CHAPTER 3

SUSCEPTIBILITY OF FIVE CROP SPECIES TO ATRAZINE IN VARIOUS SOILS

Introduction

Differences in the resistance of plant species to atrazine have been ascribed to variation in the rates of absorption and translocation of the herbicide (Vostral *et al.*, 1970), dissimilarity in metabolic degradation rates (Penner, 1971), and discrepancies in the ability of atrazine molecules to inhibit photosynthetic electron transport (Fuerst & Norman, 1991).

Seed size has been found to influence the resistance of dry bean cultivars and lines (Mennega *et al.* (1990b), as well as that of soybean cultivars (Andersen, 1970) to atrazine. Differential cultivar resistance to atrazine has been demonstrated in crops such as cucumber (*Cucumis sativa* L.)(Werner & Putnam, 1980), dry beans (Mennega *et al.*, 1990b), grain sorghum (Stahlman & Hackerott, 1979), maize (Le Court de Billot & Nel, 1985), soybeans (Andersen, 1970) and sunflower (Mennega *et al.*, 1990a).

Several soil and weather factors have been shown to influence the availability of atrazine for uptake by certain crop species (Nel & Reinhardt, 1984; Ehlers, Reinhardt & Nel, 1987, 1988). Thus a particular crop species may appear to show variable resistance to atrazine across localities because soil and weather differences between them resulted in differential availability of atrazine for uptake by plants.

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The present study was conducted to evaluate, with various soils, the tolerance to atrazine of some crop species which are commonly grown in rotation with maize. The main aim was to ascertain whether atrazine threshold values, which may be determined in particular soils for sensitive crops, could be useful for making crop choices in cases where the amounts of atrazine that had carried over in diverse soils are known.

Materials and Methods

In bioassays in a glasshouse, dry beans (cv Teebus), grain sorghum (cv NK 222), oats (cv SWK 001), soybeans (cv Forrest) and sunflower (cv SO 222) were used as test species. Lack of space in the glasshouse necessitated separate groupings of bioassays; Experiment I involved dry beans and sunflower, Experiment II - oats and soybeans, and Experiment III - grain sorghum. Test species were grown separately on a total of ten soils. Certain key characteristics of the soils appear in Table 14. Because of unsatisfactory emergence of dry bean and soybean seedlings in the Kroonstad and Pietermaritzburg soils respectively, data from the remaining nine soils were used for statistical analysis in these cases.

Ten atrazine rates were used in all experiments. A distinct difference between the susceptibility of dry beans, oats, soybeans and sunflower, as a group, and grain sorghum demanded the use of different ranges of atrazine rates. Rates used for the group of relatively sensitive crops (dry beans, oats, soybeans and sunflower) were: 0.025, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4 and 0.5 mg ai kg^{-1}. In the bioassay

Herbicide concentrations were established by mixing pre-determined volumes of a 50 mg atrazine L^{-1} solution with 500 g soil in each pot. The same volume of water was used to prepare the untreated controls.

Experimental conditions for the different test species were standardized. Water content of the soils was adjusted to 75% of the total amount per pot at field capacity level, through weighing of pots on alternate days. Nutrient supply was in the form of the nutrient solution of Nitsch (1972) - 50 cm^3 was applied on days not designated for weighing of pots. The composition of the Nitsch solution is given in Table 1B (Appendix B). A constant day/night temperature regime of 27/17°C (± 1°C) was maintained for a 12/12 h thermoperiod in a glasshouse. Supplemental lighting was used to extend the daylight period to a minimum of 12 hours. The growth period was 21 days, from seeding until harvesting of top growth. Data were expressed as percent damage, i.e. percentage reduction in shoot dry mass compared to the untreated controls. Pots were arranged according to a completely randomized design in the glasshouse because treatments took two days to complete, thus compelling handling of replicates on different days. Analyses of variance were performed on combined data for dry beans/sunflower (Exp. I) and oats/soybeans (Exp. II), as well as for individual test species.

