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# Soil Tillage System and Mineral Fertilization – Essential Elements from the Agrotechnology of Sustainable Productivity

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**Abstract:** In 2- and 6-field crop rotations (Haplic Chernozems) the effect of long-term mineral fertilization and different soil tillage systems on wheat and maize productivity was investigated during 2002 – 2008. The following soil tillage systems were tested in a stationary field trial involving a 6-field crop rotation: ploughing at 22-26 cm – ploughing at 14-16 cm, disking at 10-12 cm and ploughing at 24-26 cm – disking at 10-12 cm. The soil tillage depth, the fertilization norms and the NPK ratio varied according to the type of previous crop. In the 2-field crop rotation stationary trial (wheat-maize) the soil tillage system was ploughing-disking, and the fertilization norms for both crops were at ratios 1:3:0, 1:1:0, 1:1:1 and 3:1:1. The testing was performed with variety Enola (*T. aestivum* L.) and hybrids Stira and Anasta (*Zea maize* L.).
The combination of meteorological conditions during the investigated period highlighted the role of the two powerful factors for wheat and maize productivity. Ploughing-disking had the highest positive effect on wheat productivity regardless of the mineral fertilization norms. Wheat yields after annual ploughing and respective disking conceded to the alternation of the two types of soil tillage with 4.1 % and 3.4 %, respectively. The soil tillage system was the factor with higher effect on the productivity of maize grown in 6-field crop rotation, in comparison to the meteorological factor.The long-term alternation of ploughing and disking in crop rotation was a better system for soil tillage than the long-term independent usage of ploughing or disking. This effect was much more expressed in maize than in wheat.The increased nitrogen fertilization norm heightened the role of the meteorological factor. Agronomically most efficient was nitrogen and phosphorus fertilization of whet at ratio 1:1 at norm 120 kg/ha, as well as its combination with 60 kg $K_2O$/ha.
The high phosphorus norms had a negative effect of maize productivity regardless of the combinations with nitrogen and potassium. Agronomically most efficient was the norm $N_{180}P_{60}K_{120}$, providing sustainable productivity of the crop.The meteorological conditions during 2003 were extremely unfavorable for wheat development and the conditions in 23007 – for the development of maize.
**Key words:** soil tillage systems, crop rotation, fertilization, wheat and maize productivity

## INTRODUCTION and LITERATURE REVIEW

The purposeful investigations on the effect of major agronomy practices on the productivity of some field crops continue now for more than 50 years at Dobrudja Agricultural Institute - General Toshevo. A number of research papers consider the results obtained on the effect of the soil tillage systems and the mineral fertilization on the productivity of crops from different field trials (Klochkov, B., I. Kassimov, 1981; H. Kirchev, 1999; Kirchev, 2000; Kirchev 2001[a]; Kirchev, 2001[b]; B. Klochkov, 1983[a]; B. Klochkov, 1983[b]; Kalinov, L. et a., 1979; Kalinov, I., 1983; Kalinov, I., 1985; Tsenov et al., 1986; Kalinov, I., 1989; Petrova, M., 1984; Gospodinov, M., 1981, etc.).

In the decades that followed the researchers became more concentrated on the effect of the long-term usage of the main agronomy factors on the changes of some physical and agro-chemical properties of slightly leached chernozem soil, as well as on its fertility and quality (Nankova, Penchev, 2006; Nankova, Kalinov, 1992[a,b], Nankova et al., 1995; Yankov, 2000; Yankov, 2005; Yankov, 1996; Nankova et al., 2003; Yankov et al., 2004).

This investigation considers for the first time the results on the productivity of two of the most common field crops in Dobrudja region grown in two stationary trials aimed at investigating the effect of various agronomy practices on crop productivity.

The aim of this investigation was also to clarify the effect of long-term usage of different soil tillage systems and mineral fertilization on wheat and maize productivity grown in 6- and 2-field crop rotation.

## MATERIALS AND METHODS

The investigation was carried out in stationary field trials performed at the trial field of Dobrudja Agricultural Institute – General Toshevo (Haplic Chernozems – FAO, 2002).

The first trial was a 6-field crop rotation with wheat, bean, sunflower, and grain maize. The trial was performed in two parallel crop rotations. The soil tillage variants were designed by the long plot method in eight replicates, the trial plot being 72 m2, and the harvest plot – 25 m2 of wheat and 42 m2 of spring crops. The trial was initiated in 1987 and three soil tillage systems were chosen for the purposes of this investigation: ploughing-ploughing, disking-disking and ploughing-disking. The tillage depths were as follows: ploughing – 24-26 cm after cereals and ploughing at 14-16 cm after spring crops; disking was at 10-12 cm for all crops, and in the system with alternation of tillage types ploughing was at 24-26 cm and disking at 10-12 cm. Mineral fertilization was done with N120P120K60 (kg/ha) for wheat and N180P0K60 (kg/ha) for maize.

