Factors Determining Yield Safety of Maize

Enikő Vári

***Abstract*—** Our long term experiment was set up at the University of Debrecen, Hungary (N: 47º33', E: 21º27') on chernozem soil. Our aim was to evaluate the interactions between the crop year and certain agrotechnical factors (i.e. crop rotation, irrigation, fertilization and plant density). According to our results, irrigation is more likely to lessen annual yield fluctuation. As for plant density, we found that corn grown in a monoculture produced the most unstable and smallest yield in the 8-year experiment. In the case of bi- and tricultures, yields were significantly larger compared to the monoculture, however, there were no statistically proven differences between bi- and tricultures. The smallest yield fluctuations were experienced in the control parcels during the 8 years, although yields produced at that time were significantly below the results of other treatments. Higher yields were experienced when the amount of rainfall between October and September reached 600 mm.

***Keywords*—** crop year, maize, yield stability

I. Introduction

SOME of the biggest challenges in maize production are environmental changes caused by the lack of available water and the decrease of ground water [5]. Global climate change – temperature rising and inadequate distribution of precipitation over time – responsible for drought is expected to result in yield loss in maize production [4]. According to [11], besides the total amount of rainfall in a crop year it is its distribution over time that significantly affects yield. Adverse weather conditions show up as abiotic stress factors in the generative and the vegetative stages of corn development thus yield decreases [15]. Combined analysis of variance by [3] show that it is the crop year (especially the amount of rainfall) that affects yield the most. Smaller yields are not always linked to drought years but higher yields usually occur in wet years [10]. According to [13], crop year and agrotechnical factors jointly determine the amount and stability of corn yield. Stability is an important indicator of natural sustainability. According to [6] and [17] stability analysis is a great tool to examine the relationships between the different treatments and the environment. The most important agrotechnical factors determining yield are crop rotation, fertilization, plant density and irrigation. Higher yields can be reached in bicultures (soy – maize) than in monocultures [16]. [9] examined the effect of yield stability on crop rotation and found the yield of corn grown in a monoculture to be the most unstable. According to [12] maize tolerates partial monocultures but grown in a monoculture it produced 1.3 t ha^{-1} less yield in an average year and 3 to 4 t ha^{-1} less in a drought year compared to the yield achieved in crop rotation. Maize requires harmonic NPK supply but nitrogen has the most important role amongst primary nutrients [7,8]. Experiments by [20] between 2008 and 2010 proved that there was a significant relationship between fertilization and harvested productions of corn. Based on the studies by [1] the highest yields were achieved by using up 96 kg ha^{-1} N in 2003, then 153 kg ha^{-1} in 2004 and 159 kg ha^{-1} in 2005, which meant that optimum fertilizer doses varied significantly depending on the crop year (water supply). According to [19] and [14] fertilization in dry years not accompanied by irrigation resulted in yield depression. A long term experiment by [2] showed that, in the average of 40 years, the harvested production of maize was 2.533 t ha^{-1} less than in wet years and the optimal crop density also changed. The optimum crop density proved to be 50 000 plant ha^{-1} in dry, while 80 000 plant ha^{-1} in wet years. Increased plant density, according [18] also, was affected by site conditions, nutrient and water supply as well as the crop year.

II. Materials and Methods

Our long term experiment was set up on chernozem soil at the Látókép AGTC KIT research area of the University of Debrecen.

TABLE I
EXPERIMENTAL SOIL DATAS

Soil layes (cm)	pH value	Soil physical structure	$CaCO_3$ %	Humus content %	Total N %	$NO_3 + NO_2$ ppm	P_2O_5	K_2O
							AL soluble	
							ppm	ppm
0-25	6.46	43.0	0	2.76	0.150	6.20	133.4	239.8
25-50	6.36	44.6	0	2.16	0.120	1.74	48.0	173.6
50-75	6.58	47.6	0	1.52	0.086	0.60	40.4	123.0
75-100	7.27	46.6	10.25	0.90	0.083	1.92	39.8	93.6
100-130	7.36	45.4	12.75	0.59	0.078	1.78	31.6	78.0

The experimental site is located in Eastern-Hungary, 15 km far from Debrecen, on the area of the aeolain loess of the Hajdúság (N: 47º33', E: 21º27'). The site is plain, even and the

