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UNIVERSITY OF PRETORIA
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REINHARDT, CARL FREDERICK

BIOLOGICAL ACTIVITY AND PERSISTENCE OF ATRAZINE

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BIOLOGICAL ACTIVITY AND PERSISTENCE OF ATRAZINE

by

CARL FREDERICK REINHARDT

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Department of Plant Production

Faculty of Agricultural Sciences

University of Pretoria

PRETORIA

PROMOTER: PROF P C NEL

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Carl Frederick Reinhardt

PROMOTER: Prof P C Nel

DEPARTMENT: Plant Production

DEGREE: Ph D Weed Science

ABSTRACT

Cases of atrazine damage to maize, and occasional reports of excessive residue persistence that caused injury to susceptible following crops, prompted research on factors which influence the bioactivity and persistence of the herbicide. Bioassays with several indicator species were conducted in the field and in glasshouses. Measurement of atrazine by chemical means was done in only three of the experiments. Maize seedlings were not more sensitive to atrazine when stressed by insufficient supplies of N, P, K, Ca or Mg. Neither high P supply nor phytotoxic P concentrations in maize seedlings lowered their tolerance to atrazine. These findings on the roles of certain nutrients in the tolerance of maize to atrazine concluded a series of investigations into damage reported in the field. No satisfactory evidence for the factors which rendered maize susceptible to atrazine in the field was ever found. Another investigation showed that atrazine threshold concentrations for certain susceptible species varied from soil to soil, indicating that differential availability of the herbicide for uptake by plants in different soils precludes the allocation of fixed atrazine threshold values to different crop species. Atrazine bioactivity and persistence varied considerably in a series of field experiments which were conducted to determine the order of importance of certain soil properties in the prediction of short- and long-term bioactivity. Soil organic matter content (% C) was the best predictor in both instances. Soil pH was a poor predictor of short-term bioactivity, but became more prominent with time. Organic matter, pH and P-reversion accounted for 35%, 19% and 14% of the variation in bioactivity measured six months after atrazine application in the field. In view of the variation in atrazine persistence, and therefore, the potential for variable carry-over from soil to soil, the applicability of the recropping interval recommended for dry beans and sunflower were investigated. It was concluded that the specification could be justified for sunflower only, but then only on certain soils. It is suggested that recropping intervals, which are recommended for certain crops after atrazine use in maize, be refined on the basis of differences in follow-up crop sensitivity to atrazine, and relationships between atrazine persistence and certain soil properties. Chemical analysis showed that soil type and soil water content had greater influences on atrazine persistence than temperature. Irrespective of soil type, the rate of atrazine breakdown was faster in soil at a water content of field capacity, and in water-logged soil (2x FC), than in air-dry soil. A bioassay technique was used to estimate the concentration of atrazine and/or its phytotoxic residues in a soil profile. Basically the same procedure was followed in an incubation study with 25 soils to develop the following regression model for prediction of atrazine half-life in soil: $y = -2.29 + 1.77x_1 + 20.81x_2$, where y is half-life in days; $x_1 = [\text{soil pH}(H_2O)]^2$ and $x_2 = \%\ C$. The bioassay technique proved useful for estimating total amounts of atrazine and its phytotoxic residues in various soil types.

