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Predicting Maize (*Zea mays* L.) Tolerance to Herbicides in the Field based on Greenhouse Effects

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Greenhouse and field experiments were conducted to determine the possible correlation between the effects of herbicides on maize in a greenhouse and in the field. Simple linear correlation coefficients were calculated for relationships between pairs of growth parameters from the greenhouse and the field. Results showed good relationships between greenhouse and field results. There were generally positive correlations between major growth parameters in the greenhouse and grain yield in the field. Thus indicating that these parameters could be used to predict herbicide effects in the field. This relationship was positive and significant for at least two of the three herbicides in each experiment. Positive correlation occurred for metazachlor and dimethenamid, acetochlor and atrazine/metolachlor/terbuthylazine mixture. Results suggest that greenhouse screening could be used to reliably screen maize genotypes tolerance to herbicides. This would allow for quick crop screening and could also save valuable time and money in maize screening programs for tolerance to herbicides.

Key words: Maize genotypes, herbicide, screening.

Results from greenhouse and laboratory studies are primary indicators of how a crop could perform in the field, although this is somewhat difficult, and is regarded by many as being tenuous. If it is found to be both practical and reliable this concept could be advantageous because it would allow for quick screening of crop genotypes tolerance to herbicides under controlled conditions (Pike, 1994; Suett, 1994). Although scientists endeavour to effectively predict field performance, such that the reality is not different from the greenhouse results, there are always difficulties in the extrapolation of such results (Garrod, 1989; Krahmer and Russell, 1994). The major problem is that field conditions cannot be completely duplicated in the greenhouse. Because of this some differences in experiments under varying conditions do occur. Type of herbicide, genetic composition of the crop and environmental factors are amongst several factors contributing to these differences between experimental environments (Klingman and Ashton, 1982; Akobundu, 1987).

Differential maize tolerance to herbicides exists and cases of maize (*Zea mays* L.) injury due to herbicides have been reported from time

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to time in South Africa (Le Court De Billot, 1985; Le Court De Billot *et al*., 1986; Le Court De Billot *et al.*, 1990; Reinhardt, 1993; Kanyomeka and Reinhardt, 2000). According to findings reported by Kanyomeka and Reinhardt (2000) maize tolerance to herbicides varied according to genotypes and specific herbicides. The variations of maize tolerance to the herbicides are attributed to genetic variations. Tolerant genotypes probably metabolise herbicides faster than susceptible ones (Akobundu, 1987). Injury symptoms caused by some herbicides in the greenhouse corresponded well with those observed in the field. Kanyomeka and Reinhardt (2000) reported that more than 80 % of the herbicide visual injury in the greenhouse and in the field corresponded well. Other researchers (Barrentine *et al.*, 1976; Hardcastle, 1979; Zhaohu *et al.*, 1999) have reported similar correspondence of injury symptoms in the greenhouse and the field. Ideally all maize genotypes should be screened in terms of their tolerance to all registered herbicides so that only appropriate herbicides are recommended for use on specific maize genotypes. The practical problem associated with this ideal situation is that there are a lot of maize genotypes, South Africa, to be screened, such that field screening would not be adequate in a short time. And if all crop species are considered, the scope of the work involved is staggering and simply beyond the research capacity of most institutions.

Because of the large numbers of maize genotypes that require screening, the commonly used field screening has shortcomings such as the time it takes and the costs involved. From this there is a need to develop techniques for rapid and reliable maize screening in terms of herbicide tolerance. Alternative techniques could be laboratory and greenhouse screening that are cheaper, less time consuming, making it possible for more genotypes to be screened at the same time. These methods have been used previously for other crops (Barrentine *et al.*, 1976; Hardcastle, 1979; Goff and Miller, 1990; Grime, 1994; Bonnet and Bosschert, 1994; Zhaohu *et al*., 1999). Due to the possible variability in the performance of maize genotypes under field, greenhouse and laboratory conditions, it is important to ascertain the reliability of such methods to enable field performance to be predicted with some confidence. This may be possible through correlation of laboratory and greenhouse results with those obtained from the field, particularly the grain yield, which is usually the ultimate parameter for productivity. The objective of this study was to determine the correlation between greenhouse and field results with regard to maize tolerance to herbicides.

MATERIAL AND METHODS

Data reported by Kanyomeka and Reinhardt (2000), for both greenhouse and field experiments were used to determine the correlation between greenhouse and field results. Data for two sets (series) of greenhouse and field experiments were used. Parameters used to assess herbicide effects and also compared to determine the correlations were shoot dry mass (field and greenhouse), visual injury rating (field and greenhouse), days to 50% tasselling (field), days to 50% flowering (field) and the grain yield (field). In each case simple linear correlation coefficients were calculated for relationships between pairs of growth parameters from the greenhouse and the field. Herbicides used are listed in Table 1.