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type of soil is chernozem with lime patches. Experimental data of the baseline show that the area can be classified as loamy and nearly neutral. Phosphorus supply of the soil is medium, its potassium supply is rather medium or good as shown in Table I. As for crop rotation, we set up three models: a monoculture (maize), a biculture (wheat and maize) and a triculture (pea, wheat and maize). W applied five levels of nutrients during the fertilization process (control, $N_{60}P_{45}K_{45}$, $N_{120}P_{90}K_{90}$, $N_{180}P_{135}K_{135}$ and $N_{240}P_{180}K_{180}$), 3 variations of the plant density (40 000 plant ha^{-1}, 60 000 plant ha^{-1} and 80 000 plant ha^{-1}), and last but not least, 3 versions of irrigation methods (non-irrigated – Ö1, irrigation complemented up to 50% of the optimum – Ö2, and irrigation complemented up to the optimum – Ö3). The experimental parcels were set up in random arrangements in four repetitions. We used hybrid Reseda (PR37M81) in the research. The most important agrotechnical and meteorological data is summarized in Table II. We evaluated the result of the years 2004 - 2011 in our publication. The weather of 2004 was rather average in respect of the development of maize. The average temperature in the crop year was similar compared to the 30-year average (17.1 ^oC, average of many years: 16.8 ^oC). The amount of rainfall was favorable during the flowering and the fertilization and exceeded the long term average by 76.5 mm. Rainfall in 2005 exceed the long term average. There was no need for irrigation since sufficient rainfall provided for favorable water supply conditions for the development. July rainfall, which was 34 mm more compared to the 30-year average, and favorable weather conditions led to prosperous fertilization and grain development. Certain months of 2006 could be characterized as dry, while the rest of them were wet. On the whole, the average temperature and rainfall during the crop year were similar to the long term average. On the contrary, July ended up to be especially warm (23.2 ^oC compared to the 30-year average 20.3^oC) and dry (30.8 mm, compared to the 30-year average 65.7 mm). The weather in 2007 was extremely unfavorable in terms of maize development. The average temperature of the vegetative period exceeded the long term average by 2.0 ^oC while the amount of precipitation was 61,3 mm less.

TABLE II
METEOROLOGICAL PARAMETERS IN THE VEGETATION PERIOD OF MAIZE (DEBRECEN, HUNGARY, 2004-2011)

Year	Month	Temperature (^0C)	30 years' average (1960-1990)	Precipitation (mm)	30 years' average (1960-1990)	Data of irrigation	Ö2 amount of irrigation water	Ö3 amount of irrigation water
2004	October-September	9.7	9.8	600.2	565.3	8-11 June	25	50
	April-September	17.1	16.8	342.4	345.1	6-11 June	25	50
	July	21.1	20.3	142.2	65.7	Total (mm)	50	100
2005	October-September	9.8	9.8	707.5	565.3	-	-	-
	April-September	17.1	16.8	502.1	345.1	-	-	-
	July	21.1	20.3	99.7	65.7	-	-	-
2006	October-September	9.9	9.8	575	565.3	6-14 July	25	50
	April-September	17.6	16.8	326.2	345.1	22-28 July	25	50
	July	23.2	20.3	30.8	65.7	Total (mm)	50	100
2007	October-September	12.5	9.8	412	565.3	4-16 May	25	50
						22-24 May	25	50
	April-September	18.8	16.8	283.8	345.1	4-7 June	25	50
						27-30 June	25	50
	July	23.3	20.3	39.7	65.7	Total(mm)	100	200
2008	October-September	10.2	9.8	644.7	565.3	-	-	-
	April-September	16.6	16.8	483.9	345.1	-	-	-
	July	20.4	20.3	144.9	65.7	-	-	-
2009	October-September	11.9	9.8	372	565.3	30 April- 7 May	25	50
	April-September	19.5	16.8	168.8	345.1	15-19 May	25	50
	July	23.4	20.3	9.2	65.7	Total (mm)	50	100
2010	October-September	10.9	9.8	924.4	565.3	-	-	-
	April-September	17.2	16.8	590.1	345.1	-	-	-
	July	22.0	20.3	97.2	65.7	-	-	-
2011	October-September	10.3	9.8	564.8	565.3	27. June	25	25
	April-September	18.2	16.8	313.8	345.1	29. June	-	25
	July	20.4	20.3	175	65.7	Total (mm)	25	50

