ROMANIAN AGRICULTURAL RESEARCH, NO. 29, 2012
Print ISSN 1222-4227; Online ISSN 2067-5720

AIR TEMPERATURE AND PRECIPITATION INFLUENCE ON MAIZE GRAIN YIELD WITHIN DIFFERENT ANNUAL AND PERENNIAL CROP ROTATIONS

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ABSTRACT

This research was intended to estimate the influence of season temperatures and precipitations on maize grain yield in different several annual and perennial crop sequences (rotations) under rain-fed conditions, over 10 years, in the southern zone of Romania (Fundulea location). Maize produced less grain under higher summer temperature, but its yield increased with more summer rainfall. Crop rotation break with a perennial alfalfa (*Medicago sativa* L.), as fertility restoration plot, increased very significantly the maize grain yield. The *rotation breaking x year* interaction was distinctly significant. The advantage of rotation breaking was lower during seasons with warmer springs. The highest mean maize grain yield, of 10.08 t ha^{-1}, was recorded for the three year rotation, being with 0.66, 0.69, and 1.89 t ha^{-1} higher than those obtained with 4 year rotation, 2 year rotation, and monoculture, respectively. The benefit of rotation in terms of grain yield was greatest for maize during years with cool summers. Seasonal temperature and rainfall patterns influenced the effect of crop rotation and its breaking with a perennial crop on maize yield. This study represents a contribution to better understanding of maize plant physiology and its agronomic requirements for obtaining high grain yields in the specific soil and climate conditions of southern Romania.

Key words: maize, monoculture, crop rotation, crop rotation breaking, temperature, precipitation.

INTRODUCTION

In modern agriculture, crop rotation represents one of the most important measures for maintaining and increasing soil fertility, pest control, as well as for achieving profitable and high quantity and quality yields. Experimental data reveal that crop rotation is essential for obtaining high maize grain yields (Varvel, 1994), reducing in the same time input costs, and so increasing the economic efficiency (Nedelciuc et al., 1995). Maize – soybean rotation proved to be more effective in preventing deep leaching of nitrate N than continuous maize (Varvel and Peterson, 1990). Reduced stress from pests may be one of the reasons for improved yield with crop rotations (Boosalis and Doupnik, 1976).

This research, carried out within a long term experiment, had the goal to evaluate the influence of seasonal temperature and precipitation on the maize grain yield in several annual and perennial crop sequences (rotations).

MATERIAL AND METHODS

This research was initiated in 2002 at the National Agricultural Research & Development Institute (NARDI) Fundulea, located in Southern Romanian Plain, at 44º27’45” latitude and 26º31’35” longitude, east of Fundulea town, on a typical cambic chernozem, without irrigation.

The experiment was designed as a randomized complete block (four blocks). Crop rotation treatments were assigned to plots 32 by 5 m, that included monoculture, 2 year rotation (maize – winter wheat), 3 year rotation (maize – soybean – winter wheat) and four year rotation (maize-sunflower-pea-winter wheat). Similar rotations were also used after the 3-4 year rotation break with a perennial alfalfa crop.

Grain maize plots were planted each year around mid April and harvested at physiological maturity, by the middle of September. The distance between rows was of 70 cm. and plant population of 60,000 per ha.

Received 17 January 2012; accepted 15 February 2012

Yield was evaluated harvesting manually the two rows of the middle of the plot. Grain yield was adjusted to the constant moisture of 15.5%.

Precipitation use efficiency was determined by dividing grain yield by annual precipitation (1 October to 30 September) and expressed as kilograms per hectare per centimetre rainfall.

Data were analysed using a split plot in time analysis of variance. Years were considered as split plots in time and a random effect. Block, rotation interruption, and rotation effects were considered fixed in determining the expected mean squares and appropriate F tests in the analysis of variance. Alpha = 0.05 was used in this study to establish significance of effects or differences, unless stated otherwise.

To assess the weather influence on productivity during different parts of the season, correlations were calculated between grain yield and mean air temperature and total precipitation of weekly intervals over each season (1 October through 30 September). Weekly intervals with high correlations to grain yield tended to cluster, but the clusters were not consistent between air temperature and precipitation. Intervals with significant ($P<0.05$) correlations with grain yield are reported. Results of these analyses are reported as yield response (increase or decrease) to temperature and precipitation. When we state, for example, that yield was lower with high temperature for a specific period, we are comparing temperature and the yield response for the specific year to the average temperature for the duration of the study. Stated in other terms, if for the specified period, a negative correlation occurred between grain yield and temperature, this means that higher-than-average yields occurred in years when temperature for the period was less than average. No specific value can be assigned to high or low temperature or precipitations, the specific values differed for each period and each comparison. Even though specific values cannot be stated, the significant correlations indicate that the relative relationship occurred with a frequency greater than can be attributed to chance.

