Effect of Irrigation Parameters on Concentration of Mefenoxam in Soil over Time and Depth in Greenhouse Studies[1]

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ABSTRACT

Peanut was grown in 19-L containers for approximately 60 days and then foliage was treated with Ridomil Gold EC (0.48 g or 0.048 g mefenoxam/pot) and watered over-the-top to simulate chemigation. After application, over-the-top irrigations were made using 540, 1080, or 1800 mL (representing 0.88, 1.77, and 2.94 cm depth) per irrigation event, with three events per week. The first irrigation after application was made at either 1, 3, or 5 days after fungicide application. Soil cores were taken weekly at 10 and 20-cm depths for four weeks. Regression analysis was used to predict fungicide concentration at each depth as a function of time, irrigation rate, and day of first irrigation event after chemigation. Mefenoxam concentration at the 10-cm depth was predicted by a quadratic function of time, and by irrigation rate (either alone, or as an interaction term with day of first irrigation event). Irrigation rate alone was adequate to predict mefenoxam concentration at the 20-cm depth. Higher irrigation rate resulted in higher concentrations of mefenoxam at both the 10 and 20-cm depths. Higher concentrations of mefenoxam at the 10-cm depth may result in better *Pythium* pod rot control.

Key Words: *Arachis hypogea*, chemigation, fungicide, *Pythium*.

Management of Pythium pod rot includes crop rotation with nonhosts, good drainage, adequate calcium in the pegging zone, moderate irrigation rate, and application of fungicides such as mefenoxam and azoxystrobin (Texas Peanut Production Guide, 2001). Mefenoxam (Ridomil Gold EC, Syngenta) has good activity against *Pythium* (Taylor *et al.*, 2002; 2004). Metalaxyl is a compound with two enantiomers that form in a 1:1 ratio, with the enantiopure R form being mefenoxam (mefenoxam = R-metalaxyl). Since metalaxyl was introduced in 1977, there have been a number of studies on its uptake into plants from roots and translocated to the leaves (Carris and Bristow, 1987; Marucchini *et al.*, 1983; Stone *et al.*, 1987; Wilson *et al.*, 2001). There are relatively few studies on mefenoxam, though results would be expected to be similar to those with metalaxyl.

The solubility of metalaxyl is 7.1 g/L at 20 C and mefenoxam is even more soluble in water (26 g/L at 26 C) (Monkiedje *et al.*, 2002). Soils with high sand content and low organic matter would be considered highly prone to leaching of metalaxyl (Andrades *et al.*, 2001; Sukul and Spiteller, 2000). Application of mefenoxam through chemigation to peanut for pod rot control would result in three avenues for the fungicide distribution: translocation into the plant from the roots or retained on the leaves (and therefore lost from disease control); leaching too deep into the soil profile (and therefore lost from disease control); and distributed into the top 10-cm of the soil profile where the pods are. Metalaxyl was leached deep into the soil profile as irrigation amount increased (Sharom and Edgington, 1982, 1986; Starrett *et al.*, 1996). The effect of irrigation rate on mefenoxam leaching in a sandy soil planted with peanut is one objective of this study.

Mefenoxam when chemigated, should be applied in a volume of water which places the fungicide at a depth where pod protection is desired. The length of time between chemigation event and subsequent irrigation events can affect leaching. Metalaxyl has the ability to move upward in soil columns after leaching occurred (Sharom and Edgington, 1986). Significant leaching occurred when soil dried only 24-hr after irrigation, while a 48-hr drying period before irrigation resulted in the movement of metalaxyl upwards (Sharom and Edgington, 1986). Leaching of the herbicide flumetsulam was reduced when the initial irrigation event after chemical application was delayed by 3 or 5 day, compared with irrigation on the day the herbicide was applied (Tingle *et al.*, 1999). A second objective of this study was to observe if the delay between chemigation and the next irrigation event affected the concentration of mefenoxam in the soil profile at a depth where pod protection occurred

