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INTERPRETATION OF INTERACTIONS IN SUNFLOWER AGRONOMIC TRIALS USING MULTIPLICATIVE MODELS AND CLIMATIC INFORMATION

Balalić, I.*[1], Zorić, M.[2], and Crnobarac, J.[3]

[1]*Institute of Field and Vegetable Crops, Maksima Gorkog 30, 21000 Novi Sad, Serbia*
[2]*Institute of Field Crop Science, Faculty of Agriculture, University of Belgrade, Nemanjina 6, 11080 Belgrade-Zemun, Serbia*
[3]*Department of Field and Vegetable Crops, Faculty of Agriculture, University of Novi Sad, Trg D. Obradovića 8, 21000 Novi Sad, Serbia*

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SUMMARY

A three-year experiment (2005, 2006, 2007) including three sunflower hybrids and eight sowing dates was carried out in order to study the impact of hybrid × sowing date interaction on oil yield of sunflower hybrids. With an aim of attaching biological significance to the interaction interpretation, information on four climatic factors (minimum, maximum and mean temperature and precipitation) were used. Significant differences were found between hybrids, sowing dates and years regarding their impact on oil yield. The results of 3-way ANOVA showed that all sources of variation were highly significant (main effects and interaction effects). This indicated variations among sunflower hybrids for oil yield and variations in sowing date and hybrid × sowing date effects. The multiplicative interaction between H × R was further separated in two bilinear terms (PC1 and PC2), and both were highly significant. The $SREG_2$ biplot indicated that the hybrid Miro was the best performer at 11 planting dates. During the three-year experiment, Pobednik produced highest oil yields at 10 planting dates and Rimi only at 3. Sowing dates R1-6, R2-6 and R3-6 were best for oil yield, because they had highest PC1 values and near-zero PC2 values were ($SREG_2$). On the basis of percentages in the first significant dimension, three variables (pr3, mx3, mn3) higher than 50% and with high positive values of loading were extracted. The PLS regression tri-plot shows that all variables were distributed in 4 groups with similar (or different) effects on the total interaction. Minimum temperature (mn4) at physiological maturity had the smallest contribution to the H × R interaction for oil yield. Sowing dates R4-5 and R5-5 also had smallest contributions to the H × R interaction, because they were located near zero point (0.0) and because their oil yields were smaller than the average.

* Corresponding author: Phone/Fax: 00381 21 413 833; e-mail: igorb@ifvcns.ns.ac.yu

The results for sunflower oil yield indicated that the relative performance of the hybrids and sowing dates was strongly under the influence of their different reactions to precipitation, maximum and minimum temperatures at the flowering stage.

Key words: **climatic information, multiplicative (linear-bilinear) models, oil yield, sowing date**

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is currently the world's fourth largest oilseed crop (de Rodriguez *et al.*, 2002; Simić *et al.*, 2008), planted at more than 20 million hectares wordwide with grain yields varying from 0.5 to 3.6 t ha^{-1} and with an average grain yield of 1.16 t ha^{-1} (FAOSTAT, 2002). It is the most important crop for edible oil production in Serbia. While comparing different vegetable oils, Ryland (2003) declared sunflower to be most beneficial regarding its impact on human health due to its high oleic acid content. Sunflower is also a source of tocopherols and phytosterols, which can have many positive health effects (Gotar *et al.*, 2008). They reduce blood cholesterol level (Patel and Thompson, 2006), prevent cancer (Bramley *et al.*, 2000) and they are effective antioxidants (Niki and Noguchi, 2004). Because of its high adaptability sunflower is grown in a wide range of environments. Climatic conditions during grain filling period and maturation are important for sunflower yield (Anastasi *et al.*, 2004). In sunflower, a period bracketing flowering has been found to be most critical for seed number and yield performance (Andrade *et al.*, 2005). Extended periods of high temperature during the seed-fill period invariable result in low oil content and poor seed quality (Fernandez-Moya *et al.*, 2005). Productivity of sunflower is strongly regulated by water availability and greatest yield losses are evident when water shortage occurs at flowering, as reported by Rauf (2008). Oil yield, the primary indicator of hybrid sunflower productivity, depends on seed yield and seed oil content (Škorić *et al.*, 2005). Sunflower grain and oil yields are greatly reduced when normal sowing dates are delayed (de la Vega and Hall, 2002). A hybrid is considered to be adaptive or stable if it has a high mean yield, but a low degree of fluctuation in yielding ability when grown over diverse environments (Arshad *et al*,, 2003; Tuba and Dogan, 2006).

