Foliar Penetration and Phytotoxicity of Paraquat as Influenced by Peanut Cultivar[1]

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ABSTRACT

Field studies were conducted over a three year period to examine the sensitivity of four peanut (*Arachis hypogaea* L.) cultivars (Florunner, Sunrunner, Southern runner, and NC 7) to foliar applications of paraquat (1, 1' -dimethyl-4, 4'-bipyridinium ion). Treatments included an untreated control and four herbicide treatments: paraquat applied alone at 0.14 and 0.28 kg/ha, or tank mixed with alachlor [2-chloro -*N*-(2, 6-diethylphenyl)-*N*-(methoxymethyl)acetamide] at 4.40 kg/ha. Weeds were hand-removed so that only herbicidal treatments were variables. Paraquat phytotoxicity did not differ between cultivars. No cultivar evaluated was abnormally sensitive nor tolerant to any paraquat-containing treatment. Laboratory studies utilizing radio labelled paraquat revealed that foliar absorption and translocation of paraquat did not vary between peanut cultivars. Yield differences were attributed to differences in yield potential between cultivars.

Key Words: Cultivars, herbicide interactions, cultivar herbicide interactions, herbicide absorption.

The Environmental Protection Agency canceled all registrations for the herbicide dinoseb [2-sec-butyl-4, 6-dinitrophenol (2-(1-methylpropyl)-4, 6-dinitrophenol] in October 1986 due to newly released toxicological information (1). Dinoseb had been extensively used in peanuts (Arachis hypogaea L.) as an early postemergence treatment for control of broadleaf weeds (4, 9). Paraquat (1, 1'-dimethyl-4, 4'-bipyridinium ion) was registered for use in peanuts two years after this cancellation. Prior to registration, paraquat had been evaluated for the control of annual grasses in peanuts (12). In several later studies, paraquat was demonstrated to provide acceptable control of various broadleaf weeds in the cultivar Florunner (14), as well as in the cultivars NC 7 and Florigiant (15). Broadcast application of paraquat results in significant foliar injury to the peanuts (12). However, provided the rate is not excessive (≤ 0.28 kg/ha), and the applications are restricted to early in the growing season (not later than 28 days after emergence), yield is not adversely affected (12).

Paraquat offers no residual or soil activity (6). As a result, paraquat is often tank-mixed with alachlor [2-chloro-*N*-(2, 6-diethylphenyl)-*N*-(methoxymethyl)acetamide]. Alachlor is a soil-active herbicide, which has been commonly used to control and/or supress various annual weeds (4, 13). However, this combination may result in more phytotoxicity to the peanuts (2).

Paraquat is rapidly absorbed into foliage where it serves to inhibit photosynthesis (3, 6). Utilizing electrons directed away from photosynthetic electron transport, the paraquat cation is reduced to a stable free radicle. This form readily re-oxidizes by atmospheric oxygen to regenerate paraquat, and at the same time liberate short-lived but very active

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[5]X-77 (a mixture of alkylaryl-polyoxyethylene glycols, free fatty acids, and isopropanol). Valent USA Corp., P. O. Box 8025, Walnut Creek, CA 94596-8025.

[6]Biological Sample Oxidizer OX-400. R. J. Harvey Instrument Corp., Hillsdale, NJ 07642.

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radicals such as the peroxide radical within the plant cells. These peroxide radicals serve to oxidize cellular components. Brian (3) defined three phases of bipyridylium (the group of herbicides that includes paraquat) uptake. Adsorption begins with rapid entry into the leaf surface; this initial period lasts approximately 30 s. This is followed for approximately 2 hrs. by adsorption into to the less accessible Donnan free space. The third phase is presumed to be the slow accumulation within the cell membranes. However, if the target plant is actively photosynthesizing at the time of application, the rapid onset of tissue necrosis precludes extensive translocation. Once adsorbed, these herbicides are not readily desorbed. Thus, differences in the degree of adsorption between species may influence the amount of herbicide available to the cytoplasm, and ultimately the degree of activity.

Crop cultivars may exhibit a differential response to herbicides, the best known example being the differential tolerance of soybean cultivars to metribuzin (7). Only a few studies in which pesticide tolerance as influenced by peanut cultivar have been addressed (2, 10, 11). Hauser *et al.* (10) in a series of tests evaluated the response of three peanut runner type cultivars to progressively greater amounts of herbicide input. In general, yields reflected increased weed control; yet, in two of the eight trials, the yield of the cultivar GK3 appeared to be sensitive to excessive amounts of herbicide. In a later study (11), which included six peanut cultivars, no cultivar-by-herbicide interactions were detected. In both of these studies, weed control was included as a response variable. Thus, any negative crop response may be confounded with weed control efficacy. Brecke (2) evaluated the effects of various herbicide treatments on several peanut cultivars over a five-year period. Early Bunch and Southern Runner exhibited yield suppression from a treatment that contained two applications of paraquat at 0.3 kg ha per application. however, this is twice the normal use rate of paraquat.

Earlier research established the rate and timing of paraquat required for weed control in the cultivar Florunner (12). As paraquat usage increased, producers questioned the relative tolerance of other peanut cultivars to paraquat. Objectives of this study were; 1) to compare the tolerance of several cultivars to paraquat when applied alone and in combination with alachlor under field conditions, and 2) to evaluate the absorption and translocation of paraquat, alone and in combination with alachlor, as influenced by peanut cultivar.