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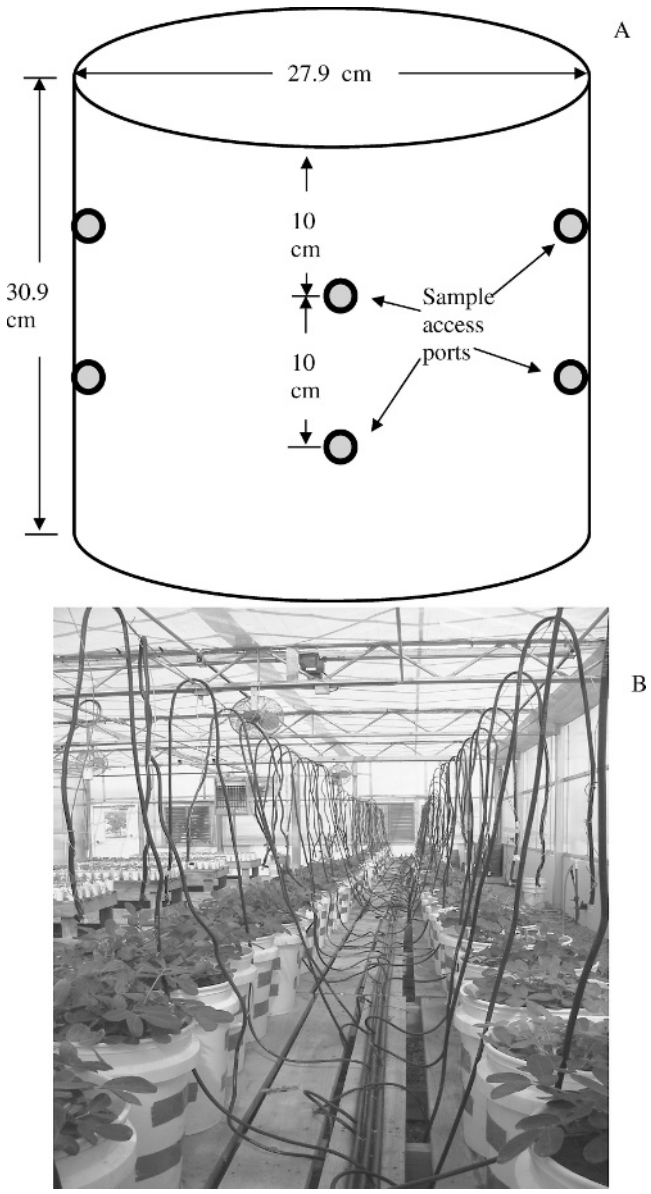

Fig. 1. Pot design (A), peanut size at time of experiment and irrigation setup (B).

and a depth where leaching below the pod zone occurred.

Materials and Methods

A soil (79% sand, 6% silt, 15% clay, 0.5% organic matter, pH 7.5, and 12.3 meq/100g CEC) typical of the peanut acreage in west Texas was collected. Four holes were drilled around a plastic bucket (18.9 L capacity, 27.9 cm diameter) at both 10 and 20 cm from the top of where the soil line was filled (Fig. 1A). The buckets were filled with soil and planted with five peanut seed of an upright-type cultivar (Valencia 'H&W 101'). After the plants emerged, they were thinned to three plants per pot. After the plants had grown sufficiently to have foliage over the pot surface area (60 to 75 days after emergence), all the pots were watered until the soil was saturated in the morning, and then in the afternoon, ½ of the pots were treated with 1 (first run) or 0.1 (second run) ml of Ridomil Gold EC (0.48 g mefenoxam/ml of product) in 30 ml of water. The foliage was sprayed with the fungicide solution, and then all pots were immediately irrigated over the top with 540 mL of water for 1.5 min to simulate chemigation (Fig. 1B).

The treatments for irrigation (540, 1080, or 1800 mL applied at a rate of 6 mL/sec for all pots [0.88, 1.77, and 2.94 cm depth]) were applied initially at either 1, 3, or 5 days after chemigation. Irrigation rates were then applied every 2–3 days (three times per week) for the duration of the experiment. This methodology means that the pots irrigated at 1 day following chemigation had two more irrigation events than the pots irrigated at 5 days following chemigation. The pots irrigated at 3 days following chemigation had one additional irrigation than those watered at 5 days. All fungicide treated pots were matched with the same irrigation treatments in a fungicide-free pot. All 18 treatments (3 irrigation rates × 3 initial timings × 2 fungicide rates (0 vs. +)) were arranged in a randomized complete block design with four replications.