When *treatment x environment* (year or site) interactions are significant, the stability model of Eberhart and Russell (1966) is a tool often used by crop breeders, geneticists and agronomists for further analysis (Lin et al., 1986). In this model, the environments mean is considered as the mean of all annual yield means of the variants which are compared. The relationship between environments mean and the mean of individual variants is expressed with the help of regressions, and the variants are compared by analysing the regression lines. Since the interaction among years, rotation breaking by a soil fertility restoration plot, and crop rotations was very significant, the annual mean regressions of rotation breaking and of crop rotation were compared against the environments mean (expressed by the annual average yield of all maize variants). The linear regression slopes of maize grain yield with environment conditions average were compared for the two rotation breaking variants and the four crop rotations, using the test for equality of slopes of several regression lines described by Sokal and Rohlf, 1995 ($P<0.05$).

RESULTS AND DISCUSSION

Total precipitations of October – September period and their distribution varied greatly in the respective 10 experimental years (Figure 1). The largest precipitation amount, of 1068.4 mm, was registered in 2004-2005 agricultural year, and the lowest amount (330.1 mm) in 2006-2007. Annual precipitation amount average over the 10 years was 639.0 mm. During the whole period, February was the driest month, with a mean of 22.0 mm and amplitude from 2.3 mm in 2008 to 69.8 mm in 2010. July was the most humid month, with a mean of 104.7 mm and values ranging between 57.5 mm in 2008 and 256.8 mm in 2002.

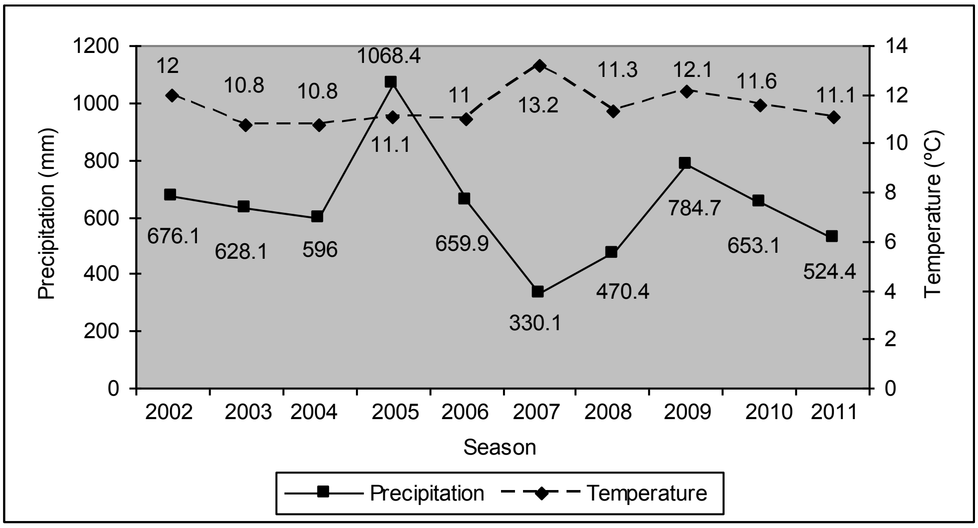

Figure 1. Seasonal (1 October - 30 September) precipitation and mean air temperature at Fundulea, 2002 to 2011

Mean air temperature of the whole experimental period was 11.5ºC. The 2006-2007 agricultural year was the hottest, with a temperature mean of 13.2ºC. The lowest temperature mean was calculated for the years 2002-2003 and also for 2003-2004 (10.8ºC). Crop rotation, rotation break with a perennial crop, year and the interaction among them influenced distinctively or very significantly the maize grain yield (Table 1).

Table 1. Analysis of variance of maize grain yield along 10 experimental years, as according to crop rotation and rotation break with a perennial crop for soil fertility restoration (Fundulea, 2002-2011)

Source of variation	DF	Mean square	F value
Year (A)	9	540.205	94.205***
Rotation break (B)	1	75.772	28.465***
A x B	9	9.185	3.450**
Rotation (C)	3	198.315	149.858***
B x C	3	22.69	17.145***
A x C	27	12.602	9.523***
A x B x C	27	8.568	6.474***

Maize grain yield mean over the 10 years without rotation break with a perennial crop for soil fertility restoration was 9.03 t/ha (Table 2). Annual yield averages varied between 4.33 t/ha and 11.43 t/ha. In the case of rotation break with a perennial crop, the maize grain yield mean over the 10 years was 9.52 t/ha, with annual values between 5.51 t/ha and 11.55 t/ha.

The very significant influence of crop rotation on maize grain yield (Table 2) should be viewed mainly as a result of the low value recorded for monoculture (8.19 t ha^{-1}), in comparison with that of 3 year rotation (10.08 t ha^{-1}). It can be seen that this difference is also quantitatively important. Yields registered for the other crop rotations look practically similar (9.39 t ha^{-1} for the 2 year rotation, and 9.42 t ha^{-1} for the 4 year rotation), and they are statistically different from the previous two variants.