The weather was extremely dry during the critical phenophase, the flowering and the fertilization of maize. Irrigation was applied four times by applying 25 mm and 50 mm of irrigation water per time. Conversely, the year 2008 was rather optimal in terms of the vegetative and generative development of maize. The total amount of precipitation in the crop year was also favorable (483.9 mm). July was especially rainy (144.9 mm) with average temperature (20.4 ^oC). The annual rainfall in 2009 was low as this was the driest year between 2004 and 2011. The amount of precipitation between April and September was 168.8 mm which was far below the long term average (345.1 mm). On the other hand, weather conditions were above the 30-year average as the temperature in July exceeded the long term average by 3 ^{o}C. By the end of August, plants lost their assimilation surfaces. 2010 was the most rainfall during the experiment as the amount of precipitation was 590.1 mm between April and September. High rainfalls in April and May provided favorable water supply conditions for development. The wet and warm weather continued in June and July which provided for further water supply and smooth development. The average temperature in 2011 exceeded the long term average by 1.4 ^{o}C. The spring and the beginning of summer were rather dry, while the amount of precipitation between April and September was 31.3 mm more compared to the long term average. On the other hand, rainfall was favorable at the time of flowering and fertilization as it was 109.3 mm more than the long term average. During the crop year, corn uses up quite a large amount of water and nutrients to produce its huge vegetative and generative mass but it is also influenced by several ecological (weather and soil conditions), biological (hybrid) and agrotechnical (crop rotation, cultivation, fertilization, plant density, irrigation) factors. We examined the interactive effects of the meteorological factors as abiotic stress factors and some of the most important agrotechnical factors (crop rotation, fertilization, plant density, irrigation) in years where weather conditions varied considerably (2007 and 2009: dry; 2004, 2006, 2008 and 2011: average; 2005 and 2010: rainy).We applied linear regression to evaluate the interactions between the crop year and the agrotechnical factors. Treatments resulting in the highest stability do not necessarily go together with the highest yields. The aim of the research was to find those cultivation methods that lessen yield fluctuations per year the most. We applied linear regression to evaluate the interactions between the year and the various agrotechnical factors (crop rotation, fertilization, plant density, irrigation). The lines fitted well, which fact was also underpinned by the high R^2 values (0.9356-0.9947), therefore they were suitable to draw our conclusions. The stability index is the steepness of the linear represented by the regression coefficient (b). If b < 1, it means that corn could adopt well to the adverse conditions due to a certain treatment. This is to say that the higher the value of the regression coefficient, the more the yield changes along with the circumstances. The most stable treatments are the ones with the smallest b values, where yield fluctuates the least in various years.

III. Results and Discussion

By evaluating the effects of irrigation, it can be concluded that the smallest b value (0.8725) was achieved in version Ö3 as shown in Figure 1. When studying the relationships between plant density and yield we found that, during the 8 years, yield fluctuation was the smallest at a plant density of 40 000 ha^{-1}. Results of the other two plant density versions were similar to each other.

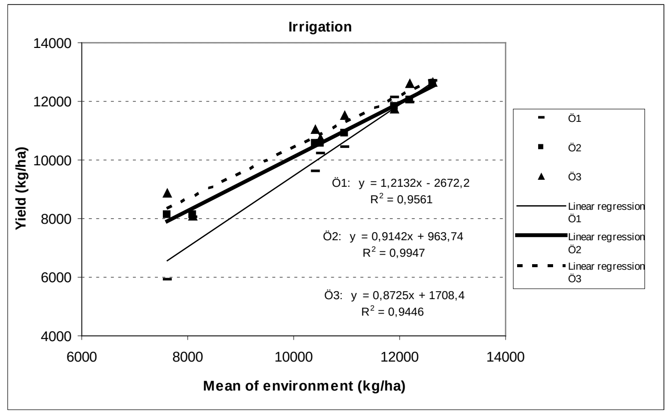

Fig.1. The effect of irrigation on maize yield stability

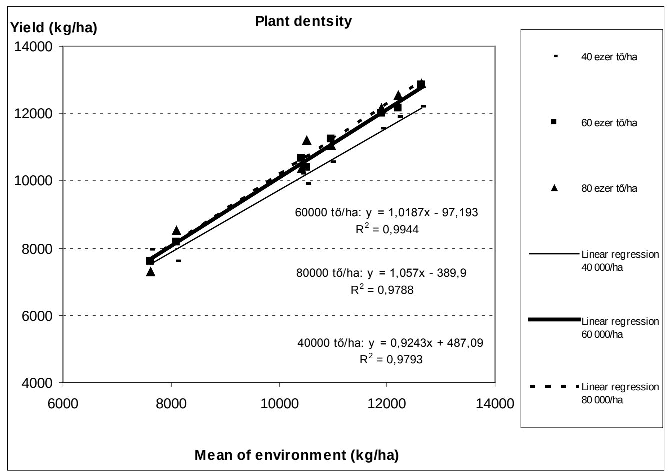

Fig.2. The effect of plant density on maize yield stability

The most favorable treatments are the ones where high yield comes with high stability. This is what we focused on when illustrating crop rotation in Figure 3. Yields achieved in a monoculture were far below the ones reached in bi- or tricultures.