Table 14 Selected characteristics of soils[1]

Locality	Clay %	Organic C %	pH H_2O	CEC cmol(+) kg^{-1}	P-reversion mg P kg^{-1}	Clay mineral content (%)		
						Kaolinite	Montmoril.	Illite
Bapsfontein A	37	0.84	5.8	7.7	35	70	15	10
Ermelo	16	0.80	5.3	8.5	82	65	-	10
Nelspruit	4	0.29	6.8	2.5	170	40	-	5
Kroonstad	19	0.36	5.6	4.8	75	70	15	10
Pietermrzb.	31	2.74	6.0	14.1	6	29[a]	-	-
Pretoria	25	0.42	6.4	4.6	151	70	-	15
Redhill	50	0.98	5.0	3.3	5	50	-	15
Viljoenskroon	8	0.19	6.5	1.9	118	87	-	8
Vryheid	53	2.04	5.5	15.8	25	80	5	5
Warmbad	35	0.50	7.8	26.6	69	10	80	-

[1]Standard soil analyses were performed by NWK Laboratory, P O Box 107, Lichtenburg 2740. Clay mineral measurements are semi-quantitative and were determined by the National Building Research Institute of the CSIR, P O Box 395, Pretoria 0002.
[a]In addition to 29% kaolinite, the Pietermaritzburg soil contained 55% chlorite.

Results and Discussion

Data for dry beans and sunflower (Exp. I) are given in Table 15, and data for oats and soybeans (Exp. II) appear in Table 16. Data from the experiment with grain sorghum (Exp. III) are given in Table 21. The grouping of test species in separate experiments, because of limited space and for reasons of practical handling, dictates that statistically valid comparisons of the tolerance of species to atrazine can only be made for the combinations dry beans/sunflower and oats/soybeans. The second order interaction of Atrazine rate x Test species x Soil type was significant in Experiments I & II (Tables 15 & 16).

Sunflower was generally more susceptible than dry beans. Significant differences in tolerance between the dry bean cultivar and the sunflower cultivar first occurred at the Nelspruit, Pretoria, Viljoenskroon and Warmbad soils treated with 0.1 mg atrazine kg^{-1} (Table 15). At the next herbicide rate these differences were significant for only the Nelspruit, Pretoria and Warmbad soils. Except at the Pretoria and Warmbad soils, subsequent increases in the atrazine rate tended to reduce dry matter yield to the same extent for both crops. The Vryheid soil was the exception, however, with a significant difference in susceptibility being recorded at the maximum atrazine rate only.

In general, the oats cultivar was more susceptible than the soybean cultivar. The first significant difference in the tolerance of these species was recorded at the Vijoenskroon soil treated with the lowest atrazine rate (Table 16). Already at the next atrazine rate (0.05 mg kg^{-1}), oats was significantly more susceptible than soybeans at an additional

two soils, Kroonstad and Nelspruit. This trend was observed in other soils (Bapsfontein, Pretoria, Warmbad and Redhill) as the atrazine rate increased to around 0.2 mg kg^{-1}. As was the case for dry beans and sunflower, further increases in herbicide rate tended to eliminate differences in tolerance between oats and soybeans. However, in the Vryheid soil the first significant difference in susceptibility was recorded at the 0.3 mg atrazine kg^{-1} rate.

The response of individual test species to ten atrazine rates in different soils are given in Table 17 (dry beans), Table 18 (oats), Table 19 (soybeans), Table 20 (sunflower) and Table 21 (grain sorghum). The reduction in growth caused by atrazine generally increased with increasing herbicide rates, and the damage caused by a particular atrazine rate varied from soil to soil. The dose-response of a particular test species can be expected to vary between different soils because the amount of herbicide absorbed by plants would be determined by, for example, the organic matter and clay contents of soils. Consequently, the threshold value at which atrazine caused damage to test species generally increased with an increase in the adsorptive capacity of soils. Strong negative correlations have been found between the organic matter content and, to a lesser degree, the clay content of soils and atrazine bioactivity (Anderson *et al.*, 1980; Ehlers *et al.*, 1987, 1988; Reinhardt, Ehlers & Nel, 1990). It therefore appears pointless to assign atrazine threshold concentrations to specific crop species, irrespective of the soil and climatic conditions they are grown under.