Annual grain maize yield was lower when the mean air temperature in June 21 - August 31 period was higher (r = -0.80; Table 3), and it correlated positively with precipitations during May 11 - August 20 (r = 0.70; Table 3).

Table 2. Maize grain yield (t/ha) over 10 experimental years, in 4 crop rotations, with and without rotation break with a perennial soil fertility restoration plot (Fundulea, 2002-2011)

Year	Monoculture			2 year rotation			3 year rotation			4 year rotation			Mean		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
2002	9.64	11.17	10.4	12.29	10.05	11.17	12.29	11.45	11.87	11.47	10.40	10.94	11.43	10.77	11.09
2003	6.14	7.16	6.65	8.40	7.29	7.84	8.06	7.87	7.97	7.09	8.93	8.01	7.42	7.81	7.62
2004	9.95	10.43	10.19	9.79	10.28	10.03	11.59	12.74	12.17	11.83	12.27	12.05	10.79	11.43	11.11
2005	9.86	9.47	9.66	10.80	12.07	11.43	11.39	11.71	11.55	10.92	12.94	11.93	10.74	11.55	11.14
2006	6.12	7.04	6.58	7.88	8.48	8.18	7.76	8.39	8.07	7.53	8.04	7.79	7.32	7.99	7.66
2007	2.93	4.60	3.77	4.32	5.79	5.05	5.29	5.70	5.49	4.76	5.95	5.36	4.33	5.51	4.92
2008	5.74	6.84	6.29	8.95	9.23	9.09	9.98	10.07	10.03	9.02	8.31	8.67	8.42	8.62	8.52
2009	8.74	9.39	9.06	10.52	11.25	10.89	10.22	11.24	10.73	9.69	8.65	9.17	9.79	10.13	9.96
2010	9.05	12.03	10.54	9.28	10.15	9.71	10.76	11.91	11.34	11.01	10.57	10.79	10.03	11.16	10.59
2011	7.37	10.17	8.77	11.14	9.84	10.49	11.94	11.25	11.59	9.59	9.51	9.55	10.01	10.19	10.09
Mean	7.55	8.83	8.19	9.34	9.44	9.39	9.93	10.23	10.08	9.29	9.56	9.42	9.03	9.52	9.27

I - without rotation break with a perennial soil fertility restoration plot; II - with rotation break with a perennial soil fertility restoration plot; III – mean; SE for comparing the means of the variants within rotation break = 0.091 t ha^{-1}; SE for comparing the means of the variants within rotations = 0.090 t ha^{-1}; SE for comparing the year means = 0.299 t ha^{-1}; SE for comparing the means of *rotation x rotation break* interaction = 0.129 t ha^{-1}; SE for comparing the means of *year x rotation* interaction = 0.287 t ha^{-1}; SE for comparing the means of *year x rotation break* interaction = 0.288 t ha^{-1}; SE for comparing the means of year x *rotation break x rotation* interaction = 0.407 t ha^{-1}

Table 3. Coefficients (r) of correlation between maize grain yield, mean air temperature, and total precipitation for specific periods during the vegetation season

	Temperature		Precipitation	
	r	Interval	r	Interval
Mean	-0.80**	June 21 - August 31	0.70*	May11 - August 20
Without rotation break	-0.78**	June 21 - August 31	0.67*	May11 - August 20
With rotation break	-0.81**	June 21 - August 31	0.71*	May11 - August 20
Monoculture	-0.74*	June 21 - August 31	0.68*	May11 - August 20
2 year rotation	-0.76**	June 21 - August 31	0.69*	May11 - August 20
3 year rotation	-0.76**	June 21 - August 31	0.70*	May11 - August 20
4 year rotation	-0.84**	June 21 - August 31	0.73*	May11 - August 20
With rotation break - Without rotation break	-0.64*	May 10-20	ns	
3 year rotation break - Monoculture	ns		0.70*	April 20 - May 10
Without rotation break, 3 year rotation - Monoculture	ns		-0.63*	July 1-20

***Significant at $p<0.001$; ** Significant at $p<0.01$;* Significant at $p<0.05$; ns = not significant at $p<0.05$.

Mean of precipitation utilization efficiency for the variant without crop rotation break with a soil fertility restoration plot was 145.9 kg ha^{-1} cm^{-1}, with annual values ranging between 111.1 and 190.0 kg ha^{-1} cm^{-1}.