BIOLOGIESE AKTIWITEIT EN NAWERKING VAN ATRASIEN

deur

Carl Frederick Reinhardt

PROMOTOR: Prof P C Nel

DEPARTEMENT: Plantproduksie

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UITTREKSEL

Beskadiging van mielies deur atrasien, en sporadiese berigte van oormatige nawerking met gepaardgaande beskadiging van gevoelige opvolggewasse, het aanleiding gegee tot navorsing oor faktore wat die bio-aktiwiteit en nawerking van die onkruiddoder beïnvloed. Biotoetse is met verskillende toetsplante in glashuis- en veldproewe uitgevoer. Bepaling van atrasien deur chemiese analise is in slegs drie proewe gedoen. Mieliesaailinge se verdraagsaamheid teenoor atrasien is nie deur tekorte aan N, P, K, Ca en Mg in die plante beïnvloed nie. Nog hoë P-voorsiening, nog fitotoksiese P-konsentrasies in saailinge, het hul weerstand teen atrasien verlaag. Hierdie bevindings oor die rol van sekere voedingselemente by die verdraagsaamheid van mielies teenoor atrasien het 'n reeks ondersoeke na destydse skade in die veld afgesluit, sonder bevredigende verklarings vir die probleem. In 'n ander ondersoek is gevind dat drumpelwaarde-konsentrasies van atrasien vir bepaalde gevoelige gewasplante van grond tot grond varieer. Differensiële beskikbaarheid van atrasien in grond sal dus die toekenning van 'n vaste drumpelwaarde aan 'n bepaalde gewasplant verhoed. Die

organiese koolstofinhoud van grond was die belangrikste voorspeller van die kort- en langtermyn bio-aktiwiteit van atrasien in 'n reeks veldproewe. Die variasie in bio-aktiwiteit wat ses maande na toediening van die doder deur organiese materiaalinhoud, pH en P-reversie verklaar is, was onderskeidelik 35%, 19% en 14%. Derhalwe het grond-pH, wat 'n swak voorspeller (1% van variasie) van die korttermyn-aktiwiteit van atrasien was, belangriker geraak met tyd. Die bio-aktiwiteit en nawerking van atrasien het aansienlik tussen lokaliteite verskil. Weens die variërende nawerking van atrasien in grond, en gevolglike verskille in die potensiële oordraging van atrasien na 'n volgende seisoen, is die toepaslikheid van die wagperiode wat vir droëbone en sonneblom gestel word vervolgens ondersoek. Die voorgeskrewe wagperiode kon slegs vir sonneblom as toepaslik bevestig word, en dan slegs op sekere grondsoorte. Dit word voorgestel dat wagperiodes verfyn behoort te word op basis van verskille tussen grondsoorte en die verdraagsaamheid van gewasplante teenoor atrasien. Met chemiese analise is bepaal dat grondsoort en -waterinhoud 'n belangriker effek op nawerking van atrasien as temperatuur gehad het. Vergeleke met die afbraaktempo in lugdroë grond het atrasien vinniger afgebreek in grond waar die waterinhoud by veldkapasiteit was, asook wanneer dit twee keer hierdie hoeveelheid water bevat het . 'n Biotoetstegniek is gebruik vir skatting van atrasien- en/of fitotoksiese residu-konsentrasies in 'n grondprofiel. Basies dieselfde prosedure is in 'n inkubasieproef met 25 gronde toegepas vir ontwikkeling van die volgende model vir voorspelling van die halfleeftyd van atrasien in grond: $y = -2.29 + 1.77x_1 + 20.81x_2$, waar y halfleeftyd in dae is; $x_1 =$ [grond-pH(H_2O)]^2 en $x_2 = \%$ C. Die biotoetstegniek was effektief vir skattings van die totale hoeveelheid atrasien en fitotoksiese atrasienresidue in grond.

INTRODUCTION

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-*s*-triazine) is a selective soil-applied herbicide used principally in the maize-producing regions of South Africa. It is the most widely used herbicide in maize (*Zea mays* L.) but is also applied in sugarcane (*Saccharum officinarum* L.), grain sorghum (*Sorghum bicolor* (L.) Moench), pineapples (*Ananas comosus* L.), and for industrial weed control. While the crop safety margin for atrazine in maize is regarded as one of the largest safety margins in herbicide-crop relationships, cases of crop injury have been reported (Thompson, Slife & Butler, 1970). During the 1981/82 and 1982/83 growing seasons reports of atrazine damage to maize, resulting in up to 25% stand loss, were received from certain parts of the main maize growing region in South Africa (Malan, Visser & Van de Venter, 1985).