Interaction among genotypes and environment can be studied and interpreted by a wide variety of statistic models and methodologies (Crossa, 1990). In agronomic trial context, the generic term "environment" is replaced by treatment factors such as mineral fertilizers management, plant spacing or sowing date. Piepho (1998) emphasized that models for understanding genotype performance under different environments can also be used for comparing different agronomic treatments. Using a dataset from a long term wheat agronomic trial, Vargas *et al.* (2001) concluded that contemporary statistical methodology can be a powerful tool for explaining interaction among treatment factors, especially in terms of using additional or external information.

The objective of this study was to determine the impact of sowing date on oil yield of sunflower hybrids, so as to evaluate the hybrid × sowing date interaction using multiplicative models such as SREG (sites regression model) and partial least squares (PLS) regression model. With an aim of attaching biological significance to the interaction interpretation, information on climatic factors (minimum, maximum and mean temperature and precipitation) were used.

MATERIAL AND METHODS

Hybrid × sowing date interactions were investigated in three hybrids (Miro, Rimi, Pobednik) developed at Institute of Field and Vegetable Crops, Novi Sad, Serbia. They were grown during three vegetation periods (2005, 2006, 2007) and sown at eight different sowing dates in 10-day intervals, (R1- March 20, R2- March 30, R3- April 10, R4- April 20, R5- April 30, R6-May 10, R7- May 20, R8- May 30). The experiment was carried out at the experiment field of Institute of Field and Vegetable Crops at Rimski Šančevi, using the RBC design with four replications. Oil yield, as a product of grain yield and oil concentration, was expressed in t/ha. For the explanation of interactions, four climatic factors (minimum, maximum and mean temperatures and precipitation) were used as additional information (http://www.hidmet.sr.gov.yu). The minimum (mn), maximum (mx) and mean temperatures (mt) and total precipitation (pr) per 10-day period were calculated for each sowing date and each year for the following approximate sunflower growth stages: 6 leaves (mn1, mx1, mt1, pr1), budding (mn2, mx2, mt2, pr2), flowering (mn3, mx3, mt3, pr3), and physiological maturity (mn4, mx4, mt4, pr4).

A two-way fixed effect model of analysis of variance (ANOVA) was used to estimate relative contribution of variation sources as well as their statistical significance. In addition, using year factor, three-way ANOVA was conducted to estimate relative importance of year related first- and second-order interactions (*e.g.*, hybrid × year, sowing date × year and hybrid × sowing date × year interaction).

For the purpose of further data analyses, a combined data matrix of mean oil yield for each hybrid in each sowing date and year was constructed. This table was then analyzed by sites regression model (SREG) and corresponding GGE biplot (Yan *et al.*, 2000). The SREG model is:

$$\overline{y}_{ij} - \mu - \beta_j = \lambda_1\alpha_{i1}\gamma_{j1} + \lambda_2\alpha_{i2}\gamma_{j2} + \varepsilon_{ij}$$

where $\overline{y}_{ij}$ is the mean oil yield of i^{th} hybrid at j^{th} sowing date; μ is grand mean; β_j is the main effect of j^{th} sowing date; λ_1 and λ_2 are the singular values for the first and second bilinear terms (PC1 and PC2, respectively); α_{i1} and α_{i2} are eigenvectors of i^{th} hybrid for PC1 and PC2, respectively; γ_{j1} and γ_{j2} are eigenvectors of j^{th} sowing date for PC1 and PC2, respectively; ε_{ij} is the residual of unexplained variation associated with i^{th} hybrid at j^{th} sowing date. Before plotting eigenvectors on a two-dimensional biplot (Gabriel, 1971), singular values for PC1 and PC2 were partitioned entirely into sowing date scores (Yan, 2002).