RESULTS AND DISCUSSION

Simple correlation coefficients (r) were compared to judge the relative strengths of these relationships. In these comparisons, the coefficient of determination (r^2) is relevant too. This quantity shows the percentage of variation attributable to the relationship between parameters. Coefficient of determination required to obtain acceptable and good correlation varies with the objective and type of the research. Van Ark (1995) stated that a generally accepted r^2 minimum is in the region of 0.49 (r=+/- 0.7). In the present study it is proposed that an acceptable minimum r-value is in the region of 0.50.

The relationships between grain yield and other tolerance parameters from the greenhouse or field were generally significant (Table 2 and 3). A positive correlation is reported between shoot dry mass (SDM) and visual injury rating (VIR) in the greenhouse with grain yield in the field. This relationship was positive and significant for at least two of the three herbicides in each experiment. In the second series of experiments (Table 3) there was no relationship between SDM and visual injury rating in the greenhouse with grain yield for flufenacet, while VIR in the greenhouse was not positively correlated with the grain yield for the herbicide combination of acetochlor and atrazine/ sulcotrione in the first series (Table 2).

Comparisons of the relationships among all parameters indicate that some were herbicide-dependent in both sets of experiments. In the first series of experiments (Table 2), parameters measured in the greenhouse showed significant correlation with yield for metazachlor and dimethenamid, while visual injury rating in the greenhouse and days to 50 % tasselling showed no relationship with grain yield for the herbicide mixture of acetochlor and atrazine/sulcotrione. Similarly, in the second set of experiments (Table 3) SDM and VIR in the greenhouse showed no relationship with grain yield for flufenacet, although other parameters were significantly correlated with yield in the case of other herbicides.

Results in Tables 4 and 5 indicate that there is generally positive and significant

Table 1. Herbicides evaluated under both greenhouse and field conditions

Experiment	Herbicide	Trade name	Application rate (Active ingredient)
Expt. Series I (1998/99)	Metazachlor	Preecede	600 g ha^{-1}
	Acetochlor+atrazine/sulcotrione	Wenner/galleon	700 g + 425 g ha^{-1}
	Dimethenamid	Frontier	675 g ha^{-1}
Expt. Series II (1999/2000)	Flufenacet	Tiara	400 g ha^{-1}
	Acetochlor	Guardian	910 g ha^{-1}
	Atrazine/metolachlor/terbuthylazine	Gardomil	1380 g ha^{-1}

Common names: acetochlor,2-chloro-*N*-(ethoxmethyl)-*N*-(2-ethl-6-methyl phenyl)acetamide; atrazine, 6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine; dimethenamid, 2-chloro-*N*-(2,4-dimethyl-3-thienyl)-*N*-(2-methoxy-1-methylethyl)acet-amide; metazachlor, 2-chloro-*N*-(pyrazol-1-ylmethyl)acet-2'-6'-xylidide; metolachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acet-amide; and sulcotrione, 2[2-chloro-4(methylsulfonyl)benzoyl]-1,3-cyclohexane-dione; terbuthylazine, 6-chloro-*N*(1,1-dimethylethyl)-*N'*-ethyl-1,3,5-triazine-2,4-diamine (Tomlin, 1994).

Table 2. Simple linear correlation coefficients (r) and r^2 values to describe the relationships between various parameters, used to assess maize tolerance to herbicides, and grain yield (Experiment series I: 1998/99 growing season)

Parameter	Herbicide					
	Metazachlor		Acetochlor+atrazine /Sulcotrione		Dimethenamid	
	r	r^2	r	r^2	r	r^2
SDM(GH)	+0.80**	0.64	+0.78**	0.61	+0.73**	0.53
VIR(GH)	+0.92**	0.85	+0.19ns	0.04	+0.63*	0.40
VIR(Field)	+0.91**	0.83	+0.55*	0.30	+0.59*	0.35
DT(Field)	+0.65*	0.42	+0.13ns	0.02	+0.89**	0.79
DS(Field)	+0.65*	0.42	+0.66*	0.44	+0.70**	0.62

*Significant at 5 % probability level. **Significant at 1 % probability level.
SDM=shoot dry mass reduction VIR=visual injury rating, DT=days to 50 % tasselling, DS=days to 50 % silking, GH=greenhouse.

correlation among parameters used to measure herbicide tolerance in maize. As mentioned earlier, important to note are the positive relationships between SDM and VIR in the greenhouse with grain yield in the field.