Although determination of herbicides by chemical means is usually more accurate and less time-consuming than bioassay techniques, analytical measurements of residues in soils would be of limited value in predicting crop reaction. For crop growers, knowledge of total residues (adsorbed part + part available for plant uptake) obtained by extraction with organic solvents and determined instrumentally is of secondary interest (Stalder & Pestemer, 1980). The best approach would be to link residue concentration in a particular soil to test plant response in bioassays conducted with that soil. Bioassay techniques have been shown to be useful and valid tools in atrazine residue studies. Stalder & Pestemer (1980) state that for the assessment of the risk involved in recropping with susceptible crops a quick determination of the part of the total residues in soils available to the plant is needed. They described a simple extraction method with water which allowed the quantitative determination of the residues of certain herbicides (including atrazine) which are potentially available to plants. Nyffeler, Gerber, Hurle, Pestemer & Schmidt (1982) evaluated different bioassay methods in order to improve the reproducibility of the bioactivity of certain soil-applied herbicides, including atrazine.

Except for grain sorghum (Table 21), which was treated with relatively high doses, atrazine elicited virtually no response from the two more susceptible test species (dry beans and sunflower) grown on the Pietermaritzburg soil (Table 15), probably due to inactivation of the relatively small amounts of herbicide in this soil (31% total clay; 2.74% C) through sorption on relatively many atrazine adsorptive sites.

Table 15 Percent reduction in dry mass of the top growth of dry bean and sunflower seedlings exposed to ten atrazine rates in nine soils (ANOVA in Table 15A)

Atrazine rate		Locality								
(mg kg^{-1})	Test crop	Baps.A	Nelsp.	Vryh.	Ermelo	Pieter.	Redhill	Viljoen.	Pta.	Warmb.
0.025	Dry beans	-25	4	-2	9	-17	6	1	-2	-7
	Sunflower	-12	16	-10	12	-7	-2	37	-4	16
0.05	Dry beans	-11	2	10	10	-15	7	52	2	-2
	Sunflower	5	20	-11	13	-13	-6	84	4	17
0.1	Dry beans	-9	25	12	13	-14	6	64	0	2
	Sunflower	41	75	-6	22	-10	0	86	41	27
0.15	Dry beans	7	60	12	10	-1	7	70	8	-2
	Sunflower	44	86	-2	16	-4	1	85	75	60
0.2	Dry beans	20	71	17	18	-11	11	66	16	20
	Sunflower	59	85	15	39	-3	7	86	77	80
0.25	Dry beans	35	75	14	21	-12	10	67	42	27
	Sunflower	59	89	16	47	-16	17	86	83	84
0.3	Dry beans	43	71	16	26	-11	14	67	58	56
	Sunflower	78	89	19	62	-4	35	86	87	84
0.35	Dry beans	59	72	19	28	-18	16	68	58	60
	Sunflower	80	87	26	70	-5	37	88	88	84

Continued overleaf

Table 15 continued

0.4	Dry beans	61	67	19	39	-20	18	69	62	56
	Sunflower	84	89	27	82	-17	43	89	84	86
0.5	Dry beans	56	71	18	46	-19	31	65	73	57
	Sunflower	86	89	59	87	-1	72	88	86	85
LSD_T (P=0.05)					Atrazine rate x Test crop x Soil = 24					

Table 16 Percent reduction in dry mass of the top growth of oats and soybean seedlings exposed to ten atrazine rates in nine soils (ANOVA in Table 16A)