Partial least squares (PLS) regression (Aastveit and Martens, 1986) was used to explore complex interaction structure using additional external climatic variables. This is a special type of bilinear model which relates several *Y* variables to several *Z* variables. The *Y* matrix (double-centered) contains oil yield data, whereas the *Z* matrix (column centered and standardized) contains climatic variables recorded during the experiment. The two data matrices can be expressed as:

$$Y = \mathrm{T}Q' + F$$

$$Z = \mathrm{T}P' + E$$

where matrix T contains the *Z* scores; matrix *P* contains the *Z* loadings; matrix *Q* contains the *Y* loadings and *F* and *E* is the residual of variation. Vargas *et al.* (1998) stated that the relationship between *Y* and *Z* is transmitted through the latent variables (or dimensions) T. The number of latent variables (T), which optimally predict variation in the *Y* matrix, is determined using cross-validation procedure (Stone, 1974). Results of the PLS procedure were presented using the biplot graph (Gabriel, 1971) and interpreted by means of the "inner-product" principle (Kroonenberg, 1995).

All data analyses were done using Statistica 8.0 software (StatSoft, 2006) and R (R Development Core Team, 2006; http://www.r-project.org).

RESULTS AND DISCUSSION

Mean values and ANOVA

Concerning mean values for oil yield, significant differences were found between hybrids, sowing dates, years and interactions (Table 1).

It can be seen on the basis of 2-way ANOVA that all sources of variation were highly significant. This indicated variations among sunflower hybrids for oil yield and variations in sowing date and hybrid × sowing date effects. Sowing date effect (77.8%) accounted for most of the sums of squares indicating the substantial effect of sowing date on the oil yield performance of the three hybrids evaluated in this study. The influence of hybrid on oil yield amounted to 10.7%, and interaction to 11.5%. Significant hybrid × sowing date interaction demonstrated that the hybrids responded differently to variations in sowing date conditions (Table 2). These results are in close agreement with the findings of de la Vega and Hall (2002) who claimed that sowing date was the main source of variation for oil yield in sunflower. In their experiment, on two-year average for the conditions of Argentina, oil yield varied from 817 kg/ha (sowing in December) to 2300 kg/ha (sowing in October). Ekin *et al.* (2005) found that, on average over experiment years, oil yield ranged from 0.66 t/ha to 1.58 t/ha in Van region, Turkey. Their results showed that oil yield was affected by cultivar and year of investigation. In a three-year trial with hybrids Dukat, Velja and Krajišnik, Balalić *et al.* (2006) found that the contribution of year to oil yield was 76% and of sowing date 3.9%.

Table 1: Mean values for oil yield (t/ha) in sunflower

Hybrid (H)	Sowing date (R)							
	R1	R2	R3	R4	R5	R6	R7	R8
				2005				
Miro	1.28	1.28	0.96	0.77	1.35	1.10	0.95	0.73
Rimi	1.19	1.19	1.14	1.18	0.86	1.01	0.83	0.80
Pobednik	1.53	1.53	0.95	0.68	1.03	0.97	0.92	0.71
				2006				
Miro	1.94	2.02	2.07	2.06	2.03	1.72	1.69	1.29
Rimi	1.60	1.61	1.55	1.59	1.47	1.35	1.34	1.29
Pobednik	2.02	2.08	2.13	1.96	1.77	1.51	1.52	1.35
				2007				
Miro	1.97	1.95	1.69	1.86	2.08	2.03	1.72	1.45
Rimi	1.40	1.58	1.31	1.52	1.46	1.56	1.37	1.22
Pobednik	1.95	2.11	2.03	2.13	2.09	2.34	1.95	1.85
	Y	H	R	Y×H	Y×R	H×R	Y×H×R	
$LSD_{0.05}$	0.05	0.05	0.08	0.08	0.13	0.13	0.23	
$LSD_{0.01}$	0.06	0.06	0.10	0.11	0.18	0.18	0.31	