Krahmer and Russel (1994) described the problems of glasshouse to field transfer of pesticides performance. In the present study, relationships between herbicidal effects in the greenhouse and effects on grain yield in the field were strong in most cases. This shows that greenhouse effects could be predictors of herbicide effects on yield in the field. Therefore it is suggested that maize screening for tolerance to herbicides could be reliably done in the greenhouse, provided that herbicide rates and environmental conditions are carefully selected. Research in a controlled environment offers the opportunity to investigate worst-case scenarios in terms of herbicide/crop interaction. Screening in the greenhouse would save valuable time and money in programmes aimed at assessing crop tolerance to herbicides. Results have shown that correspondence of data from the greenhouse and

Table 3. Simple linear correlation coefficients (r) and r^2 values to describe the relationships between various parameters, used to assess maize tolerance to herbicides, and grain yield (Experiment series II: 1999/2000 growing season)

Parameter	Herbicide					
	Acetochlor		Atrazine/metolachlor /Terbuthylazine		Flufenacet	
	r	r^2	r	r^2	r	r^2
SDM(GH)	+0.60*	0.36	+0.65*	0.42	-0.25ns	0.06
VIR(GH)	+0.77**	0.59	+0.62*	0.38	-0.31ns	0.10
VIR(Field)	+0.80**	0.64	+0.70**	0.49	+0.65*	0.42
DT(Field)	+0.71**	0.50	+0.76**	0.58	+0.69*	0.48
DS(Field)	+0.73**	0.53	+0.69*	0.48	+0.64*	0.41

*Significant at 5 % probability level. **Significant at 1 % probability level.
SDM=shoot dry mass reduction, VIR=visual injury rating, DT=days to 50 % tasselling, DS=days to 50 % silking, GH=greenhouse.

Table 4. Simple correlation coefficients (r) among parameters used to assess herbicide damage to maize (Experiment series I)

Parameter	Correlation coefficients						
	Yield	SDM(GH)	SDM(F)	VIR(GH)	VIR(F)	Tasselling	Silking
Yield	-	+034*	+0.45**	+0.33*	+0.62**	+0.34*	+0.41*
SDM(GH)	+0.34*	-	+0.36*	+0.55**	+0.28NS	-0.02NS	+0.30NS
SDM(F)	+0.45**	+0.36*	-	+0.59**	+0.51**	+0.26NS	+0.28NS
VIR(GH)	+0.33*	+0.55**	+0.59**	-	+0.50**	+0.15NS	+0.35*
VIR(F)	+0.62**	+0.28NS	+0.51**	+0.50**	-	+0.34*	+0.24NS
Tasselling	0.34*	-0.02NS	+0.26NS	+0.15NS	+0.34*	-	+0.50**
Silking	0.41*	+0.30NS	+0.28NS	+0.35*	+0.24NS	+0.50**	-

*Significant at 5 % probability level; **Significant at 1 % probability level.
Yield=grain yield reduction; SDM(GH)=shoot dry mass reduction (greenhouse); SDM(F)=shoot dry mass reduction (Field); VIR(GH)=visual injury rating (greenhouse); VIR(F)=Visual injury rating (field); Tasselling =Days to 50 % tasselling; Silking=Days to 50 % silking

that from the field could sometimes be herbicide-dependent. This is probably due to differences in herbicide modes of action. It should also be noted that the influence of soil and environmental factors on plant responses to herbicides vary from compound to compound. Ideally, this would necessitate determining the correspondence of greenhouse and field data for individual herbicides.

Since there are many cases of crop injuries reported in South Africa and that the differential maize tolerance to herbicides is confirmed (Kanyomeka and Reinhardt, 2000), it is important that screening maize genotypes for all registered herbicides is done. With large numbers of unscreened genotypes this exercise could only be achieved by using a quick greenhouse screening method. Since the positive correspondence of herbicides effects in the greenhouse and the field has been confirmed in this experiment, it is therefore recommended that greenhouse screening should be used for this purpose.

Table 5. Simple correlation coefficients (r) among parameters used to assess herbicide damage to maize (Experiment series II)

Parameter	Correlation coefficients					
	Yield	SDM(GH)	VIR(GH)	VIR(F)	Tasselling	Silking
Yield	-	+0.38*	+0.34*	+0.65**	+0.46**	+0.56**
SDM(GH)	+0.38*	-	+0.60**	+0.25NS	+0.28NS	+0.16NS
VIR(GH)	+0.34*	+0.60**	-	+0.27NS	+0.24NS	+0.16NS
VIR(F)	+0.65**	+0.25NS	+0.27NS	-	+0.35*	+0.28NS
Tasselling	+0.46**	+0.27NS	+0.24NS	+0.35*	-	+0.60**
Silking	+0.56**	+0.16NS	+0.16NS	+0.28NS	+0.60**	-

