ZESZYTY PROBLEMOWE POSTĘPÓW NAUK ROLNICZYCH 2002 z. 481: 83–88

EFFECT OF GENOTYPE x ENVIRONMENT ON MAIZE ROOT TRAITS

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Introduction

Several authors have concentrated on the effects of environment on the roots; they have brought evidence of the effects of temperature [ENGELS, MARSCHNER 1992], water [ROBERTSON et al. 1980] and light [DEMOTES-MAINARD, PELLERIN 1992] on root growth. Inversely, very few works deal with the question of genotype x environment (GE) interaction for root morphology. Some works have shown that genetic variation in maize roots interfered with some effects of the environment, such as soil and air temperature, soil moisture or evapotranspiration [HEBERT et al. 1995].

A more thorough knowledge of GE interaction in the root system, would be significant to breeding improvement, since it would give information about the way plant survive circumvent stresses [TOLLENAAR, WU 1999]. In maize this research would especially be relevant to improvement of production stability against contrasting climate conditions.

Among techniques used to fit an analysis of GEI (genotype x environment interaction), factorial regression makes it possible to identify genotypic or environmental parameters that are significant to phenomenon of GEI, and thus is a pertinent tool for characterisation of interaction causes [HEBERT et al. 1995].

The present paper intends to investigate the effects of contrasted climatic regimes on the variations among maize genotypes in plant growth. The GE interactions are analysed through factorial regression models in order to find clues to the effects of climatic factors.

Materials and methods

The set of studied maize genotypes was composed of 9 Polish and 8 French hybrids. Trials were randomised block designs with 3 replications. Plots were made of 2 rows, 5.2 m long, 0.75 m apart. Plant density was 90 000 plants per hectare. Field experiment was conducted at INRA Research Station at Lusignan (France) from 1996 to 1999 and at the Institute of Soil Science and Plant

Cultivation in Puławy (Poland) from 1997 to 1999.

Observations were made at mid-silking stage to characterise the maximal performance of genotypes. Following traits of the roots were measured on 5 plants per plot: RA7 – root angle on 7th node with reference to vertical (deg.), RD7 – root diameter (mm) on the 7th node measured at 5 mm from the stem, RN25 – root number on the 2–5 node, RN69 – root number on the 6–9 node. Roots were numbered according to the description proposed by GIRARDIN et al. [1986]. Traits measured on the shoot were as follows: SD – stem diameter of 7th internode (cm), CLA – cob leaf area (dm^2), SDM – stem dry matter (g).

The magnitude of GE interaction was checked by the F-tests of the analysis of variance (ANOVA). To evaluate the quantitative effect of the GEI on the observed traits, the factorial regression method was used [WOOD 1976; DENIS 1988]. For I genotypic covariates $(X^{(k)}, k=1...I)$ and J environmental covariates $(Z^{(l)}, l=1...J)$ the model is as follows:

$$E(Y_{ij}) = \mu + \lambda X_i + \alpha_i + \delta. Z_j + \beta_j + \varphi X_{i.} Z_j + \tau_j X_i + \rho_i Z_j$$

where:

λ, δ are regression coefficients for main effects of genotype and environment respectively;

α_i, β_j are residual terms of genotypic and environmental main effects;

φ is regression coefficient for the product of covariates X and Z, is environmental regression coefficient for genotypic covariate X;

ρ_i is genotypic regression coefficient for environmental covariate Z.

The model decomposes main effects and interaction sums of squares into terms (covariates) related with environment and genotype. As genotypic covariates were chosen: SDM, CLA and SD. As environmental covariates serve: MAT – mean, MinAT – minimal and MaxAT – maximal daily air temperature (°C), MST – daily mean soil temperature at 10 cm depth (°C), RFS – sum of rainfalls (mm), SSH – sum of sunlight hours (h), EVTP – sum of daily amounts of evapotranspiration (mm), SSR – sum of daily solar radiation ($J \cdot cm^{2} \cdot s^{-1}$).

The best factorial regression model was obtained by successive test of covariates, according to stepwise process proposed by DENIS [1988]. Estimations of error terms from ANOVA were used for significance testing in factorial regression model. INTERA statistical package (INRA Versailles) and Splus 4.0 for Windows (Mathsoft Inc.) were used.

Results and discussion

Results of the analyses of variance showed that all traits related with root system exhibited significant environment (E), genotype (G) and interaction (GEI) effects (Table 1). In most cases, GEI sums of squares were greater than the sums of squares of genotype effect (except NR69 and NRT). GEI/G sum of square ratio is particularly high for RA7 and RD7. These differences mean that there exist divergent relations between genotypes performance and environmental conditions. HEBERT et al. [1995] proved as well, that maize genotypes (in the shoot part of plant) did not have the same response on climatic factors.