Of greater concern than infrequent and isolated lapses in selectivity is the frequently recurring problem of excessive persistence of soil residues of atrazine affecting the growth of sensitive follow-up crops. In spite of exhaustive research on atrazine since its discovery in the 1950's, occasional problems of carry-over to sensitive crops (Pestemer, Stalder & Potter, 1983; Shea, 1985; Haigh & Ferris, 1991) and contamination of water resources (Wood, Harold, Johnson & Hance, 1991) are encountered worldwide. The discovery that trace amounts of certain agrochemicals such as atrazine can occur in ground and surface waters has heightened public awareness and interest in the environmental behaviour of pesticides (Leonard, Shirmohammadi, Johnson & Marti, 1988; Schiavon, 1988; Riley, 1991). In Italy the use of atrazine was barred after residues were detected in ground water (Del Re, Capri, Bergamaschi & Trevisan, 1991), while elsewhere in Europe a limit of 0.1 $\mu g\ L^{-1}$ for individual pesticides in ground and surface waters has been imposed through the European Community Drinking Water Directive (Tooby & Marsden, 1991).

Knowledge of factors that govern herbicide uptake by plants, crop sensitivity, and the active lifetime of compounds in soil is required to properly manage the use of potentially persistent herbicides. Persistent herbicides should be administered in ways that acceptably limits residual biological activity, thereby lowering the risk of damage to susceptible follow-up crops. In addition, residues should be prevented from reaching surface-water and groundwater below the rooting zone. From an agronomical viewpoint, the terms "bioactivity" and "persistence" are interrelated. Persistence has been defined as "the continuation of herbicidal bioactivity beyond the time of planting a sensitive following crop". Herein lies the ambiguous nature of the term "persistence" - it is positive in the sense that the ideal herbicide should persist long enough to provide acceptable weed control during the season in which it was applied, but negative in the sense that persistence must not be so long that phytotoxic residues carry over to sensitive following crops. Herbicidal bioactivity and persistence are both determined by the following four factors: characteristics of the compound, application rate, plant sensitivity, and rate of dissipation in the environment (Beyer, Duffy, Hay & Schlueter, 1988; Hance, 1988; Nash, 1988; Leistra & Green, 1990).

Forecasts of the presence and bioactivity of atrazine residues are often perplexing. Behavioural inconsistencies locally and abroad have occasionally manifested in either poor weed control by the herbicide, loss of selectivity which leads to crop injury, or excessive persistence that causes damage to sensitive following crops. Research presented here formed part of a comprehensive study to identify environmental and plant factors which influence the behaviour of atrazine in South African soils. Although past research on atrazine in this country focused on factors affecting the bioactivity of the herbicide, excessive persistence and the concomitant injury to follow-up crops is the real problem.

Some additional facets of the bioactivity of atrazine were investigated in the present study, but the main aim was to accrue information on factors which govern atrazine persistence in soils. Specific aims were: a) to establish whether growth-retarding levels of N, P, K, Ca and Mg and excessive amounts of P in the growth medium could influence the resistance of maize to atrazine; b) to assess the variability in the resistance shown by several susceptible crops to atrazine in various soils; c) to substantiate under field conditions the order of importance of some soil variables in the prediction of atrazine bioactivity, as found in a previous study in the glasshouse; d) to assess to what extent atrazine persistence varied between soils in the field, and to establish which soil variables predicted the bioactivity of residual atrazine best; e) to demonstrate that recropping periods, which are specified for crops that are susceptible to atrazine, require refinement; f) to show that soil type, soil water content and temperature influence atrazine persistence; g) to assess whether the bioassay technique could be useful in monitoring the movement of atrazine in soil, and h) to establish the importance of selected soil properties on atrazine half-life. It was hoped that the work would contribute towards the improved prediction of atrazine persistence in soils.