Table 2: 2-way ANOVA for oil yield in sunflower, planted in eight sowing dates

Source of variation	df	SS (%)	MS	P
Hybrid (H)[1]	2	10.7	2.89	0.000
Sowing date (R)	23	77.8	1.82	0.000
H × R	46	11.5	0.13	0.000
PC 1	24	87.8	0.43	0.000
PC 2	22	12.2	0.06	0.000

** $P < 0.01$
[1]all sources of variation are tested with respective error term

The 3-way ANOVA showed highly significant differences for all main effects, as well as for their interactions. The highest contribution to oil yield was made by the year of investigation (58.9%, Table 3). Similar results were reported by Mijić *et al.* (2006). In a two-year experiment which included 14 OS hybrids and 3 locations, they found significant differences in oil yield between the hybrids, their stability and adaptability. Main effects and all interactions were highly significant. Several recent studies have also shown that differences among consecutive years are larger than differences among test sites within a region (Riza *et al.*, 2004; Sudarić *et al.*, 2006; Dodig *et al.*, 2008).

Site regression model and GGE biplot

The multiplicative interaction H × R was further separated in two bilinear terms (PC1 and PC2) both of which were highly significant (Table 2).

In the hybrids, the PC1 values showed high correlation with the mean oil yield (r=0.872**). The ratio H/HR was 48.4%, which showed that the main effect (hybrid) predominated in the PC1 value. These results agree with the report of Yan *et al.* (2001).

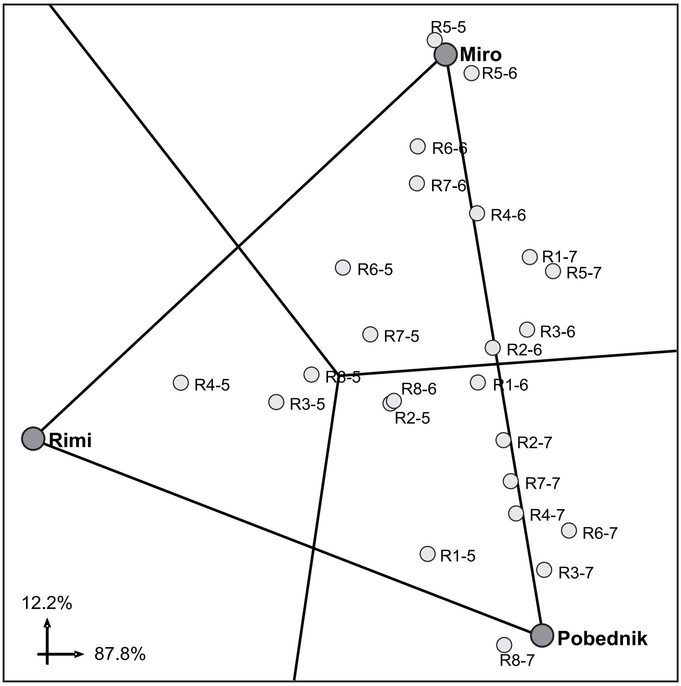

Figure 1: SREG$_2$ biplot for oil yield trial data in sunflower (three year experiment). Abbreviations for sowing dates are: R1 (20th of March), R2 (30th of March), R3 (10th of April), R4 (20th of April), R5 (30th of April), R6 (10th of May), R7 (20th of May), R8 (30th of May)

Table 3: 3-way ANOVA for oil yield in sunflower, planted in eight sowing dates during three years

Source of variation	df	SS (%)	MS	P
Replication[1]	3	0.3	0.05	0.167
Hybrid (H)	2	10.7	2.89	0.000
Year (Y)	2	58.9	15.85	0.000
Sowing date (R)	7	12.9	0.99	0.000
Y × H	4	6.7	0.91	0.000
H × R	14	2.1	0.08	0.000
Y × R	14	5.8	0.22	0.000
Y × H × R	28	2.6	0.05	0.006

** P < 0.01
[1]all sources of variation are tested with respective error term

$SREG_2$ is theoretically the most effective model for explaining the variation due to GGE, because the two bilinear terms are computed to explain maximum amount of variation (Yan *et al.*, 2001).