For the variant with crop rotation break this mean was 154.9 kg ha^{-1} cm^{-1}, calculated from annual values ranging between 108.1 and 194.3 kg ha^{-1} cm^{-1}. The means of precipitation utilization efficiency for crop rotation variants were as follows: 131.3 kg ha^{-1} cm^{-1} for monoculture (with annual values between 90.4 and 171.0 kg ha^{-1} cm^{-1}), 152.3 kg ha^{-1} cm^{-1} for maize - winter wheat rotation (with annual values between 107.0-200.0 kg ha^{-1} cm^{-1}), and 153.2 kg ha^{-1} cm^{-1} for the 4 year rotation (with annual values between ranging between 111.6-202.2 kg ha^{-1} cm^{-1}). The highest value of precipitation utilization efficiency (164.8 kg ha^{-1} cm^{-1}) was recorded for maize – soybean – winter wheat rotation (with annual values between 108.1 and 221.0 kg ha^{-1} cm^{-1}).

Rotations break with a perennial crop x year interaction significantly influenced the maize grain yield (Table 1).

Table 4. Influence of interaction between crop rotation and rotation break with a soil fertility restoration plot on maize grain yield, described by the regression between mean of individual variants and the environment index consisting of annual yield average of all variants (in t ha^{-1})

Crop rotation	Rotation type	Mean yield	Intercept	Slope	r²
Monoculture	Without rotation break	7.55	-2.53	1.09	0.84
	With rotation break	8.83	-0.86	1.05	0.85
2 year rotation	Without rotation break	9.34	0.25	0.98	0.83
	With rotation break	9.44	2.09	0.80	0.84
3 year rotation	Without rotation break	9.93	0.21	1.05	0.93
	With rotation break	10.23	0.45	1.05	0.95
4 year rotation	Without rotation break	9.29	-0.76	1.08	0.96
	With rotation break	9.56	1.34	0.89	0.97
Mean	Without rotation break	9.03	-0.71	1.05	0.98
	With rotation break	9.53	0.75	0.95	0.98

Linear regressions between the yield obtained within the variants of crop rotation with and without break with a perennial fertility restoration crop and the environment index (consisting in annual yield means: t ha^{-1}) showed statistically similar slopes ($Fs = 1.94 < F\ 0.05[3.32] = 2.92$). The positive effect of crop rotation break with a perennial fertility restoration crop was associated with low temperatures of May 10-20 period (r = -0.64; Table 3). An explanation may be a slower nutrients mineralization. Maize grain yield recorded with maize – soybean – winter wheat rotation was significantly higher than with monoculture.

Crop rotation x year interaction also significantly influenced the maize grain yield (Table 1). Linear regressions between the yield obtained within variants of crop rotation with and without break with a perennial crop did not reveal interaction (Table 4), having not significantly different slopes ($Fs = 1.36 < F\ 0.05[3.32] = 2.92$). The lowest r^2 value was registered for the variant maize x winter wheat without rotation break with a perennial crop ($r^2 = 0.83$), due to the negative deviations from the regression line in 2002, 2003, 2006, 2008, 2009 and 2011. However this is not evident when the decadal climatic conditions are analysed.

When precipitation amount in the period of April 20 - May 10 was higher, maize grain yield in monoculture was significantly lower than that obtained within maize – soybean – winter wheat rotation (r = 0.70; Table 3). Reduced precipitations in July 1-20 period favoured the maize grain yield in the 3 year rotation without break with a perennial crop, when compared to monoculture (r = -0.63; Table 3).

The interaction between rotation break with a perennial crop and rotation without break also significantly influenced maize grain yield (Table 1), having an important agronomic value. The slopes of linear regressions for the variants without rotation break was 0.98 t ha^{-1}, and for 2 year rotation variant with rotation break was 0.80 t ha^{-1}, indicating a lower response to environment changes than in the case of the other rotation types (Table 4).

Maize grain yield registered within maize – winter wheat rotation was over the average mean when the annual mean was low, but under average mean when the annual mean was high.

The interaction of rotation break with a perennial crop with crop rotation and with years also influenced very significantly maize grain yield (Table 1), due to the different responses of different variants to the environment index (Table 4). The effect of this interaction results mainly from the higher deviations of four variants: monoculture without and with rotation break (r^2 = 0.84, r^2 = 0.85), 2 year rotation without and with rotation break (r^2 = 0.83, r^2 = 0.84) from the response of the other variants to the environment index, as r^2 values are suggesting.

CONCLUSIONS

Annual crop rotation break with a 3-4 year perennial alfalfa (*Medicago sativa* L.), as a fertility restoration plot, increased very significantly the maize grain yield.

The 3 year rotation proved to be the best agronomic choice, assuring statistically significant and also economically important yield increases. In the respective environment-tal conditions, crop rotation influence on maize grain yield was more pronounced in cooler and more humid summers.

This study represents a contribution to a better understanding of maize plant physiology and its agronomic requirements for obtaining high grain yields in the specific soil and climate conditions of southern Romania.

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