Atrazine rate		Locality								
(mg kg^{-1})	Test crop	Baps.A	Krnst.	Nelsp.	Vryheid	Ermelo	Redhill	Viljoen.	Pta.	Warmb.
0.025	Oats	0	11	19	7	4	1	76	4	3
	Soybeans	2	10	5	13	12	1	11	6	5
0.05	Oats	0	66	62	7	-5	12	83	26	20
	Soybeans	7	13	6	23	10	2	25	21	13
0.1	Oats	40	73	77	21	2	22	85	67	59
	Soybeans	14	22	14	21	8	10	63	27	15
0.15	Oats	60	78	75	18	22	43	84	71	66
	Soybeans	12	46	61	19	6	20	69	41	30

Continued overleaf

Table 16 continued

0.2	Oats	63	80	76	29	55	56	84	76	75
	Soybeans	26	52	59	21	6	14	66	43	40
0.25	Oats	58	80	78	43	64	66	86	78	77
	Soybeans	41	61	64	31	14	14	66	49	51
0.3	Oats	64	78	79	56	65	65	83	78	78
	Soybeans	64	60	63	20	16	13	67	54	66
0.35	Oats	65	80	79	73	70	66	84	74	78
	Soybeans	58	65	65	29	16	14	68	56	64
0.4	Oats	67	79	80	73	70	66	84	74	78
	Soybeans	61	63	66	18	25	17	69	61	65
0.5	Oats	71	80	81	66	68	66	84	76	79
	Soybeans	63	62	66	21	67	25	71	62	67

LSD_T (P=0.05) Atrazine rate x Test crop x Soil = 19

Table 17 Percent reduction in dry mass of dry bean (cv Teebus) seedlings caused by 10 atrazine rates in nine soils (ANOVA in Table 17A)

Atrazine rate	Locality								
(mg kg^{-1})	Baps.A	Nelsp.	Vryh.	Ermelo	Pieter.	Redhill	Vilj.	Pta.	Warmb.
0.025	-25	4	-2	9	-17	6	1	-2	-7
0.05	-11	2	10	10	-16	7	52	2	-3
0.10	-9	25	12	13	-14	6	64	0	2
0.15	7	60	12	10	-1	7	70	8	-2
0.20	20	71	17	18	-11	11	66	16	20
0.25	35	75	14	21	-12	10	67	42	27
0.30	43	71	16	26	-11	14	67	58	56
0.35	59	72	19	28	-18	16	68	58	60
0.40	61	67	19	39	-20	18	69	62	56
0.50	56	71	18	46	-19	31	65	73	57
Mean	24	52	14	22	-12	13	59	32	27
$LSD_T(P=0.05)$	Atrazine rate x Soil = 25								

Table 18 Percent reduction in dry mass of oats (cv SWK 001) seedlings caused by ten atrazine rates in ten soils (ANOVA in Table 18A)

Atrazine rate	Locality									
(mg kg^{-1})	Bap.A	Krnst.	Nels.	Vryh.	Erm.	Piet.	Redh.	Vilj.	Pta.	Warmb.
0.025	0	11	19	7	4	-8	1	76	4	3
0.05	0	66	61	7	-5	-8	12	83	26	20
0.10	40	73	77	21	2	-5	22	85	67	59
0.15	60	78	75	18	22	2	43	84	71	66
0.20	63	80	76	29	55	4	56	84	76	75
0.25	58	80	78	43	54	-4	66	86	78	77
0.30	64	78	79	56	65	2	65	83	78	78
0.35	65	80	79	70	72	-3	64	83	76	78
0.40	67	79	80	73	70	0	66	84	74	78
0.50	71	80	81	73	68	13	66	84	76	79
Mean	49	71	71	39	42	0	46	83	63	61
$LSD_T(P=0.05)$	Atrazine rate x Soil = 19									

Table 19 Percent reduction in dry mass of soybean (cv Forrest) seedlings caused by ten atrazine rates in nine soils (ANOVA in Table 19A)