Starting from the biplot origin, perpendicular lines are drawn to each side, which divide the biplot into three sectors, as defined by vertex hybrids. The $SREG_2$ biplot predicted that the hybrid Miro was the best performer in 11 sowing dates. Pobednik produced highest oil yields in 10 sowing dates, and Rimi only in 3 during the three-year experiment (Figure 1). Although Rimi had the mean value bellow the general mean, it showed best performance in 2005, an unfavorable year for sunflower at R3-5, R4-5, R8-5, as can also be seen from the mean values for oil yield (Table 1). Miro, being located in the bottom right quadrant, gave higher oil yield than the average (high primary effect), but it was not very stable as evidenced by its relatively large secondary effects (Figure 1). Years of investigation and sowing dates had different behavior in the three years of the experiment, which meant that a strong crossover (COI) interaction pattern existed between the years and sowing dates.

A most important decision in plant cultivation is determining the best sowing date for each cultivar. Early sowings of sunflower in Mediterranean environments increased yields relatively to the later sowing date in two experiments, as reported by Soriano *et al.* (2004). Sowing dates R1-6, R2-6 and R3-6 were best for oil yield, because they had highest PC1 values and near-zero PC2 values (Figure 1). It is in agreement with the findings of other researches. According to Yan *et al.* (2001) and Ma *et al.* (2004), ideal cultivar should have large PC1 values (high average yield) and near-zero PC2 values (increased stability). Similarly, the ideal test environment (sowing date) should have large primary effects (PC1 values more discriminating for the cultivars) and near-zero secondary effects (PC2 values more representative of an average environment), as reported by Lillemo *et al.* (2005).

Analysis of oil yield across eight sowing dates during three years of investigation showed that the hybrid Miro (largest arrow) contributed most to the hybrid × sowing date interaction, followed by Pobednik and Rimi. Sowing dates R5-5, R5-6 and R8-7 (largest arrows) contributed most to the hybrid × sowing date interaction for oil yield (Figure 1).

Partial least squares regression

Results of multiplicative decomposition obtained from PLS regression can be presented graphically in the form of a tri-plot, with treatments, environments and variables represented as vectors in two-dimensional plane (Vargas *et al.*, 1999). Detailed information on interactions of particular variables, hybrids and sowing dates are presented using PLS tri-plot (Figure 2). The partial least squares regression model relates genotype × environment interaction effects (G × E) as dependent variables (Y) to external climatic (or cultivar G) variables as the explanatory variables (Z) in a single procedure (Vargas *et al.*, 1998).

First latent variable was highly significant and it explained 24% and second 15% of the hybrid × sowing data interaction for oil yield (Figure 1).

