Abiotic stress impacts caused by weather and nutrient replenishment on the yield of maize (*Zea mays* L)

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Abstract: In the long-term experiment established by the University of Debrecen, we were examining how the amount and distribution of yearly precipitation, as well as nutrient replenishment affect maize productivity during the growing season in 2014, 2015 and 2016.

Environmental factors have a significant impact on yield. In all examined cases, there was a significant ($P<0.001$) difference between crop years. The most significant difference was observed between the yield of 2015 and 2016 (3475 kg ha^{-1}, $P<0.001$). The growing season of 2016 – which ended with significant precipitation surplus (+110 mm) – provided the availability of nutrients, thereby resulting in the highest yield both in treatments A and B.

Averaged over the examined years, treatment B resulted in a non-significant yield increasing effect (603 kg ha^{-1}) in comparison with treatment A. When evaluating the different crop years one by one, it can be concluded that there was a significant yield difference in 2015 (1036 kg ha^{-1}; $P<0.05$) (averaged over the different fertiliser treatments), despite the fact that it was a dry year. This phenomenon is explained by the fact that the silking of the examined maize hybrid ended before the dry period and the unfavourable effect of weather could be reduced with a high amount of nutrient replenishment.

Keywords: maize, nutrient replenishment, environmental factors

Introduction

The intensive growth of world population and the change of dietary habits prompt agriculture to increase productivity at an accelerating rate. Food production has to be increased with 70% by 2050 (FAO 2009), as the world's population is expected to be higher by 2.2 billion people and the quantity of cereals has to be increased by one billion in order to provide food for the population. However, in order to do this, increased amount of irrigation water must be applied and mineral fertilisation accessible for growing crops also needs to be performed (Yang et al. 2006).

Various research findings show that maize yield is mainly related to fertilisation, which has a more significant impact than genotype and all other examined production technological factors (crop rotation, tillage, irrigation, sowing density and crop year) (Berzsenyi and Győrffy 1995; Nagy 2012).

Nitrogen fertiliser is an essential crop nutrient which increases vegetative mass and plays a fundamental role in increasing yield (Modhej et al. 2008) and it also has an impact on yield quality (Ványiné and Nagy 2012), as well as access to other elements (Bruns and Ebelhar 2006). 61% of nitrogen taken up by maize is transferred into the grain yield (Berzsenyi 2013). A sufficient amount of nitrogen must be available in the whole vegetation period. In the case of N deficiency, yield loss is inevitable (Alvarez and Grigera 2005). The amount of N fertiliser used in excess of the crop's needs reduces economicalness and harms the environment (Nagy 2012). Phosphorus is also an indispensable nutrient and the most important element of the generative development and energy supply of maize. Consequently, phosphorus deficiency causes metabolic disturbance, the water balance of

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crops deteriorate, while silking and ripening delay. However, phosphorus oversupply leads to significant nutrient imbalance. The excess phosphorus resulting from P-Zn antagonism results in relative Zn deficiency, which has a negative impact on yield quantity and quality (Szakál et al. 2004). 70% of the phosphorus taken up during the vegetation period is transferred into the grain yield, which shows the significant role of phosphorus in yield formation (Berzsenyi 2013).

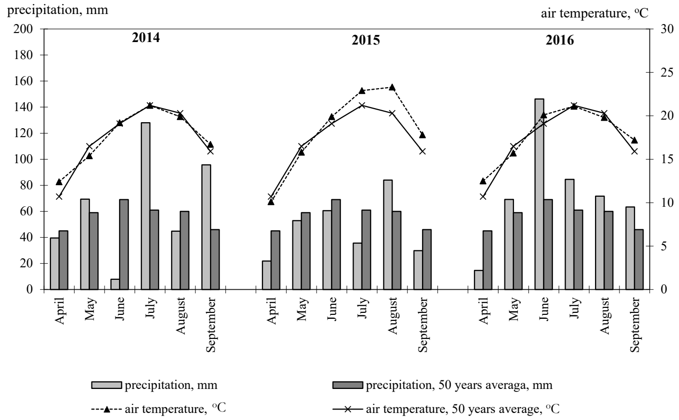
Potassium affects photosynthesis (Árendás et al. 1998), increases the active water uptake of crops (Mengel et al. 2001) and it has a role in the process of opening and closing stomata. Balanced potassium supply improves stress tolerance (frost and drought tolerance) (Sárdi 1999). Insufficient potassium supply leads to significant yield decrease.NPK fertilisation can be used to increase yield, while the unwanted impact of certain agrotechnical factors can also be mitigated (Széll et al. 2004). However, nutrient conversion greatly depends on crop year (Csathó et al. 1991; Wiswakumar 2008). The unfavourable impact of crop year can be avoided or mitigated with rational nutrient and water management. This research carried out in different crop years (2014, 2015 and 2016) focused on revealing how the amount of yearly precipitation and its distribution over the growing season, as well as nutrient replenishment affect maize productivity. It was also the aim of this research to identify the NPK ratio, which results in the highest yield at the lowest cost.