The second trial was 2-field rotation of wheat and maize grown with ploughing-disking soil tillage system. After harvesting of wheat deep ploughing was performed (24-26 cm), and after harvesting of maize triple disking at 10-12 cm was done. This trial was initiated in 1967 by the Latin square method in five replicates. The trial plot size was 63 m2, and the harvest plot – 25 m2. Four nitrogen and phosphorus norms were being tested in this trial: 0, 60, 120 and 180 kg/ha, respectively, as well as three potassium norms: 0, 60 and 120 kg/ha against the full design of the trial. The trial included an additional variant with 180 kg K2O/ha in combination with the same nitrogen and phosphorus norm. Thus the total number of the tested variants was 49.

The investigation was carried out with two crops – common winter wheat (Triticum aestivum L.), variety Enola (2002 – 2008), and maize (Zea maize L.), hybrid Klarika (2002 – 2004) and hybrid Anasta (2005 – 2008).

The mathematical processing of the results obtained on the crops' productivity was performed with the help of software SPSS 13.0.

The investigation period included years with variable weather conditions. The amount of autumn-and-winter moisture reserves varied within a wide range (Figure 1). It was highest during harvest year 2005, exceeding the mean long-term sum (averaged for 1953-2000) with 32.6 %. Harvest years 2003 and 2004 also had higher autumn-and-winter rainfalls in comparison to the long-term data. The exceeding was with 30.6 and 21.3 %, respectively.

During the investigation only harvest year 2007 had autumn-and-winter moisture reserves lower than the mean value for the 47-year period. Only two years were characterized with extreme drought in the entire period of long-term meteorological statistics: harvest years 1968 (261.0 mm) and harvest year 1974 (273.2 mm). In these years, however, the vegetation rainfalls sum was higher than the sum in harvest year 2007.

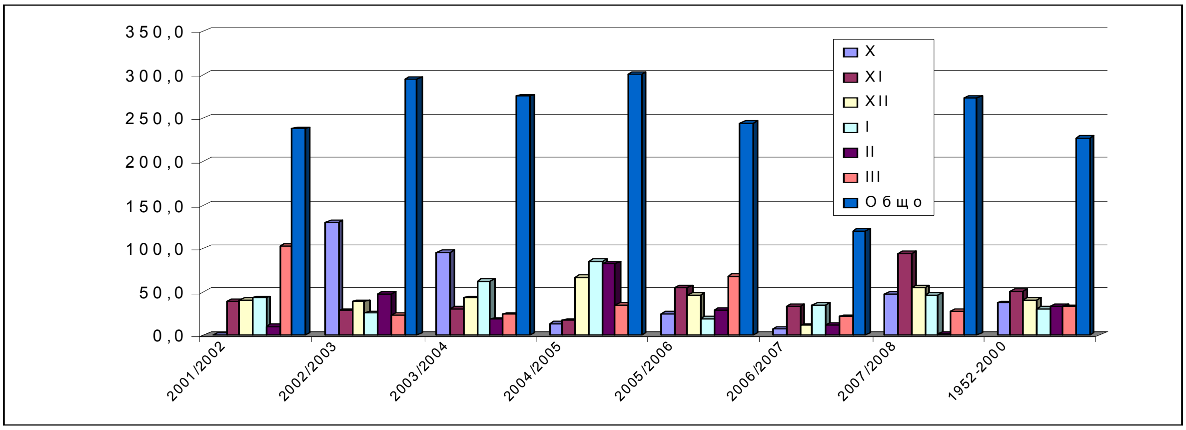


**Figure 1. Autumn-and-winter rainfalls, mm**

**Table 1. Rainfalls during permanent spring vegetation of wheat, mm**

| Years | IV | V | VI | VII-1st decade | Vegetation rainfals |
|---|---|---|---|---|---|
| **1953-2000** | **44.6** | **49.5** | **66.8** | **23.5** | **234.7** |
| 2002 | 36.2 | 9.1 | 25.8 | 0.0 | 187.6 |
| 2003 | 17.9 | 18.3 | 29.0 | 40.7 | 154.1 |
| 2004 | 2.2 | 93.7 | 71.2 | 0.0 | 251.7 |
| 2005 | 21.6 | 51.3 | 48.0 | 46.4 | 266.1 |
| 2006 | 35.5 | 94.4 | 29.8 | 62.7 | 285.6 |
| 2007 | 30.6 | 20.2 | 16.3 | 1.0 | 75.5 |
| 2008 | 116.6 | 79.9 | 32.9 | 3.0 | 248.5 |

The years in the investigated period varied significantly by the amount and distribution of vegetation rainfalls as well (Table 1). Harvest years 2004, 2005, 2006 and 2008 had amounts exceeding the mean long-term values. Years 2004, 2005 and 2008 had comparatively the most favorable distribution of rainfalls during the critical stage of wheat development. The rest of the years had amounts of spring-and-summer rainfalls below the mean long-term value. During the year with extreme drought (2007), the winter cereal crops received only 26.8 % of the mean long-term rainfalls during the spring-and-winter vegetation. This fact determined the entire complex of its meteorological characterization as extremely unfavorable for the expression of the productive potential of field crops.