Table 1; Tabela 1

Analysis of variance (sums of mean squares)
Analiza wariancji (sumy średnich kwadratów)

Trait Cecha	Environment Środowisko (E) df = 6	Genotype Genotyp (G) df = 16	Interaction Interakcja (GEI) df = 96	Error Błąd df = 183
RA7	28990*	2336*	9549*	6603
RD7	20,87*	17,98*	58,59*	28,1
RN25	335,9*	174,7*	313,6*	231,3
RN69	5762*	6230*	2293*	1195

* significant at $\alpha = 0.05$; istotny dla $\alpha = 0,05$

Table 2 gives the percentage of additive and interaction effect sums of squares associated with either environmental or genotypic characteristics. Considered together, several groups of environmental covariates seemed to be able to explain a major part of the main or GEI sums of squares: soil and air temperature, rainfall, evapotranspiration. HEBERT et al. [1995] found that year additive effect was related to the same factors. The percentages obtained for both effects varied a lot between traits and covariates. For additive part noticeable differences between traits appeared, such as no effect of soil temperature on NR69, whereas strong effect on NR25 was measured. EVTP also had a major influence on NR25 variation. Root angle was influenced mainly by rainfall and less by sunlight duration. In the case of RD7, three covariates had an equal effect on the GEI: soil, minimal and maximal air temperatures.

Table 2; Tabela 2

Percentages of the sum of squares of main effect (Main)
and GE interaction (Inter) accounted for the environmental and genotypic covariates

Procentowy udział sum kwadratów efektu głównego (Main)
i interakcji GE (Inter) wyjaśnianych poprzez środowiskowe i genotypowe
zmienne stowarzyszone

Covariates; Zmienne stowarzyszone	RA7		RD		RN25		RN69	
	Main	Inter	Main	Inter	Main	Inter	Main	Inter
Environmental; Środowiskowe								
MAT	0	0	0	0	29*	21*	0	0
MinAT	0	0	31*	21*	0	0	4*	19*
MaxAT	0	0	30*	13*	0	0	0	0
MST	10*	26*	27*	34*	7*	25*	77*	18*
RFS	37*	21*	0	0	0	0	0	20*
EVTP	0	14*	2	11*	45*	28*	3*	12*
SSR	1	13*	0	0	0	0	7*	13*
SSH	49*	17*	9*	12*	0	0	0	0
Genotypic; Genotypowe								
SDM	13*	0	0	0	0	0	13*	1
CLA	0	0	16*	0	0	0	0	0
SD	0	0	0	0	1	2	0	0

* significant at $\alpha = 0.01$; istotny dla $\alpha = 0,01$

For GEI effect, generally, soil temperature plays the most important role for all root characters. But, it is interesting to see, that interaction for traits related with productivity of genotype: RD, RN25 and RN69, could be explained also by air temperature changes, while in the case of root angle (RA7), trait considered as nonproductive originating, air temperature did not have any effect. TARDIEU and PELLERIN [1991] proved that trajectory of nodal roots is determined by soil temperature during a short period after root appearance, as was considered in our study. The biggest number of covariates takes part in GEI explanation for NR69. This is in agreement with the results of PICARD et al. [1985], who found a greater environment-originating variation of the root number on the upper nodes. Genotypic covariates sums of squares generally had low percentages in main effect, near zero. These covariates did not have practically any influence on interaction magnitude. GEI phenomenon depends only on climatic factors, however others underline also genotype effect importance [DAVIDSON 1969; PICARD et al. 1985].

Conclusions

Factorial regression model is a very helpful tool to evaluate the environmental effects on genetic variability of maize. It was confirmed that GEI affecting root parameters has a relatively simple interpretation, since rts variation can be described by the use of linear relations among covariates. GE interaction influences root growth essentially due to variability of temperature (in the soil or in the air) and water accessibility (EVTP or rainfall magnitude).

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Key words: maize, roots, genotype x environment interaction, factorial regression

Summary

Root system quality is very important for maize growth, development and productivity. The maize breeding, generally, is focused on the performance of aboveground part of plant. It is interesting to compare the relationship between root and shoot of maize studied in divergent conditions. Results of the study of the effects of climatic regimes on variations among maize genotypes were described in paper. The genotype x environment interaction (GEI) are analysed through factorial regression models in order to explicate of the effects of environmental factors on root growth.

Chosen statistical method is very helpful tool to evaluate the environmental effect on genetic variability of maize root traits. There was confirmed significant effect of GEI on the root traits. GxE interaction has simply interpretation, because it can be described by the use of linear relations among covariates. It concerns soil and air temperature and water availability (EVTP or rainfall amount).

WPŁYW INTERAKCJI GENOTYPOWO-ŚRODOWISKOWEJ NA CECHY KORZENI KUKURYDZY

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Słowa kluczowe: kukurydza, korzenie, interakcja genotypowo-środowiskowa, regresja czynnikowa

Streszczenie

Jakość systemu korzeniowego jest bardzo istotna dla rozwoju i plonowania kukurydzy. Hodowla kukurydzy, na ogół, skupia się na doskonaleniu cech części nadziemnej rośliny. Interesujące jest porównanie zależności pomiędzy parametrami korzeni i łodygi badanych w zróżnicowanych warunkach. W opracowaniu opisano rezultaty badań wpływu kontrastujących warunków środowiskowych na zmienność pomiędzy genotypami kukurydzy. Interakcja GE jest analizowana przy pomocy regresji czynnikowej dla wytłumaczenia wpływu czynników środowiskowych na wzrost korzeni.

Wybrana metoda statystyczna jest bardzo pomocnym narzędziem oceny

wpływu efektu środowiskowego na genetyczną zmienność cech korzeni kukurydzy. Stwierdzono istotność wpływu GEI w przypadku cech korzeni. Interakcja GxE ma prostą interpretację, ponieważ może być opisana przy użyciu zależności liniowych pomiędzy zmiennymi stowarzyszonymi, dotyczy to temperatury gleby i powietrza oraz dostępności wody (wielkość ewapotranspiracja lub opadów).

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