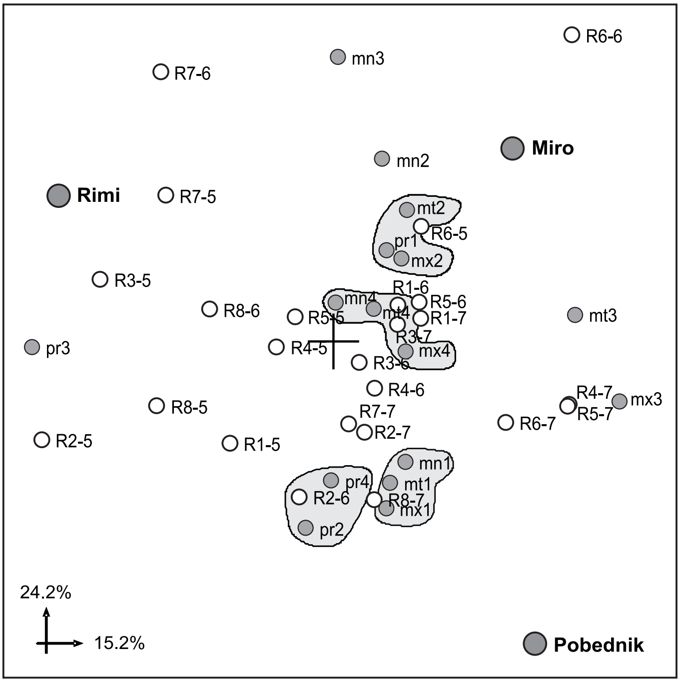

Figure 2: Partial least squares (PLS) regression based tri-plot for oil yield. Abbreviations for climatic variables are: mx=maximum temperature, mn=minimum temperature, mt=mean temperature (all in °C) and pr=total rainfall (mm). Developmenta phases are: 1-6 leaves, 2- budding, 3-flowering, 4-physiological ripeness

On the basis of the percentages in the first dimension, three variables (pr3, mx3, mn3) higher than 50% and with high positive values of loading were extracted, except for precipitation at the flowering stage (pr3). The first latent dimension could be interpreted as a contrast between maximum, minimum temperatures and precipitation during vegetation period of sunflower (April, May, June, July, August and September). On the other side, there were 13 variables with a very poor explanation (0.1-17.3%), and with low loading values and different signs in the first latent dimension. The first latent variable was highly significant and it explained 24%, and second 15% in the hybrid × sowing date interaction in *Y* for oil yield. For oil yield, the first PLS dimension explained a large portion of the total variability of precipitation (86.1%), maximum temperature and mean temperature at flowering (72.7%, Table 4).

The PLS triplot shows that all variables were distributed in 4 groups with similar (or different) influences on the total interaction (Figure 2). In the first group there were 3 variables (mt3, mx3, mx4), with highest positive loading values and low variability in the first dimension (Table 4). They were significant in the interpretation of interactions in this set of data. They had positive interactions with the hybrid Miro and with R6-5. In the second group there were also 3 variables (mx4, mn4, mt4), all of them belonging to the stage of physiological maturity and with positive first dimension of loadings. They showed positive effects with the hybrid Miro and with the sowing dates R1-5, R1-6, R1-7 and R3-7. The negative first dimension loading had 2 variables in the third group. Those were precipitation at budding (pr2) and physiological maturity (pr4). The fourth cluster of climatic variables included 3 temperature variables (mx1, mn1, mt1) at the earliest stage of measurement (6 leaves). The climatic variables which were located further from the centre of the PLS tri-plot (pr3, mx3, mt3), caused largest hybrid × sowing date interactions (Figure 2, Table 4). Minimum temperature (mn4) at physiological maturity had the smallest contribution to the H × R interaction for oil yield. The sowing dates R4-5 and R5-5 also had smallest contributions to the H × R interaction, because they were very near to the zero point (0.0), although their oil yields were below the average. The variable pr3 was significant for a specific negative interaction with Rimi (lowest mean value for oil yield in the trial), and with sowing dates (R1-5, R2-5, R3-5, R8-5) in 2005. These sowing dates are grouped in the bottom left quadrant of the tri-plot. The year 2005 had poor meteorological conditions for sunflower growing. The positive interaction of the hybrid Miro with R6-5 seems to be due to the higher maximum and mean temperatures at budding. Pobednik, the hybrid with the highest mean value for oil yield was in positive interaction with the latest sowing date in 2007 (R8-08, Figure 2).