During maize vegetation, years 2003 and 2007 had rainfalls below the mean long-term values (Table 2). During the rest of the years of the investigation the vegetation rainfalls exceeded the mean long-term values. The exceeding was most significant in 2004 – with 36.1 %. This year was characterized with very good distribution of rainfalls by months, which ensured optimal development of the crop.

## RESEARCH RESULTS

The tested soil tillage systems and the meteorological year conditions were factors whose direct effect and interaction had a maximum significant effect on wheat and maize productivity (Table 3). The interaction between these factors had a high level of significance. The dispersion analysis showed that in wheat the complex of meteorological factors during the investigation period had a higher effect on the crop productivity than the soil tillage system. The opposite correlation was established in maize: the factor soil tillage had a stronger effect on crop productivity.

In the 2-field crop rotation, where different norms and ratio of long-term mineral fertilization with nitrogen, phosphorus and potassium were tested under systematic alternation of ploughing and disking, a maximum significant effect of the year conditions and the type of the fertilization varian

on wheat and maize productivity was determined (Table 4).

The mutual effect of these two factors on productivity also had a high level of significance. The analysis of variances showed that the meteorological factor had a higher effect on the formation of productivity of the two crops than mineral fertilization.

On the basis of the statistical analysis on the sum of squares, the Waller-Duncan test divided the effect of the years during the investigated period in the 6-

field crop rotation into six groups (Table 5).

In the 2-field crop rotation the differentiation by year was more expressed in maize than in wheat (Table 6). The Waller-Dincan test divided the yields obtained from wheat into 5 groups and a similarity was established in the complex of meteorological conditions in 2002 and 2008, and in 2006 and 2004.

The effect of the three long-term soil tillage systems was expressed to various degrees according to the type of crop (Table 7). In wheat the systematic usage of disking and ploughing did not lead to significant variations in the productivity of wheat variety Enola. Their alternation caused a 3% mean increase of yield in comparison to their independent gave the fertilization norms most suitable for a fuller expression of the production potential of the two crops (Table 8).

Fertilization variants with norms and ratios identical with the fertilization used in the 6-field crop rotation were selected from the trails with 2-field wheat-maize crop rotation. The dispersion analysis once again confirmed the high level of significant effect of the tested factors on wheat and maize productivity in both trials (Table 9).

The soil tillage system and fertilization being the same, the Waller-Duncan test differentiated to a higher degree the investigated years in the 6-field crop rotation in comparison to the 2-field crop rotation in both crops (Table 10). The main tendencies of the complex effect of the meteorological factors during the years remained the same.

Both trials confirmed the extremely unfavorable conditions in 2003 and 2007 for wheat productivity, and in 2007 – for maize productivity.

**Table 2. Rainfalls during maize vegetation, mm**

| Years | IV | V | VI | VII | VIII | IX | Total |
|---|---|---|---|---|---|---|---|
| **1953-2000** | **43.7** | **50.2** | **66.4** | **49.9** | **40.5** | **41.3** | **292.0** |
| 2002 | 36.2 | 9.1 | 25.8 | 116.5 | 77.1 | 92.3 | 357.0 |
| 2003 | 17.9 | 18.3 | 29.0 | 48.2 | 36.9 | 116.0 | 266.3 |
| 2004 | 2.2 | 93.7 | 71.2 | 84.6 | 103.1 | 42.7 | 397.5 |
| 2005 | 21.6 | 51.3 | 48.0 | 98.8 | 17.5 | 96.2 | 333.4 |
| 2006 | 35.5 | 94.4 | 29.8 | 63.2 | 84.0 | 46.5 | 353.4 |
| 2007 | 30.6 | 20.2 | 16.3 | 7.4 | 33.4 | 68.6 | 176.5 |
| 2008 | 116.6 | 79.9 | 32.9 | 16.1 | 3.0 | 57.1 | 305.6 |

**Table 3. Dispersion analysis in 6-field crop rotation (2002–2008)**

| Source | df | Wheat | | | | Maize | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Type III Sum of Squares | Mean Square | F | Sig. | Type III Sum of Squares | Mean Square | F | Sig. |
| Corrected Model | 20 | 3897044.2(a) | 194852.2 | 470.9 | .000 | 7611735.3(a) | 380586.8 | 119.2 | .000 |
| Intercept | 1 | 24561189.5 | 24561189.5 | 59360.1 | .000 | 39002927.2 | 39002927.2 | 12212.9 | .000 |
| Tillage | 2 | 5457.7 | 2728.8 | 6.6 | .003 | 6401535.9 | 1066922.7 | 334.1 | .000 |
| Years | 6 | 3825169.6 | 637528.3 | 1540,8 | .000 | 452920.8 | 226460.4 | 70.9 | .000 |
| Tillage * Years | 12 | 66417.0 | 5534.7 | 13.4 | .000 | 757278.6 | 63106.5 | 19.8 | .000 |
| Error | 63 | 26067.2 | 413.8 | | | 201195.3 | 3193.6 | | |
| Total | 84 | 28484300.9 | | | | 46815857.8 | | | |
| Corrected Total | 83 | 3923111.5 | | | | 7812930.6 | | | |
| | | a R Squared = .993 (Adjusted R Squared = .991) | | | | a R Squared = .974 (Adjusted R Squared = .966) | | | |