Material and methods

The examinations were performed in Eastern Hungary (horizontal degree: 47°56', longitudinal degree: 21°44') *in a long-term small plot field experiment on calcareous chernozem soil with deep humus layer formed on loess. The experiment had a strip plot design and four replications and it was carried out under natural precipitation supply conditions between 2014-2016*. The examined hybrid was FAO 490 in all three years. The proportions of the constant NPK fertiliser active ingredient doses of treatment "A" were 1 N : 0.75 P_2O_5 : 0.88 K_2O. The nitrogen base dose was 30 kg ha^{-1}. In addition to non-fertilised control, we applied 1, 2, 3, 4 and 5 times this dose. Increasing N dose and the same P and K doses (184 kg ha^{-1} P_2O_5 and 216 kg ha^{-1} K_2O) were applied in treatment "B". The harvested grain yield was provided for 14% moisture content. Weather was evaluated based on the data measured and logged by the automatic weather station installed on the experiment site. *In 2014*, the amount of precipitation in the growing season was 385 mm, which was 13% higher than the 50-year-average (Figure 1). There were two significantly drier months during the growing season: 2% of precipitation was observed in June and 12% in August. The 40 mm rainfall observed in April is considered to be the average amount. In May, the amount of precipitation was 10 mm more than the multiple year average. In July (128 mm) and September (96 mm), the amount of rainfall was more than twice higher than the average. The number of wet days (61) when rainfall reached 10 mm was 47, while there were 11 days when rainfall was above 10 mm. Rainfall was above 20 mm for three days altogether. The mean temperature of the growing season was 0.2 °C higher than the 50-year average. April was significantly warmer (+1.7 °C). The mean temperature of May (-1.1 °C) and August (-0.4 °C) was lower than the multiple year average. The mean temperature of June and July was in accordance with the average, while it was 0.8 °C higher in September. *In 2015*, the average precipitation sum of the growing season was 285 mm, which is 84% of the 50-year-average (Figure 1). May was somewhat drier than usual, the amount of rainfall was 90% of the average. June and July were rather dry. In

June, the amount of rainfall was 9 mm lower than the normal value, while the precipitation in July was 25 mm lower. The amount of rainfall in August is significant, as 24 mm excess was measured. In September, rainfall was lower than the average, as its amount did not reach 65% of the average. There were 43 rainy days in the growing season of 2015, and the amount of rainfall exceeded 1 mm during 32 of these days. For 9 days, precipitation was above 10 mm, while there were only two days with rainfall above 20 mm. The mean temperature of the growing season was higher (+1.0 °C) than the multiple year average. The mean temperature values of April and May were below the multiple year average. The rest of the observed months were significantly warmer than the average. The biggest positive anomaly was observed in August, when the monthly mean temperature was 3.0 °C higher than the 50-year average. This value is followed by those of September (+1.9 °C), July (+1.7 °C) and June (+0.8 °C).