Table 4: Loadings of climatic variables and proportion of total variance explained in first and second latent dimension of PLS model

Climatic variables	Loadings with PLS1	Dim1 (%)	Loadings with PLS2	Dim2 (%)
pr3	–0.589	86.1	–0.012	0.0
mx3	0.554	87.5	–0.119	0.6
mt3	0.470	72.7	0.048	0.3
mt2	0.141	16.0	0.252	10.9
mx4	0.139	6.6	–0.022	0.6
mn1	0.139	7.4	–0.235	22.1
mx2	0.129	12.6	0.157	7.8
mt1	0.107	4.8	–0.275	34.5
mx1	0.101	3.4	–0.322	45.0
pr1	0.099	0.3	0.174	34.6
mn2	0.093	15.3	0.347	19.4
mt4	0.076	3.0	0.059	0.1
pr2	–0.053	17.3	–0.361	10.9
mn3	0.008	12.2	0.544	24.1
pr4	–0.003	11.0	–0.271	26.4
mn4	0.002	0.1	0.072	2.3

In our investigation, three variables (pr3, mx3, mn3) higher than 50% and with high positive values of loading, except for precipitation with high negative values of loading at flowering stage (pr3), were extracted as most important for explaining the interaction. Vargas *et al.* (1998) reported for *durum* wheat cultivars that sun hours per day in December, February and March and maximum temperatures in March were related to the factor that explained more than 39% of GEI, while for bread wheat cultivars, minimum temperatures in December and January and sun hours per day in January and February were climatic variables related to the factor that explained the largest proportion (circa 40%) of GEI. A study undertaken by Reynolds *et al.* (2003) has shown that temperature sensitivity during the spike primordial stage in wheat contributed significantly to the observed G × E interaction for grain yield in heat-stressed environment. Other climatic factors too can influence oil yield and cause interaction. According to Faramarzi and Korshidi (2008), plant yield in sunflower was determined by the sum radiation received via canopy, so that a decrease in received radiation caused decrease in seed and oil yield.

CONCLUSION

The $SREG_2$ biplot predicted that hybrid Miro was the best performer in 11 planting dates. Pobednik produced the highest oil yields in 10 planting dates, and Rimi only in 3 during the three-year experiment. Sowing dates R1-6, R2-6 and R3-6 were best regarding oil yield, because they had the highest PC1 values and near-zero PC2 values ($SREG_2$).

The partial least squares (PLS) regression model was applied to sunflower data set with objective to determine the most relevant set of climatic variables that explained hybrid × sowing date effects for oil yield.

Climatic variables such as precipitation (pr3), minimum (mn3) and maximum (mx3) temperatures at flowering stage accounted for a sizeable proportion of the hybrid × sowing date interaction for oil yield.

Minimum temperature (mn4) at physiological maturity had the smallest contribution to the H × R interaction for oil yield. Sowing dates R4-5 and R5-5 had also smallest contributions to the H × R interaction, because they were very near to zero point (0.0) and their oil yields were below the average.

Results for oil yield in sunflower indicate that the relative performance of the hybrids and sowing dates was strongly affected by the hybrid reaction to precipitation, maximum and minimum temperatures at the flowering stage.

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INTERPRETACIÓN DE LA INTERACCIÓN EN ENSAYOS AGRONÓMICOS DE GIRASOL USANDO MODELOS MULTIPLICATIVOS E INFORMACIÓN CLIMÁTICA

RESUMEN

Se condujo un experimento durante tres años (2005, 2006, 2007) incluyendo tres híbridos de girasol y ocho fechas de siembra con el objetivo de estudiar el impacto de las fechas de siembra sobre el rendimiento de aceite de los híbridos de girasol y para evaluar la interacción híbrido × fecha de siembra. Con el objetivo de agregar contenido biológico a la interpretación de la interacción, se utilizó información de cuatro factores climáticos (temperaturas mínima, máxima y media y precipitación). Se encontraron diferencias significativas entre híbridos, fechas de siembra y años para rendimiento de aceite. Los resultados del ANOVA trimodal mostraron que todas las fuentes de variación fueron altamente significativas (efectos principales y de interacción). Esto indicó variaciones entre híbridos de girasol para rendimiento de aceite y variaciones en los efectos de fecha de siembra e híbrido × fecha de siembra. La interacción multiplicativa H × R fue luego separada en dos términos bilineales (PC1 y PC2), y ambos fueron altamente significativos. El biplot $SREG_2$ predijo que el híbrido Miro fue el de mayor rendimiento en once fechas de siembra.