**Table 4. Dispersion analysis in 2-field crop rotation (2002–2008)**

| Source | df | Wheat | | | | Maize | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Type III Sum of Squares | Mean Square | F | Sig. | Type III Sum of Squares | Mean Square | F | Sig. |
| Corrected Model | 342 | 55359664.1(a) | 161870.4 | 62.9 | .000 | 29770660.3(a) | 87048.7 | 8.1 | .000 |
| Intercept | 1 | 239424890.5 | 239424890.5 | 93062.6 | .000 | 920809637.4 | 920809637.4 | 85326.0 | .000 |
| Years | 6 | 32245787.9 | 5374298.0 | 2088.9 | .000 | 15975463.2 | 2662577.2 | 246.7 | .000 |
| Variants | 48 | 16613212.1 | 346108.6 | 134.5 | .000 | 5249524.5 | 109365.1 | 10.1 | .000 |
| Years * Variants | 288 | 6500664.1 | 22571.8 | 8.8 | .000 | 8545672.6 | 29672.5 | 2.8 | .000 |
| Error | 1029 | 2647338.2 | 2572.7 | | | 11104623.1 | 10791.7 | | |
| Total | 1372 | 297431892.8 | | | | 961684920.8 | | | |
| Corrected Total | 1371 | 58007002.3 | | | | 40875283.4 | | | |
| | | a R Squared = .954 (Adjusted R Squared = .939) | | | | a R Squared = .728 (Adjusted R Squared = .638) | | | |

**Table 5. Effect of the meteorological conditions on crop productivity according to the soil tillage system in 6-field crop rotation, Waller-Duncan (N=12)**

| Wheat | | | Maize | | |
|---|---|---|---|---|---|
| Years | Groups | Value | Years | Groups | Value |
| 2003 | a | 171.95 | 2007 | a | 74.79 |
| 2007 | b | 272.18 | 2008 | b | 626.43 |
| 2002 | c | 584.34 | 2002 | b | 639.67 |
| 2008 | d | 611.52 | 2003 | c | 727.83 |
| 2005 | e | 662.28 | 2006 | d | 824.82 |
| 2004 | e | 676.70 | 2005 | e | 882.75 |
| 2006 | f | 806.19 | 2004 | f | 993.58 |

**Table 6. Effect of meteorological conditions on crop productivity under soil tillage system in 2-field crop rotation, Waller-Duncan (N=196)**

| Wheat | | | Maize | | |
|---|---|---|---|---|---|
| Years | Groups | Value | Years | Groups | Value |
| 2003 | a | 99.49 | 2007 | a | 654.57 |
| 2007 | b | 309.55 | 2008 | b | 712.57 |
| 2005 | c | 395.21 | 2003 | c | 749.23 |
| 2008 | d | 513.83 | 2005 | d | 845.52 |
| 2002 | d | 521.88 | 2002 | e | 871.04 |
| 2006 | e | 541.43 | 2006 | f | 943.99 |
| 2004 | e | 542.82 | 2004 | f | 957.72 |

**Table 7. Effect of the type of the soil tillage system on wheat and maize productivity in 6-field crop rotation, Waller-Duncan (N=28)**

| Wheat | | | Maize | | |
|---|---|---|---|---|---|
| Tillage systems | Groups | Value | Tillage systems | Groups | Value |
| Disking-Disking | a | 533.88 | Disking-Disking | a | 582.22 |
| Ploughing-Ploughing | a | 536.28 | Ploughing-Ploughing | b | 704.38 |
| Ploughing- Disking | b | 552.05 | Ploughing- Disking | c | 757.63 |

**Table 8. Effect of NPK fertilization with different norms and ratios on crop productivity in 2-field crop rotation, Waller-Duncan (N=28)**