Figure 1. Precipitation and temperature trends in the growing season (Debrecen, 2014–2016)



The growing season of *2016* was rich in rainfall (Figure 1). The precipitation sum of 2016 (450 mm) was 110 mm higher than the 50-year average (340 mm). April was dry, as there was less than 15 mm rain, which is well below the multiple year average of 45 mm. There was 69 mm rain in May, which was 17% higher than the 50-year average. The amount of rainfall in June (146 mm) was more than twice as much as the average precipitation sum (69). Unfortunately, more than one third of this rain (45 mm) arrived in only one day. There was significant excess rain also in July, August and September. We observed 39% excess rain in July, 20% in August and 37% in September in comparison with the 50-year average. Both in August and September, more than half of all precipitation arrived in one day – on 21st August and 21st September. There were 48 rainy days in the growing season, of which there were 40 days when the amount of rainfall was above 10 mm. Precipitation increased 20 mm for five days and there were only three days when the amount of rainfall was lower than 10 mm. Altogether, the mean temperature of the growing season was 16.5 °C, which differed from the 50-year average by only a few tenths. The month of sowing was much warmer than the average (+1.8 °C), while May was 0.9 °C colder. June was more than 1 °C warmer than the 50-year average, while the temperature in July was in accordance with the average. In August, the amount of average temperature decrease was

0.5 °C, while September was warmer again, exceeding the average by 1.3 °C. *Statistical analysis.* The correlation between the dependent variable (yield) and the production factor (fertilisation, irrigation) was evaluated using a general linear model (GLM). Duncan's test was used to compare yield to its mean values. The correlation between dependent variables was evaluated using a linear function. Functions were fitted with regression analysis and by minimising the sum of squared deviations. The correctness of fitting the functions was determined using the R value and the mean squared error. Evaluation was performed using SPSS for Windows 14.0.

Results

The yield quantified for each crop year – averaged over the different treatments – shows significant differences. The yield difference was significant in all three years at a 0.1% level. The most significant difference was observed between the dry year of 2015 and the wet year of 2016 (3475 kg ha^{-1}). Based on the paired T test of the fertilisation treatment, it can be concluded that treatment "B" (10.876 t ha^{-1}) provided better conditions for maize, but the 603 kg ha^{-1} excess yield was not shown to be significant difference in comparison with treatment "A" (10.273 t ha^{-1}). By examining the two fertilisation treatments, it can be concluded that treatment "B" was more successful in 2014 – averaged over the different treatments – by 1006 kg ha^{-1}, but the difference is not significant. In the dry year of 2015, higher yield was observed on fields where the fertilisation treatment "B" was applied and the difference (1306 kg ha^{-1}) was significant ($P<0.05$). There was no notable difference between the two treatments in 2016 (Table 1).

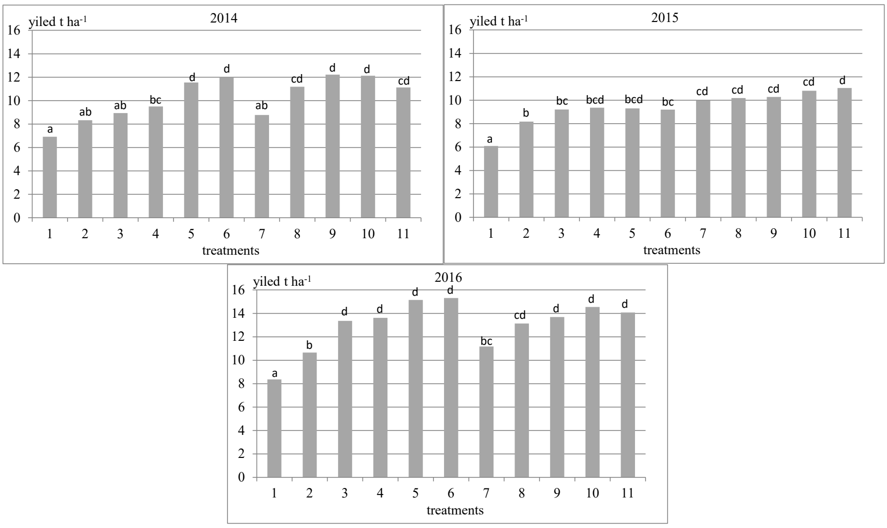
Table 1. The impact of crop year and fertilisation treatments on maize yield (Debrecen, 2014–2016)

	Average yield (t ha^{-1})		
Fertilisation treatment	2014	2015	2016
"A"	9.460^{ns}	8.490*	12.870^{ns}
"B"	10.466	9.796	12.366