Atrazine rate	Locality								
(mg kg^{-1})	Bap.A	Krnst.	Nels.	Vryh.	Erm.	Redh.	Vilj.	Pta.	Warmb.
0.025	2	10	5	13	9	1	11	6	5
0.05	7	13	6	23	10	2	25	21	13
0.10	14	22	14	21	8	10	63	27	15
0.15	12	46	61	19	6	20	69	41	29
0.20	26	52	59	21	6	14	66	43	40
0.25	41	61	64	31	14	14	66	49	51
0.30	64	60	63	20	16	13	67	54	66
0.35	58	65	65	29	16	14	68	56	64
0.40	61	63	66	18	25	17	69	61	65
0.50	63	62	66	21	67	25	71	62	67
Mean	35	45	47	22	17	13	58	42	42
$LSD_T(P=0.05)$	Atrazine rate x Soil = 18								

Table 20 Percent reduction in dry mass of sunflower (cv SO 222) caused by ten atrazine rates in ten soils (ANOVA in Table 20A)

Atrazine rate	Locality									
(mg kg^{-1})	Bap.A	Krnst.	Nels.	Vryh.	Erm.	Piet.	Redh.	Vilj.	Pta.	Warmb.
0.025	-12	-7	16	-10	12	-7	-2	37	-4	16
0.05	5	17	20	-11	13	-13	-6	84	4	17
0.10	41	69	75	-6	22	-10	0	86	41	27
0.15	44	78	86	-2	16	-4	1	85	75	60
0.20	59	84	85	15	39	-3	7	86	77	80
0.25	59	87	89	16	47	-16	17	86	83	84
0.30	78	86	89	19	62	-4	35	86	87	84
0.35	80	87	87	26	70	-5	37	88	88	84
0.40	84	87	89	27	82	-17	43	89	84	86
0.50	86	86	89	59	87	-1	72	88	86	85
Mean	52	67	73	13	45	-8	21	81	62	62
$LSD_T(P=0.05)$	Atrazine rate x Soil = 22									

Table 21 Percent reduction in dry mass of grain sorghum (cv NK 222) caused by 10 atrazine rates in nine soils (ANOVA in Table 21A)

Atrazine rate	Locality								
(mg kg^{-1})	Bap.A	Krnst.	Nels.	Vryh.	Erm.	Piet.	Vilj.	Pta.	Warmb.
0.1	2	8	2	3	6	1	1	3	6
0.2	4	18	4	3	10	10	10	12	17
0.4	6	33	23	6	15	8	37	21	26
0.8	15	43	46	6	19	19	68	42	42
1.0	14	44	54	12	26	23	71	51	46
1.4	40	58	70	16	32	20	84	64	62
1.8	48	73	79	28	34	23	87	76	63
2.4	53	74	81	32	32	26	88	77	70
2.8	55	78	89	37	45	27	91	83	72
Mean	26	48	50	16	24	18	60	48	45
$LSD_T(P=0.05)$	Atrazine x Soil = 18								

Results presented above show that prediction of potential damage to susceptible crops should reflect the differential availability of atrazine residues in different soils. Also, amounts of residues available for uptake by plants in a particular soil, and not merely total residue concentration in that soil should regulate crop choice. Thus differential availability of residues for uptake by plants in different soils precludes the allocation of fixed herbicide threshold values to specific crops. Ideally, knowledge of a particular cultivar's response to known amounts of atrazine residues in a specific soil should determine crop choice. Recropping intervals that are specified on labels of atrazine products neither reflect the variability in atrazine threshold values for crop species nor differential threshold concentrations for different soils.

Own research reported in subsequent chapters was focused on determining the relative importance of certain soil characteristics on the bioactivity and persistence of atrazine. Basically the same procedures as those described under *Materials and Methods* were employed in subsequent bioassays that were conducted in glasshouses. Certain crop cultivars which had been employed in the present investigation were used as indicators of the availability of atrazine and/or its phytotoxic residues for uptake by plants.