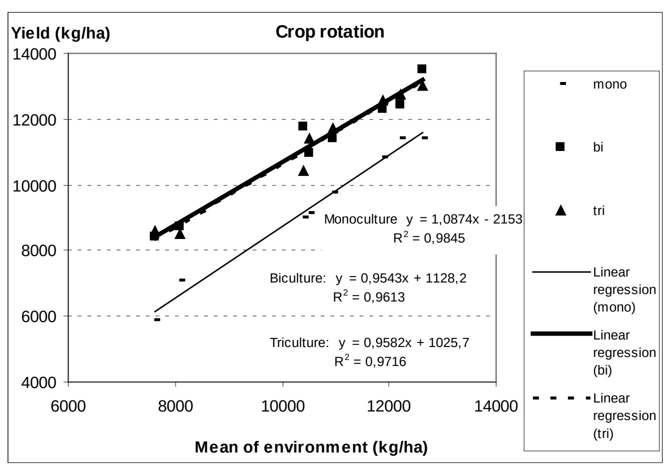

Fig.3. The effect of crop rotation on maize yield stability

The slope of the line was the largest as for the monoculture (the value of the regression coefficient was 1.0874) which refers to the most unstable yield achieved during the examined years. Enhanced fertilization significantly enhanced yields, however, the smallest yield fluctuations during the 8 years were observed in the control parcels where the value of the regression coefficient was 0.7683 (yield in 2010: 6 422 kg ha^{-1}, and in 2008: 10 481 kg ha^{-1}). Level $N_{240}P_{180}K_{180}$ reacted the more intensely to improved environmental conditions where the value of b was 1.1302. The years were also compared to each other one by one as shown in Table III.

In dry years (2007, 2009) and in 2011, there was a statistically proven increase in yields due to irrigation, both in the terms of Ö2 and Ö3. When evaluating the rest of the years, significant differences emerged only between versions Ö1 and Ö3.

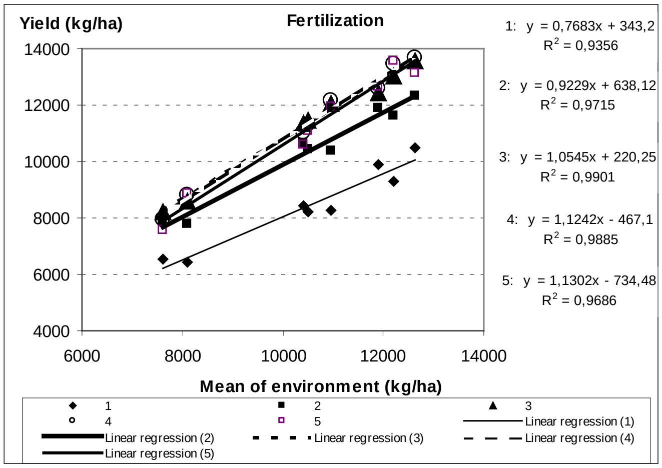

Fig.4. The effect of fertilization on maize yield stability

Yields increased by increasing plant density. Yields increased significantly until a plant density of 60 000 ha^{-1} but when reaching up to 80,000 ha^{-1}, notable growth could only be observed in 2 other years (2006, 2010). The effects of environmental factors (irrigation) on plant density optimum also proved that the maximum yield (7,952 kg ha^{-1}) was achieved in the extremely dry year of 2007 at a plant density of 40 000 ha^{-1}. Increased plant density at this time decreased yield, however, not significantly. The yield forming effect of plant density is complex. Lower results were measured in the monoculture (5 857 kg ha^{-1} to 11 433 kg ha^{-1}). As for the bi- and tricultures, yield results were significantly better compared to the monoculture. On the other hand, there were no statistically proven differences between the bi- and triculture. Yields in the average of treatments varied between 8 400 – 13 507 kg ha^{-1} in the biculture and between 8 606 – 13 016 kg ha^{-1} in the triculture depending on the year. By the application of the appropriate amount of fertilizers, in years with favorable rainfall, yields could grow up to 13 500 kg ha^{-1} on chernozem soil. Yields increased due to increased levels of nutrients, however, various levels of nutrients per years were needed to achieve an outstanding yield. In the average of treatments this increase was significant between 2005 and 2011 up to level $N_{120}P_{90}K_{90}$. In certain cases, increased nutrient levels resulted in enhanced yields but the growth was no longer significant. In 2004 yields enhanced up to level $N_{180}P_{135}K_{135}$ (13 481 kg ha^{-1}).