*Significant at 5 % probability level; **Significant at 1 % probability level.
Yield=grain yield reduction; SDM(GH)=shoot dry mass reduction (greenhouse); VIR(GH)=visual injury rating (greenhouse); VIR(F)=Visual injury rating (field); Tasselling =Days to 50 % tasselling; Silking=Days to 50 % silking

REFERENCES

1. Akobundu, I.O., Weed Science in the tropics: Principles and practices. John Wiley and Sons, New York 1987.
2. Barrentine, W.L., Edwards, Jr., C.J. and Hartwige. E., Screening soybean for tolerance to metribuzin. *Agron. J.* 1976; **68**: 351-353.
3. Bonnet, M.E. and Bosschaert, L.M., Glasshouse and field comparison of simulated rain on the activity of glyphosate. In: Hewitt, H.G., Caseley, J., Copping, L.G., Grayson, B.T. and Tyson, D. (eds). Comparing glasshouse and field pesticide performance II. BCPC Monograph No 59. British Crop Protection Council, Nottingham 1994.
4. Garrod, J.F., Comparative responses of laboratory and field grown test plants to herbicides. In: Copping, L.G., Merritt, C.R., Grayson, B.T., Wakerly, S.B. and Really, R.C. (eds). Comparing laboratory and field pesticide performance, *Aspects of applied biology* 1989; **121**: 51-64.
5. Goff, W.D. and Miller, R.W., Laboratory and field-testing of fungicides against *Mycosphaerella caryigena*. *Applied Agricultural research* 1990; **5**: 134-141.
6. Grime, J.P., The role of laboratory experiments and field studies in analysing Plant growth; An ecological perspective. In: Hewitt, H.G., Caseley, J., Copping, L.G., Grayson, B.T. and Tyson, D. (eds), (1994). Comparing glasshouse and field pesticide performance II. BCPC Monograph No 59. British Crop Protection Council, Nottingham 1994.
7. Hardcastle, W.S., Soybean (*Glycine max*) cultivar response to metribuzin in solution culture. *Weed Sci*. 1979; **27**: 278-279.
8. Kanyomeka, L. and Reinhardt, C.F., Corn genotypes show distinctive growth responses to various herbicides. *J. New Seeds* 2000; **2**: 13-28.

9. Klingman, G.C. and Ashton, F.M., Weed Science: Principles and Practices. John Wiley and Sons, New York 1989.
10. Krahmer, H. and Russell, P.E., General problems in glasshouse to field transfer of pesticide performance. In: Hewitt, H.G., Caseley, J., Copping, L.G., Grayson, B.T. and Tyson, D. (eds). Comparing glasshouse and field pesticide performance II. British crop protection monograph No: 59, Nottingham 1994.
11. Le Court de Billot, M.R., Atrazine tolerance in South African maize (*Zea Mays* L.) cultivars. D.Sc. (Agric.) Thesis, University of Pretoria, South Africa 1985.
12. Le Court de Billot, M. R., Fourie, A.P. and Nei, P.C., Preliminary studies on the inheritance of atrazine tolerance in maize (*Zea mays* L.). *S. Afr. J. Plant Soil* 1986; **3**: 27-30.
13. Le Court de Billot, M.R., Nel, P.C. and Gevers, H.O., Inheritance of atrazine tolerance in South African maize. *S. Afr. J. Plant Soil* 1990; **7**: 81-86.
14. Pike, D.J., Experimental variation in laboratory and field situations. In: Hewitt, H.G., Caseley, J., Copping, L.G., Grayson, B.T. and Tyson, D. (eds). Comparing glasshouse and field pesticide performance II. British Crop Protection monograph No: 59, Nottingham 1994.
15. Reinhardt, C.F., Biological activity and persistence of atrazine. Ph D thesis, University of Pretoria, South Africa 1993.
16. Suett, D.L., Accelerated degradation of soil insecticides-correlating laboratory behaviour with field performance. In: Hewitt, H.G., Caseley, J., Copping, L.G., Grayson, B.T. and Tyson, D. (eds). Comparing glasshouse and field pesticide performance II. British crop protection monograph No: 59, Nottingham 1994.
17. Tomlin, C. (ed), The Pesticide Manual. Crop protection publication, Cambridge 1994.
18. Van Ark, H., Introduction to linear correlation and regression. Agricultural Research council, Agrimetrics Institute, Pretoria, South Africa 1995.
19. Zhaohu, L.I., Walker, R. H., Wehje, G. and Hackock, H.G., Use of seedling growth parameters to classify soybean (*Glycine max*) cultivar sensitivity to sulfentrazone. *Weed Technol*. 1999; **13**: 530-535.