Soil cores were removed using a 2.5 cm-diameter × 10 cm long core device at the 10 and 20 cm depths. In the first run, cores were removed at the 10-cm depth on 1 (before irrigation), 7, 14, and 21 days after chemigation. Cores were removed at the 10-cm depth in the second run, and for both runs at the 20-cm depth on 7, 14, 21, and 28 days after application. Cores were placed in a zipper-seal plastic bag, mixed and stored in a freezer until assays were run.

Assays were conducted on all the samples at one depth for a single sampling date on the same day using ELISA (enzyme-linked immunosorbent assay) kits. Metalaxyl ELISA kits from Envirologix Inc. (Portland, ME) were used to quantify the fungicide in the soil. Soil samples (40 g) were shaken for 3 min in 100 mL of methanol. After settling, a 100-µl aliquot was removed through a Millex-HV syringe 0.45 µm filter (Millipore Corp., Bedford, MA). The aliquot was diluted with water 100 X, unless a higher dilution was necessary. The assays were sensitive from 0 to 1.75 ppb, so samples that exceeded 1.75 ppb were run again at a higher (500 X) dilution. Samples were run according to kit protocols. Mefenoxam concentrations of 0, 0.1, 0.4, and 1.75 ppb were run

on each plate with three replications of each concentration for calibration purposes. Plates were read with a Statfax 2100 microplate reader from Awareness Technologies, Inc. (Palm City, FL). Four models were tested to calibrate the readings: (mefenoxam concentration in ppb [M] = $a + b$Elisa reading (E); LN(M) = $a + b$E; M = $a + b$LN(E); and LN(M) = $a + b$LN(E)), where a and b were parameters to be fitted. These models were run on the 12 control values for each plate. The model with the lowest t-test probability was used to calculate mefenoxam concentration in each soil sample for that plate. If t-test probabilities were greater than 0.05 for all models then the results for that plate were discarded. Soil moisture content from each sampling time and depth was determined by gravimetric soil moisture method (oven drying).

The factors included in the analysis were: irrigation (540, 1080, and 1800 mL); day of first irrigation (DFI) after chemigation (1, 3, 5); day of soil sample collection from pot (1 [only in the first run], 7, 14, 21, 28); and depth (10, 20 cm). The fungicide concentration was expressed in ppb, and the average value for the nonfungicide treatments for each combination of irrigation rate, DFI, day and depth were subtracted from the average value of the fungicide treatments for the same set of factors. This was done to remove the background noise of the assay that occurred in the absence of mefenoxam. A model was fitted by depth to all the factors, two-way interactions between factors, and quadratic form of the factors by using PROC STEPWISE in SAS (SAS Institute, Cary, NC). Factors were accepted in the model if the t-test was significant at $P < 0.08$.

Soil moisture was analyzed for each sampling date and depth by PROC RSREG using the terms IRR and DFI, their quadratic forms, and their interactions. Those terms that were found to be significant ($P \leq 0.05$) were then fitted to soil moisture using PROC REG. In addition, in the second run, soil moisture was fitted with linear and quadratic regression models to irrigation rate using PROC REG. Factors were accepted in the model if the t-test was significant at $P \leq 0.05$.

Results and Discussion

In the first run, neither irrigation rate nor DFI led to significant differences in gravimetric moisture content at the 10-cm depth (average of 16.4% moisture content). At the 20-cm depth, the lowest irrigation rate was slightly drier (16.9%) than the moderate (17.5%) or wettest (17.6%) rate. The test was conducted in the winter months, when evapotranspiration demands were low. These soil moisture levels represent very wet conditions for this soil texture.