TABLE III
EFFECT OF FERTILIZATION, CROP ROTATION, IRRIGATION AND PLANT DENSITY ON YIELD OF MAIZE (DEBRECEN, HUNGARY, 2004-2011)

		Yield (kg ha^{-1})							
Years		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
IRRIGATION	**$LSD_{5\%}$**	**423**	**324**	**365**	**330**	**361**	**355**	**286**	**415**
Ö1		11951	12119	10211	5896	12680	9589	8040	10441
Ö2		12043	11831	10580	8114	12599	10569	8147	10921
Ö3		12610	11732	10723	8855	12635	11063	8102	11523
PLANT DENSITY	**$LSD_{5\%}$**	**424**	**321**	**351**	**417**	**355**	**375**	**275**	**421**
40 000 ha^{-1}		11900	11529	9905	7952	12195	10188	7601	10568
60 000 ha^{-1}		12161	12007	10410	7606	12838	10674	8177	11255
80 000 ha^{-1}		12544	12146	11200	7308	12882	10359	8510	11062
CROP ROTATION	**$LSD_{5\%}$**	**411**	**286**	**306**	**331**	**309**	**294**	**242**	**385**
monoculture		11433	10841	9142	5857	11391	8996	7067	9739
biculture		12419	12284	10965	8400	13507	11783	8716	11426
triculture		12753	12557	11408	8608	13016	10442	8505	11720
FERTILIZATION	**$LSD_{5\%}$**	**345**	**319**	**349**	**520**	**343**	**401**	**273**	**377**
1 (control)		9301	9918	8202	6519	10481	8414	6422	8273
2 ($N_{60}P_{45}K_{45}$)		11647	11871	10434	7862	12308	10651	7772	10386
3 ($N_{120}P_{90}K_{90}$)		13007	12442	11457	8238	13551	11331	8592	12064
4 ($N_{180}P_{135}K_{135}$)		13481	12597	11324	7938	13692	11034	8837	12155
5 ($N_{240}P_{180}K_{180}$)		13571	12642	11106	7552	13160	10605	8859	11930

IV. CONCLUSION

Based on the results of the regression coefficients we found that yield fluctuation could be lessened by irrigation. The most suitable version turned out to be the irrigation complemented up to the optimum. We saw a statistically proven yield increase between version Ö1 (non-irrigated) and Ö3 (complemented up to the optimum). As evaluating plant density we found that the most stable yield was produced at a plant density of 40 000 ha^{-1} during the 8 years. Yield varied between 7 606 to 12 838 kg ha^{-1} at 60 000 ha^{-1} and the fluctuation was quite similar in the case of

80 000 ha^{-1}. Yields increased remarkably until 60 000 ha^{-1}. Results by Berzsenyi et al. (2011) and Sárvári (1995) prove the effects of environmental conditions (water supply) on optimum plant density as maximum yields were achieved in draught years at low plant density. Our experiences regarding crop rotation were in line with the result of Mead et al. (1986). Corn grown in a monoculture produced the most unstable yield during the 8 years amounting to 5 857 – 11 433 kg ha^{-1} in the average of treatments. In corn monocultures, water and nutrient supply of the soil notably decreases which leads to decreased yields. As for the bi- and tricultures, the yield results were significantly better compared to the monoculture but there were no statistically proven differences between the bi- and triculture. Fertilization had a double effect. Enhanced fertilization significantly enhanced yields and the value of the regression coefficient. This meant that the lowest fluctuation of yields occurred in the control parcels (b= 0.7683) however, yields were far below compared to the other treatments. Our results regarding the extent of water supply were in accordance with the result of Nagy (2007). Yields were higher in those years where the amount of precipitation between October and September reached 600 mm. Extreme rainfalls (2010), however, had an adverse effect on corn yields.

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