| Wheat | | | Maize | | |
|---|---|---|---|---|---|
| Fertilization norm | Groups | Value | Fertilization norm | Groups | Value |
| $N_0P_0K_{12}$ | a | 207.78 | $N_0P_0K_0$ | a | 672.00 |
| $N_0P_0K_6$ | ab | 217.55 | $N_0P_0K_6$ | ab | 687.90 |
| $N_0P_0K_0$ | abc | 223.84 | $N_0P_0K_{12}$ | ab | 702.70 |
| $N_0P_6K_0$ | abcd | 230.56 | $N_0P_6K_0$ | ab | 702.80 |
| $N_0P_{18}K_6$ | bcd | 234.21 | $N_0P_{18}K_0$ | ab | 707.60 |
| $N_0P_6K_{12}$ | bcd | 234.35 | $N_0P_{12}K_{12}$ | abc | 720.50 |
| $N_0P_{12}K_0$ | bcd | 237.80 | $N_0P_{18}K_{12}$ | bc | 723.60 |
| $N_0P_{12}K_{12}$ | bcd | 237.85 | $N_0P_6K_{12}$ | bcd | 733.20 |
| $N_0P_{12}K_6$ | cd | 242.93 | $N_{18}P_{18}K_{18}$ | bcd | 733.60 |
| $N_0P_{18}K_0$ | cd | 247.27 | $N_0P_{12}K_0$ | cde | 768.80 |
| $N_0P_{18}K_{12}$ | d | 248.02 | $N_{12}P_{18}K_{12}$ | def | 780.50 |
| $N_0P_6K_6$ | d | 248.74 | $N_0P_{18}K_6$ | defg | 783.30 |
| $N_6P_0K_{12}$ | e | 400.06 | $N_{12}P_{18}K_6$ | efgh | 792.20 |
| $N_6P_0K_6$ | e | 404.81 | $N_0P_{12}K_6$ | efghi | 801.00 |
| $N_6P_{12}K_{12}$ | ef | 411.14 | $N_6P_0K_0$ | efghij | 805.70 |
| $N_6P_6K_{12}$ | efg | 411.26 | $N_6P_0K_{12}$ | efghij | 806.70 |
| $N_6P_0K_0$ | efgh | 416.10 | $N_{18}P_{18}K_{12}$ | efghij | 812.10 |
| $N_6P_{12}K_6$ | efghi | 423.04 | $N_0P_6K_6$ | efgghijk | 818.50 |
| $N_6P_{18}K_{12}$ | fghij | 432.22 | $N_6P_0K_6$ | efgghijk | 818.60 |
| $N_6P_{12}K_0$ | ghij | 434.66 | $N_6P_{18}K_0$ | efgghijk | 818.70 |
| $N_{12}P_0K_{12}$ | hij | 435.97 | $N_{18}P_{18}K_6$ | fghijkl | 821.41 |
| $N_6P_6K_6$ | hij | 437.88 | $N_{12}P_{18}K_0$ | fghijkl | 822.72 |
| $N_6P_{18}K_6$ | Ij | 440.51 | $N_{18}P_{18}K_0$ | fghijkl | 824.60 |
| $N_6P_6K_0$ | ij | 445.97 | $N_{18}P_6K_0$ | fghijkl | 827.05 |
| $N_6P_{18}K_0$ | jk | 455.33 | $N_6P_{18}K_{12}$ | fghijklm | 830.27 |
| $N_{12}P_0K_0$ | kl | 477.70 | $N_6P_{12}K_6$ | fghijklm | 830.27 |
| $N_{18}P_0K_0$ | lm | 491.14 | $N_6P_{18}K_6$ | ghijklm | 832.95 |
| $N_{18}P_{18}K_6$ | lmn | 495.58 | $N_{18}P_{12}K_{12}$ | hijklmno | 834.16 |
| $N_{12}P_0K_6$ | lmno | 496.49 | $N_{18}P_{12}K_0$ | hijklmnop | 841.86 |
| $N_{18}P_{18}K_0$ | lmno | 497.20 | $N_{12}P_0K_{12}$ | ijklmnop | 845.34 |
| $N_{12}P_{12}K_{12}$ | lmno | 500.19 | $N_{12}P_{12}K_{12}$ | ijklmnop | 849.25 |
| $N_{12}P_{18}K_{12}$ | lmno | 500.28 | $N_6P_{12}K_{12}$ | ijklmnop | 850.52 |
| $N_{18}P_0K_{12}$ | lmno | 501.05 | $N_{18}P_{12}K_6$ | jklmnopq | 855.06 |
| $N_{18}P_{18}K_{12}$ | mno | 503.05 | $N_{12}P_0K_6$ | klmnopq | 855.06 |
| $N_{18}P_6K_0$ | mno | 503.38 | $N_6P_6K_6$ | klmnopqr | 863.82 |
| $N_{18}P_6K_{12}$ | mno | 504.17 | $N_{12}P_0K_0$ | klmnopqr | 865.62 |
| $N_{12}P_{12}K_6$ | mno | 504.39 | $N_6P_6K_0$ | klmnopqr | 866.80 |
| $N_{18}P_{12}K_6$ | mno | 504.39 | $N_6P_{12}K_0$ | lmnopqr | 870.98 |
| $N_{18}P_{12}K_{12}$ | mno | 505.10 | $N_{12}P_6K_0$ | mnopqr | 878.73 |
| $N_{18}P_{12}K_0$ | mno | 506.61 | $N_{12}P_6K_{12}$ | mnopqr | 879.05 |
| $N_{12}P_6K_{12}$ | mno | 507.31 | $N_{18}P_0K_{12}$ | mnopqr | 880.31 |
| $N_{18}P_6K_6$ | mno | 508.48 | $N_{12}P_{12}K_6$ | nopqr | 882.39 |
| $N_{18}P_{18}K_{18}$ | mno | 508.59 | $N_{12}P_{12}K_0$ | nopqr | 883.06 |
| $N_{18}P_0K_6$ | mno | 508.66 | $N_{18}P_0K_6$ | opqr | 884.21 |
| $N_{12}P_6K_6$ | no | 514.80 | $N_{18}P_6K_6$ | pqr | 885.47 |
| $N_{12}P_{18}K_6$ | no | 515.63 | $N_{12}P_6K_6$ | pqr | 886.01 |
| $N_{12}P_6K_0$ | no | 516.56 | $N_{18}P_0K_0$ | pqr | 891.62 |
| $N_{12}P_{18}K_0$ | o | 519.13 | $N_6P_6K_{12}$ | qr | 903.54 |
| $N_{12}P_{12}K_0$ | o | 519.62 | $N_{18}P_6K_{12}$ | r | 913.82 |