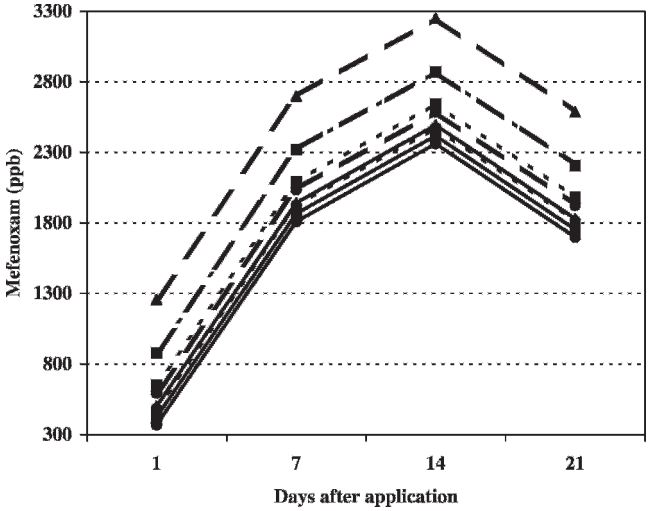

Fig. 2. Effect of irrigation rate and day of first irrigation after chemigation event on concentration of mefenoxam at the 10-cm depth. Irrigation rates were 0.88 cm (●), 1.77 cm (■), and 2.94 cm (▲) applied three times per week. Irrigation was applied at 1 (—), 3 (.....), or 5 (--) days after the chemigation event. Evapotranspiration was low during the test.

The model which was fitted to mefenoxam concentration at the 10-cm depth was: M = − 14.9 + 339.3(DAY) − 12.4(DAY^2) + 0.105 (IRR × DFI), $R^2 = 0.48$, where M = mefenoxam in parts per billion and IRR = irrigation rate. Since the interaction between irrigation rate and day of first irrigation was included in the model, both had significant impacts on concentration of mefenoxam, however, this term only accounted for 6% of the variation in fungicide concentration. The quadratic function of sampling time accounted for 42% of the variation at the 10-cm depth for fungicide concentration. An increase in irrigation or DFI resulted in a higher concentration of mefenoxam (Fig. 2). The overall concentration of mefenoxam increased over time until day 14 after chemigation, and then decreased slightly by day 21 (Fig. 2), as indicated by the quadratic function involving time after the chemigation event.

Concentration of mefenoxam at the lower depth (20-cm) represents loss of fungicide for pod protection, since pods are not likely to be that deep in the soil. The equation fitted was: M = 5.1 + 0.65(IRR^2), $R^2 = 0.41$. The concentration at the lower depth was a function only of irrigation rate, with higher irrigation rate resulting in more fungicide loss from the system. However, as was seen at the 10-cm depth, higher irrigation rate also resulted in higher concentrations of mefenoxam in the pod zone.

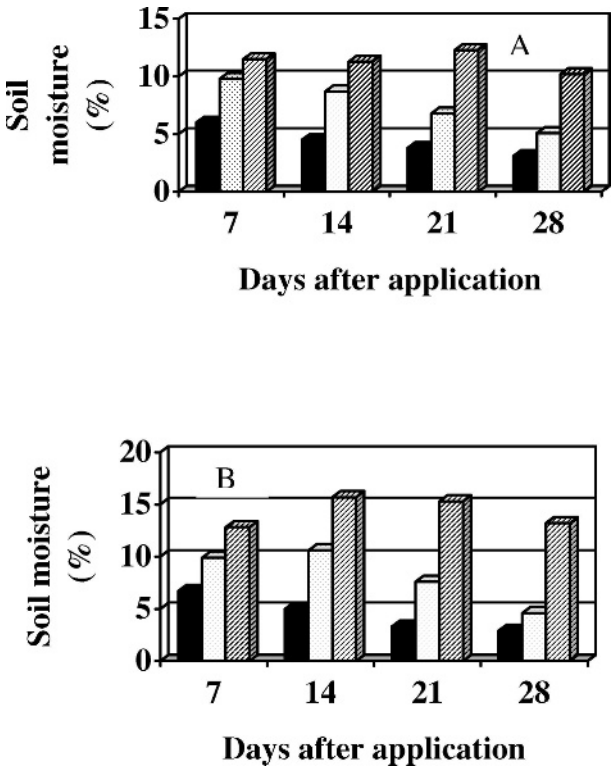

Fig. 3. Effect of irrigation rate on % soil moisture at A) 10-cm and B) 20-cm depths. Irrigation rates were 0.88 cm ■, 1.77 cm ▥, and 2.94 cm ▨ applied three times per week.