Pobednik produjo los rendimientos de aceite más altos en diez fechas de siembra y Rimi sólo en tres fechas de siembra durante el experimento de tres años. Las fechas de siembra R1-6, R2-6 y R3-6 fueron las mejores para rendimiento de aceite ya que presentaron los mayores valores para el PC1 y tuvieron valores cercanos a 0 para el PC2 ($SREG_2$). Sobre la base de su porcentaje en la primera dimensión significativa se extrajeron tres variables (pr3, mx3, mn3) con más del 50% y con altos valores positivos, excepto por la precipitación durante la fase de floración (pr3). Se puede observar sobre el triplot de regresión PRS que todas las variables se distribuyeron en cuatro grupos con influencia similar (o diferente) sobre la interacción total. La temperatura mínima en madurez fisiológica (mn4) tuvo la menor contribución a la interacción H × R. Las fechas de siembra R4-5 y R5-5 tuvieron también la menor contribución a la interacción H × R dado que se localizaron cerca del cero (0,0), aunque tuvieron rendimiento de aceite menor al promedio.

Los resultados de rendimiento de aceite en girasol indican que el comportamiento relativo de híbridos y fechas de siembra estuvo fuertemente influido por la sensibilidad diferencial a las precipitaciones y temperaturas máximas y mínimas durante la fase de floración.

INTERPRÉTATION DES INTERACTIONS DANS LES ÉTUDES AGRONOMIQUES DU TOURNESOL PAR L'UTILISATION DE MODÈLES MULTIPLICATIFS ET DE DONNÉES CLIMATIQUES

RÉSUMÉ

Une experience tri-annuelle (2005, 2006, 2007) incluant trois hybrides de tournesol et huit dates de semis a été conduite pour étudier l'impact de la date de semis sur le rendement en huile des hybrids de tournesol, de même que pour évaluer les interactions hybrides × dates de semis. Avec l'objectif d'accorder une importance biologique à l' interprétation de l' interaction, de l'information sur quatre facteurs climatiques (température minimale, maximale, moyenne, et précipitations) a été utilisée. Des différences significatives entre hybrides, entre dates de semis et entre années ont été trouvées. Les résultats de l'analyse de variance à trois facteurs ont montré que toutes les sources de variation (effets principaux et interactions) étaient hautement significatives. Ceci indique des variations entre hybrides pour le rendement en huile, et des variations entre dates de semis et des effets d'interactions hybride × date de semis. L' interaction a été de plus décomposée de façon multiplicative en deux composantes bilinéaires (PC1 et PC2), et ces deux termes ont été hautement significatifs. L'analyse biplot a prdit que l'hybride Miro était le plus performant pour 11 des dates de semis au cours des trois années d' expérimentation. Pobednik a donné le plus fort rendement en huile pour 10 des dates de semis, et Rimi seulement pour 3 des dates de semis. Les dates de semis R1-6, R2-6 et R3-6 ont été les meilleures pour le rendement en huile, parce qu'elles avaient les plus hautes valeurs pour la PC1, et avaient des valeurs proches de zéro pour la PC2 ($SREG_2$). Les trois variables (pr3, mx3, mn3) présentent la plus forte contribution. Sur l'analyse tri-plot il peut être observé que toutes les variables se répartissent en 4 groupes ayant une influence similaire ou différente sur l'interaction. La plus petite des contributions à

l' interaction est la temperature minimale (mn4) au cours de la maturation physiologique.

Les résultats pour la production d'huile chez le tournesol indiquent que les effets relatifs des hybrides et des dates de semis sont fortement influences par les sensibilités différentielles aux précipitations, et aux températures minimales et maximales durant la période de floraison.