Legend: *P=0.05, ns= not significant

As a result of examining the significance of fertilisation treatments carried out each year, it was shown that larger fertiliser doses had a favourable effect in *2014*. However, the effect of the fertiliser doses of 120:92:108, 150:115:135, 120:184:216, 180:184:216, 240:184:216 and 300:184:216 kg NPK ha^{-1} cannot be separated from each other. All six treatments were equally shown to provide significantly better impacts in terms of yield compared to the non-treated control and the 30:23:27, 60:184:216 and 60:46:54 kg NPK ha^{-1} treatments. Compared to the non-treated control, the response to the higher doses of 30:23:27, 60:46:54 and 60:184:216 kg NPK ha^{-1} was properly realised in yield, but the Duncan's test showed that the yield resulting from these four fertilisation treatments were classified into the same homogeneous group. The yield of the 90:69:81 kg NPK ha^{-1} treatment (9.506 t ha^{-1}) was significantly different from the yield resulting from lower and higher fertiliser doses. In 2014, yield increased as a result of nutrient supply and the highest value was observed in the case of 120:92:108 kg NPK ha^{-1} (11.546 t ha^{-1}) (Figure 2). There was a notable difference (3658 t ha^{-1}) between the yield of the non-treated control and the fertilised plots in the driest year of *2015*. Even the lowest dose of 30:23:27 kg NPK ha^{-1} resulted in an excess yield of 2074 kg ha^{-1}, but the impact of this treatment did not show any significant yield increase in comparison with the other treatments of treatment "A". There was a slight, non-significant difference between the impact of the NPK fertiliser doses evaluated in treatment "B". In this year, the fertiliser level of 90:69:81 kg NPK ha^{-1} was shown to have a favourable effect (Figure 2).

Figure 2. The impact of fertilisation on maize yield (Debrecen, 2014–2016)



Legend: Columns indicated with different letters significantly differ from each other at the level of P≤0.05, based on Duncan's test

The more favourable weather impact of *2016* made larger yields possible (13403 kg ha^{-1}). The yield of the non-treated control was 8.353 t ha^{-1}, which was properly separated from the other fertiliser levels. There was no significant yield increase between the doses of 30:23:27 and 60:184:216 81 kg NPK ha^{-1} (519 kg/ha). Similarly, no significant difference was observed between the doses of 60:184:216 81 and 120:184:216 kg NPK ha^{-1} (1958 kg ha^{-1}). The other fertiliser treatments carried out in the experiment resulted in nearly identical yields, which formed a homogeneous group based on the Duncan's test. In 2016, the highest yield resulted from the fertiliser dose of 60:46:54 kg NPK ha^{-1} (Figure 2).

Conclusions

Based on the MQ value of the multivariate ANOVA, the environmental factor had the most significant yield impact (at a level of 0.1%), averaged over the three examined years. Treatment "B" was not shown to be significantly better than treatment "A". The different fertiliser doses used in these treatments had a significant impact ($P<0.001$). Similarly to the conclusions of Izsáki (2008), the highest and economically attainable yield was not observed in the same year during either of the examined years. In 2014, the highest yield resulted from the 180:184:216 kg NPK ha^{-1} treatment, which was only 6% higher than the yield resulting from 120:92:108 kg NPK ha^{-1}, which provided the highest significant yield. In 2015, the difference between the results of the statistically significant 90:69:81 kg NPK ha^{-1} and the extreme 300:184:216 NPK ha^{-1} treatments was 18%. In 2016, there was a 16% difference between the treatment of 60:46:54 NPK ha^{-1} which was statistically significant and the treatment of 150:115:135 NPK ha^{-1} which provided the highest yield. Averaged over the three examined years, 90:69:81 kg NPK ha^{-1} was the most effective treatment. Similarly to the results of Pepó (2012), it was shown with statistical methods that crop year greatly affects the impact of applied fertilisers. The most effective NPK ha^{-1} level resulted in 23% yield difference between the rainfall-deficient (-55 mm) year of 2015 and

2014, when the amount of rainfall was 45 mm higher than the 50-year average, while it was 43% in 2016, when the precipitation surplus was 110 mm. The difference between the yields of the two years with excess rainfall (2014 and 2016) was the lowest (16%).

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