The second run was conducted in the spring as temperatures began to increase in the greenhouse. As a result of higher evapotranspiration, soil moisture content was much lower than in the previous experiment even though irrigation rates were the same. Moisture content increased as irrigation rate increased either with a linear function (day 7:20-cm depth; day 21:both depths; day 28:10-cm depth) or a quadratic function (day 7:10-cm depth; day 14:10-cm depth; day 14:20 cm depth, and day 28:20 cm depth) (Figure 3). Moisture content declined over time linearly for the 540 and 1080 mL rates at both depths, indicating that evapotranspiration demands were exceeding applied water as the plants grew (Fig. 3). Moisture content was similar over time with the highest irrigation rate (1800 mL) at both depths (Fig. 3). DFI was not significantly associated with soil moisture at any time or depth.

Under more extreme soil moisture differences, mefenoxam concentration was affected by irrigation rate and day of sampling, but not by DFI: $M = -142.4 + 0.077(IRR) + 16.1(DAY) - 0.4(Day^2)$, $R^2 = 0.49$. Unlike the first run, when the interaction between irrigation rate and DFI had only a small effect on mefenoxam concentration, in the second run, irrigation rate accounted for 35% of the variation in mefenoxam concentration and sampling day accounted for 14%. The higher the irrigation rate, the more mefenoxam was found in the pod zone (10-cm depth). Mefenoxam concentration below the pod zone was also a function of irrigation rate, and was not affected by sampling date: $M = 24.8 + 0.000029(IRR^2)$, $R^2 = 0.12$.

Though both experiments were conducted under different environmental conditions, they presented fairly consistent results. Irrigation rate was positively correlated with increased fungicide concentration in the pod zone. Leaching of product below the pod zone was also positively associated with irrigation rate and did not change over time, indicating that by day 7, much of the leaching had already occurred. There was not a zero sum of product in these experiments across the two sampling depths. A low value in the 10-cm depth did not indicate that leaching had occurred to the 20-cm depth. Instead, there was more fungicide at both depths when irrigation rate was increased.

Mefenoxam at the lower irrigation rates must have been either retained on the plant foliage initially or taken up by the roots preferentially compared with higher irrigation amounts. Higher irrigation rate may have been more successful at removing product from the foliage to the soil. When metalaxyl was applied as a foliar spray on mustard, the residue on the leaves was completely dissipated by 15 days after application, possibly indicating metabolic decomposition inside the plant tissues (Mehta *et al.*, 1997). So, if the higher irrigation rate initially removed more of the fungicide from the plant foliage, then there was less fungicide to be metabolized by the plants. Translocation of metalaxyl into the plant from the soil was increased when transpiration was increased by withholding water (Carris and Bristow, 1987). Both mechanisms could explain why there was less fungicide in the soil system when irrigation rate was lower, and at times, deficient to meet the plant needs.

There was only a very small effect of day of first irrigation after chemigation and only in the first test. If the producer can resume their normal irrigation schedule after chemigation, then that may keep the field from becoming water stressed. Irrigating the same day after application was found to leach significantly more herbicide, compared with waiting 3 or 5 days (Tingle *et al.*, 1999). However, in a chemigation situation, irrigation would not occur on the same day that the products were applied. This situation might be significant if mefenoxam was banded over the top of the plants and then irrigated heavily on the same day, but in our experiments, waiting at least one day after

application was sufficient to reduce the threat of leaching.

Concentration of mefenoxam in the pod zone was enhanced by higher irrigation rates applied at least one day after chemigation. Higher leaching also occurred with higher irrigation rates, but the benefits of having more fungicide in the pod zone may outweigh the risk of leaching. There are at least two conflicting factors that affect getting the maximum amount of mefenoxam into the pod zone: water stress can cause the plant to uptake more fungicide and remove it from the pod zone; and higher irrigation rates will place more fungicide deeper in the soil. A producer should carefully consider the leaching potential (i.e. clay content, organic matter, depth to ground water) before irrigating at high rates after chemigation with mefenoxam.

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