**Table 9. Dispersion analysis in 6- and 2-field crop rotation in selected fertilization variants**

| Source | df | 6-field crop rotation – wheat ($N_{12}P_{12}K_6$) | | | | 6-field crop rotation – maize ($N_{12}P_0K_6$) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Type III Sum of Squares | Mean Square | F | Sig. | Type III Sum of Squares | Mean Square | F | Sig. |
| Corrected Model | 6 | 1256923.5(a) | 209487.2 | 783.3 | .000 | 2536024.1(a) | 422670.7 | 251.3 | .000 |
| Intercept | 1 | 8533257.7 | 8533257.7 | 31906.6 | .000 | 16072181.0 | 16072181.0 | 9554.4 | .000 |
| Years | 6 | 1256923.5 | 209487.2 | 783.3 | .000 | 2536024.1 | 422670.7 | 251.3 | .000 |
| Error | 21 | 5616.4 | 267.4 | | | 35325.6 | 1682.2 | | |
| Total | 28 | 9795797.5 | | | | 18643530.7 | | | |
| Corrected Total | 27 | 1262539.8 | | | | 2571349.7 | | | |
| | | a R Squared = .996 (Adjusted R Squared = .994) | | | | a R Squared = .986 (Adjusted R Squared = .982) | | | |
| | | 2-field crop rotation – wheat ($N_{12}P_{12}K_6$) | | | | 2-field crop rotation – maize ($N_{12}P_0K_6$) | | | |
| Corrected Model | 6 | 1046442.1(a) | 174407.0 | 53.8 | .000 | 470631.6(a) | 78438.6 | 12.3 | .000 |
| Intercept | 1 | 7123338.6 | 7123338.6 | 2196.8 | .000 | 20471778.1 | 20471778.1 | 3216.2 | .000 |
| Years | 6 | 1046442.1 | 174407.0 | 53.8 | .000 | 470631.6 | 78438.6 | 12.3 | .000 |
| Error | 21 | 68097.1 | 3242.7 | | | 133671.1 | 6365.3 | | |
| Total | 28 | 8237877.8 | | | | 21076080.8 | | | |
| Corrected Total | 27 | 1114539.2 | | | | 604302.7 | | | |
| | | a R Squared = .939 (Adjusted R Squared = .921) | | | | a R Squared = .779 (Adjusted R Squared = .716) | | | |

**Table 10. Effect of the meteorological conditions on crop productivity under the ploughing-disking soil tillage systems in 6- and 2-field crop rotation, Waller-Duncan (N=4)**

| 6-field crop rotation – wheat ($N_{12}P_{12}K_6$) | | | 6-field crop rotation – wheat ($N_{12}P_{12}K_6$) | | |
|---|---|---|---|---|---|
| Years | Groups | Value | Years | Groups | Value |
| 2003 | a | 211.80 | 2007 | a | 103.78 |
| 2007 | b | 256.73 | 2008 | b | 666.25 |
| 2002 | c | 585.48 | 2003 | c | 736.60 |
| 2008 | d | 614.48 | 2002 | d | 832.40 |
| 2004 | e | 670.75 | 2006 | e | 907.23 |
| 2005 | f | 720.68 | 2005 | e | 921.63 |
| 2006 | g | 804.45 | 2004 | f | 1135.55 |
| 2-field crop rotation – wheat ($N_{12}P_{12}K_6$) | | | 2-field crop rotation – maize ($N_{12}P_0K_6$) | | |
| Years | Groups | Value | Years | Groups | Value |
| 2003 | a | 118.83 | 2007 | a | 668.55 |
| 2007 | b | 404.88 | 2008 | ab | 732.95 |
| 2005 | b | 425.33 | 2003 | bc | 787.00 |
| 2008 | c | 553.68 | 2006 | cd | 883.15 |
| 2002 | c | 612.68 | 2005 | cd | 890.18 |
| 2006 | d | 706.78 | 2002 | d | 933.83 |
| 2004 | d | 708.55 | 2004 | e | 1089.80 |

## DISCUSSION AND CONCLUSIONS

The effect of the agro-technical elements constructing the integrated technology for crop cultivation finds its final expression in the productivity and quality of the obtained produce. The analysis of the results from the 6- and 2-field crop rotation proved that the meteorological factor played a decisive role for wheat productivity during the years of investigation. This factor superseded the effect of some of the most powerful agro-technical factors such as soil tillage system and mineral fertilization.

