>
<td>37.27</td>
<td>38.50</td>
<td>44.17</td>
<td>41.07</td>
</tr>
</tbody>
</table>

**Figure 6.** Effect of the factors on the values of absolute weight, %
test weight values, a little above 81 kg under both crop rotations. The long-term growing of wheat in two-field rotation, averaged for the period, under two-field rotation types 28.7% of the values of the index were influenced by this interaction, two rotations were not found – permanent negative tendency toward lower test weight of grain with the higher fertilization norms. Grain had highest weight in the check variant and insignificant in cultivar Enola.

The values of test weight over years, depending on the mineral fertilization and the type of crop rotation, varied from 72.47 kg to 82.50 kg (Table 6). The physical properties of grain were not found under the two crop rotation types. Within the limits of the investigated factors in the crop rotation, averaged for the period, under two-field rotation (wheat-maize), the correlation of the values of grain size with its test weight showed that in contrast to absolute weight the complex of meteorological conditions in combination with the applied mineral fertilization allowed the cultivar to reach its maximal test weight values, a little above 81 kg under both crop rotations. The mineral fertilization, regardless of the crop rotation type, led to a

Conclusions

The long-term growing of wheat in two-field rotation increased the productivity of the crop with averagely 16.8% in comparison to its

### Table 6. Test weight of grain by years and mineral fertilization norms depending on crop rotation, kg (Waller-Duncan test, p ≤ 0.05)

<table>
<thead>
<tr>
<th>Crop rotation</th>
<th>Fertilization</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoculture</td>
<td>NPK</td>
<td>77.60*</td>
<td>74.47*</td>
<td>80.97*</td>
<td>81.27*</td>
<td>83.57*</td>
</tr>
<tr>
<td></td>
<td>NPK</td>
<td>75.88*</td>
<td>74.37**</td>
<td>79.37**</td>
<td>81.07**</td>
<td>82.40**</td>
</tr>
<tr>
<td></td>
<td>NPK</td>
<td>75.80**</td>
<td>73.20**</td>
<td>78.30**</td>
<td>80.57**</td>
<td>80.40**</td>
</tr>
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<td>NPK</td>
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<td>72.87**</td>
<td>76.97**</td>
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<td>78.50**</td>
</tr>
<tr>
<td>Two-field rotation</td>
<td>NPK</td>
<td>77.85*</td>
<td>75.40*</td>
<td>82.50*</td>
<td>81.47**</td>
<td>83.67**</td>
</tr>
<tr>
<td></td>
<td>NPK</td>
<td>76.83*</td>
<td>74.37*</td>
<td>81.63*</td>
<td>80.70**</td>
<td>83.27**</td>
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<td></td>
<td>NPK</td>
<td>76.03*</td>
<td>75.57*</td>
<td>79.77*</td>
<td>81.77**</td>
<td>80.77**</td>
</tr>
<tr>
<td></td>
<td>NPK</td>
<td>72.53*</td>
<td>72.47*</td>
<td>78.97*</td>
<td>80.27*</td>
<td>80.07*</td>
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</table>

<table>
<thead>
<tr>
<th>Year of investigation</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
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</thead>
<tbody>
<tr>
<td>Two-field</td>
<td>11.98</td>
<td>3.59</td>
<td>84.43</td>
<td>81.88</td>
<td></td>
</tr>
<tr>
<td>Monoculture</td>
<td>13.16</td>
<td>4.96</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 7. Correlation of productivity with physical properties of grain**

<table>
<thead>
<tr>
<th>Yield</th>
<th>1000 kernel weight</th>
<th>Test weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoculture</td>
<td>.050</td>
<td>.029</td>
</tr>
<tr>
<td>Two-field rotation</td>
<td>.142</td>
<td>.014</td>
</tr>
</tbody>
</table>

**Figure 7.** Correlation between absolute and test weight according to crop rotation

permanent negative tendency toward lower test weight of grain with the higher fertilization norms. Grain had highest weight in the check variant. With the low and optimal fertilization norms, the decrease of the mean values of the index was more gradual, while with the intensive fertilizer norms the decrease was sharp. Averaged for the period of investigation, significant variations of the test weight in the two rotations were not found – 78.14 kg under non-rotation and 78.80 kg under two-field crop rotation growing.

The determined strength of effect of the tested factors on the test weight of grain showed that in contrast to absolute weight the effect of the meteorological conditions exceeded 80% and was unconditionally the decisive factor for heavier grain (Figure 8). Under two-field crop rotation, increasing effect of mineral fertilization was observed, as well as higher interaction effect of the two factors in comparison to non-rotation growing. During the period of investigation, statistically significant correlations of yield with the physical properties of grain were not found under the two crop rotation types (Table 7). Within the limits of the investigated factors in the crop rotation, averaged for the period, under two-field rotation (wheat-maize), the correlation of the values of grain size with its test weight was positive and statistically very well expressed (Figure 9). Under long-term non-rotation growing of wheat, averaged for 2009 – 2013, the correlation of physical properties of grain was negative and insignificant in cultivar Enola.

**Figure 8.** Effect of factors on test weight, %

proportionally distributed, with slightly higher effect of mineral fertilization. The combined interaction of the factors was significant for grain size under both crop rotations; in the two-field rotation, 28.7% of the values of the index were influenced by this interaction, and in the non-rotation growing – 21.4%. The values of test weight over years, depending on the mineral fertilization and the type of crop rotation, varied from 72.47 kg to 82.50 kg (Table 6). This exceptional response of the cultivar was provoked by the strong dependence of the values of the index on the meteorological conditions of the investigated years. The mean values over the years of investigation showed that in 2010 the least satisfactory results were obtained with regard to test weight under both crop rotations: 73.75 kg under growing without rotation and 74.75 kg under two-field rotation, respectively (Figure 7). The
non-rotation growing. The yield from cultivar Enola under long-term non-rotation growing was influenced to much higher degree by the meteorological conditions of the year (1.6 times) in comparison to two-field rotation with maize.

The systematic mineral fertilization increased wheat productivity under both types of rotation. In the two-field crop rotation yield increase according to the non-rotation growing was with 20.9%. Averaged for the investigated period, wheat had higher productivity at mineral fertilization with \( N_P K = 30 \) \((N:P:K=1:0.8:0.5)\). The intensive nitrogen fertilization reduced productivity, even at the same ratio with the other main macro elements, especially under non-rotation growing of wheat. The decisive factor for wheat productivity in two-field crop rotation was mineral fertilization; its effect was 1.9 times higher in comparison to long-term non-rotation growing. The test weight of grain under the two crop rotations decreased with the higher fertilization norms.

The meteorological conditions of wheat growing influenced the physical indices of grain and the effect was especially high on test weight. Under low nutrition regime (check and \( N_P K = 30 \)), the size of the grain in the monoculture was with lower values than in the two-field rotation. Under higher fertilization levels in monoculture, there was a tendency toward larger grain of wheat.

No significant correlations were found of productivity with the physical properties of grain under the two types of growing of wheat. Under long-term two-field crop rotation, there was a high positive correlation of absolute and test weight of the grain.

**Acknowledgments**

The research team of the Agro Technology Department of Dobrudzha Agricultural Institute dedicates this investigation to the memory of the late Prof. Tony K. Tonev (1956 – 2009) and expresses gratitude to the technical assistants Elenka Ilieva, Penka Dragneva and Milena Peneva for their high professional work during the performance of the longest stationary field trial at DAI, General Toshevo.

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