The years during the period of investigation, due to their specific considerable differences at the separate stages of the crops development, had a strong positive effect on crop productivity, all other conditions being equal. The mean wheat yields varied from 1719.5 kg/ha in 2003 to 8061.9 kg/ha in 2006 regardless of the soil tillage system. Based on productivity, the Waller-Duncan test found out some similarities in the year conditions during harvest years 2005 and 2004. The yield from variety Enola varied within a narrow range under these conditions: from 6622.8 kg/ha to 6767.0 kg/ha and therefore they fell within the same group.

The soil tillage system combined with the complex role of the 6-field crop rotation in maize had a stronger effect on crop productivity in comparison to the role of the meteorological factor. The growing of maize in many-field crop rotation under different soil tillage systems stabilized yields at a higher level in comparison to the 2-field crop rotation, regardless of the mineral fertilization applied. Similar results were obtained when growing maize in crop rotation with monoculture (Dick W. & Van Doren, 1986). In the 6-field crop rotation mean yields varied within a very wide range. Averaged for the tested soil tillage systems, a similarity was found out in maize productivity during 2008 and 2002. These years were not very favorable for expression of the crop's production potential. Even more unfavorable was year 2007 when a severe drought occurred and the mean yields were as low as 747.9 kg/ha. The conditions in 2004 were most favorable for maize productivity. The tested hybrid realized a mean production potential of 9935.8 kg/ha. In the 2-field crop rotation year 2007 had the lowest yields, and year 2004 – the highest. Based on productivity, a similarity was established between the meteorological conditions of 2006 and 2004, with an insignificant difference of 137.3 kg/ha in favor of year 2004.

Considering in greater details the effect of the year meteorological conditions on wheat productivity in the crop rotations, it becomes evident that year 2003 had the most unfavorable effect. Variety Enola demonstrated extremely unsatisfactory mean productivity, especially in the 2-field crop rotation. Against the wide range of fertilization variants, 3 contrasting years were identified, which can be classified as unfavorable (2003, 2007, 2005). Harvest year 2005 had the highest precipitation sum during wheat vegetation, and rainfalls were abundant at the end of it. During this year there was a severe occurrence of fusarium which led to insufficient yields. The productivity of the wheat variety was almost the same in harvest years 2008 and 2002; these years were most favorable for wheat development. The entire complex of meteorological conditions during the 7-year period of investigation was best in harvest years 2006 and 2004. In these two years the variety grown in 2-field crop rotation reached a maximum mean productivity, its values being insignificantly different during the two years. These two years had highest precipitation sums in May (an average of 94 mm), and the moisture reserves were comparatively optimal during the months till the end of vegetation.

The effect of the tested soil tillage systems in the 6-field crop rotation on wheat productivity was low. The long-term usage of disking or ploughing at different depths did not cause significant variations in the yield from variety Enola. The probable reason for this is that such tillage systems do not create the most favorable conditions for nutrients uptake, and ploughing particularly increased the mineralization of the organic substance (Nankova, Kalinov, 1992; Nankova et al., 1995; Yankov, 2005). The alternation of these two types of soil tillage in the 6-field crop rotation had a positive effect on wheat productivity, the yield variations, though not very high, being significant in comparison to their independent use.

The results for maize productivity showed that annual disking was the most unfavorable system for soil tillage for this crop. Annual ploughing increased the mean productivity with 1221.6 kg/ha, i.e. with 21.0 %. During the period of investigation highest yields from maize were obtained with the soil tillage system including alternation of ploughing and disking – 7575.3 kg/ha. This yield was with 532.5 kg/ha higher in comparison to annual ploughing, and with 1754.1 kg/ha higher in comparison to annual disking, respectively. The percent increase was 7.6 and 30.1 %, respectively.

The rich variety of fertilization combinations tested in the 2-field crop rotation divided wheat yield into 15 groups, which demonstrated the similarities and differences between them according to productivity. Evidently, the independent potassium fertilization, regardless of the fertilization norm, had a negative effect on productivity, although a similarity was established between the yield from the check variant and the independent phosphorus fertilization with 60 kg/ha. The independent phosphorus fertilization and its combination with potassium led to some increase of the yield from variety Enola. Fertilization with $N_0P_{60}K_{60}$ increased yield with a mean of 19.7 % in comparison to the variant with $N_0P_0K_{120}$. The variation of wheat productivity as a result from long-term independent or combined fertilization with phosphorus and potassium was within a narrow range; the yields were divided into 4 groups only and between many of these fertilization combinations a similar effect on productivity was found.

The addition of various nitrogen norms to these combinations strongly increased the effect of mineral fertilization on wheat productivity and contributed for the formation of another 11 groups. The low nitrogen norm (60 kg/ha), applied independently or in combination with P, K and PK increased yield from 4001.0 kg/ha ($N_{60}P_0K_{120}$) to 4553.0 kg/ha ($N_{60}P_{180}K_0$).

The increase of the nitrogen norm to 120 and 180 kg/ha led to further increase of productivity and to similarity between a large number of fertilization combinations. The analysis of results showed that the long-term fertilization with 180 kg N/ha independently and in double and triple combinations with phosphorus and potassium conceded to the long-term use of fertilization with 120 kg N/ha. The yields during the last 7 years from the 41-year period of the trial demonstrated that the fertilization variant with $N_{120}P_{120}K_0$ had the highest productivity – a mean of 5196.0 kg/ha. During the period of investigation the yields in this variant varied from 1681.0 kg/ha in 2003 to 6803.0 kg/ha in 2004. In spite of the low values of the yield in 2003, this was the highest yield obtained from the variants included in the trial.

The long-term mineral fertilization of maize against the background of the ploughing-disking soil tillage system divided productivity into a larger number of groups in comparison to wheat – 18. In contrast to wheat, in maize there was no clear differentiation between the fertilization variants without nitrogen and the fertilization variants with high nitrogen norms. An example is provided by the variants $N_{180}P_{180}K_{180}$ (7336.0 kg/ha) and $N_{180}P_{180}K_{120}$ (8121.0 kg/ha), which belonged to groups demonstrating similarities to fertilization variants without nitrogen or variants with nitrogen norm 60 kg/ha. The results showed that the use of these high fertilization norms, although at balanced ratios, led to suppression of productivity.

The analysis of the results also showed that nitrogen and potassium fertilization with nitrogen norms 120 and 180 kg/ha was the reason for yield decrease in comparison to independent nitrogen fertilization from the same norms. At nitrogen norm 60 kg/ha, its combination with the same potassium norm increased productivity with a mean of 129.0 kg/ha, and after the use of $K_{12}$ productivity was equal to independent nitrogen fertilization with 60 kg/ha.

Nitrogen and phosphorus fertilization had the highest agronomy effect when combining the three nitrogen norms with 60 kg $P_2O_5$/ha. The increased amount of phosphorus in the NP combination in all nitrogen norms lead to decrease of maize productivity. One of the reasons for stunted plants at high phosphorus fertilization norms was the impeded uptake of zinc expressed as occurrence of specific symptoms of zinc deficiency in maize. When using nitrogen norms of 120 and 180 kg/ha productivity fell below the level of their independent application. The variant with $N_{180}P_{60}K_{120}$ gave a maximum yield regardless of the meteorological conditions during the investigated period – 9138.0 kg/ha.

When discussing the obtained results, it is worth mentioning that the yields from variety Enola in the 6-field crop rotation were with 9.5 % higher than the yields obtained in the 2-field crop rotation. Each of the years fell in a separate group, which guaranteed its significant variation. In the 2-field crop rotation, all other conditions being equal, year 2003 was the only different one. In the rest of the years there was similarity in couples: 2007 – 2005; 2008 – 2002; 2006-2004, with increasing variations in their yields.

In maize, besides the greater differentiation of yields in the 6-field crop rotation, a similarity was found only between years 2006 and 2005. In the 2-field crop rotation years 2007 and 2004 differed most. Maize in this crop rotation had higher productivity (with 12.9 %) in comparison to the 6-field crop rotation. This result confirmed the fact that maize is a crop less sensitive to crop rotation that wheat.

The complex of meteorological conditions was a determining factor for wheat productivity regardless of the crop rotation type, the soil tillage system and the mineral fertilization used.

In years with precipitation sum during wheat and maize vegetation below 200 mm, productivity decreased several times even at optimal fertilization norms regardless of the type of soil tillage.

In maize grown in 6-field crop rotation, the soil tillage system was the factor with higher effect on the crop productivity in comparison to the meteorological factor.

The long-term alternation of ploughing and disking in crop rotation was the better system for soil tillage in comparison to the long term independent use of ploughing or disking. This effect was better expressed in maize than in wheat.

Most efficient was the nitrogen fertilization of wheat with nitrogen and phosphorus at ratio 1:1 at norm 120 kg/ha, as well as the combination with 60 kg $K_2O$/ha.

In maize the high phosphorus norms had a strong negative effect on the crop productivity regardless of the combinations with nitrogen and potassium. Most efficient was the fertilization with $N_{180}P_{60}K_{120}$; this fertilization norm ensured sustainable productivity in maize.

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