Materials and Methods

Field Study

Field experiments were conducted during 1987, 1988, and 1989 at the Wiregrass Substation, at Headland Ala., on a Dothan sandy loam (Plinthic Paleudults). Organic matter was 1.3%. The test area was limed to pH 6.5 in the fall. Following a winter cover crop of rye (*Secale cereale* L.), the experimental area was moldboard plowed in the spring. The area had most recently been planted to corn (*Zea mays* L.) as part of a 4-yr corn-corn-peanut-peanut rotation. Separate test areas were used each year of the experiment.

Since the focus of the study was crop response, complete weed control was sought. For the control of annual grasses, the experimental area was treated with a broadcast, preplant incorporated application of benefin [*N*-butlyl-*N*-thtyl-2, 6-dinitro-4-(trifluoromethyl)benzenamine] at 1.7 kg ai ha^{-1}. Broadleaf weeds were removed by hand on a weekly basis. Four peanut cultivars were used. Three were the runner types, Florunner, Southern Runner and Sunrunner; while the fourth was NC 7, a virginia-type cultivar. NC 7, first released in 1978, has consistently been the leading cultivar in dollar returns per acre in the Virginia-North Carolina peanut production area[4]. All peanut cultivars were planted with conventional equipment at a seeding rate of 112 kg/ha.

Five herbicide treatments were used. In the first and second, paraquat

Table 1. Peanut yield as influenced by cultivar and herbicide treatment, 1987.

Herbicide treatment	Rate	Florunner	NC 7	Southern runner	Sunrunner	Mean
	kg/ha	(kg/ha)				
Paraquat	0.14	3730	2830	3690	3520	3440
Paraquat	0.28	3100	2770	3930	3610	3350
Paraquat + alachlor	0.14 + 4.40	3500	2440	3890	3910	3440
Paraquat + alachlor	0.28 + 4.40	3520	2550	4430	3850	3590
Untreated	---	3640	2620	4470	4040	3690
Mean	---	3500	2640	4080	3790	

Analysis of variance

Source	Probability
Cultivar	>0.001
Treatment	0.421
Cultivar X treatment	0.657
LSD0.05 between any two cultivar means within a treatment	635 kg/ha

was applied at either 0.14 or 0.28 kg/ha, respectively. The former rate is registered for a single application, the latter is the maximum amount that may be used in a single growing season. The third and fourth treatments were identical to the first two except alachlor was included at a rate of 4.40 kg/ha. The fifth treatment was a nontreated control. A split plot design with four replications was used, with cultivar assigned to whole plot and herbicide treatment assigned to subplots. Herbicide treatments were applied with 4 days of crop emergence, and nonionic surfactant[5] at 0.25% (v/v) was included with all treatments. Treatments were applied to plots which consisted of four rows spaced 91 cm apart and 6.1 m long. Herbicide applications were made with a tractor-mounted, compressed-air sprayer that delivered 140 L ha^{-1} at 220 kPa.

Peanuts were dug with a conventional digger-shaker-invertor 140 days after planting and harvested with a peanut combine after air-drying for 3 days.

Absorption and translocation

The absorption and translocation of paraquat, applied both alone and in combination with alachlor, were evaluated in each of the peanut cultivars. Seedlings of all cultivars were grown in a Dothan sandy loam soil three plants per species per pot) in 1-L pots. Plants were grown for 3 weeks in

Table 2. Peanut yield as influenced by cultivar and herbicide treatment, 1988.

		Cultivar				
Herbicide treatment	Rate	Florunner	NC 7	Southern runner	Sunrunner	Mean
	kg/ha	----------	----------	(kg/ha)	----------	----------
Paraquat	0.14	2040	1430	1790	2070	1830
Paraquat	0.28	1740	1440	2480	2080	1940
Paraquat + alachlor	0.14 + 4.40	1940	1100	2690	2320	1580
Paraquat + alachlor	0.28 + 4.40	2050	1530	2650	2120	2090
Untreated	---	1640	1060	1920	2000	1290
Mean	---	1880	1310	2310	2120	

Analysis of variance	
Source	Probability
Cultivar	>0.001
Treatment	0.003
Cultivar X treatment	0.023
LSD0.05 between any two means	310 kg/ha

Table 3. Peanut yield as influenced by cultivar and herbicide treatment, 1989.

		Cultivar				
Herbicide treatment	Rate	Florunner	NC 7	Southern runner	Sunrunner	Mean
	kg/ha	----------	----------	(kg/ha)	----------	----------
Paraquat	0.14	3350	2450	4540	3940	3570
Paraquat	0.28	3470	2370	4290	3870	3500
Paraquat + alachlor	0.14 + 4.40	3360	2910	3540	3870	3420
Paraquat + alachlor	0.28 + 4.40	3550	2840	3890	3560	3460
Untreated	---	2520	2770	4180	3190	3170
Mean	---	3250	2670	4090	3690	

Analysis of variance	
Source	Probability
Cultivar	>0.001
Treatment	0.363
Cultivar X treatment	0.161
LSD0.05 between any two cultivar means within a treatment	625 kg/ha

a greenhouse with approximate day/night temperatures of 32/24 C and a photoperiod of 16 hr. Plants were surface watered daily.

Commercially formulated and ^{14}C-labeled paraquat were used to prepare a solution that contained a total paraquat concentration of 0.48 g L^{-1}, and 5000 dpm ul^{-1} of ^{14}C-paraquat. This paraquat concentration was equivalent to the rates used in the field study (0.14 kg/ha). The specific activity of the ^{14}C-paraquat was 22.1 mCi/mmol. The second solution was identical to the first except alachlor was also included at 2.3 g/L. The concentration was equivalent to that prepared for a field application (4.4 kg/ha). A nonionic surfactant was addd as previously described to both solutions at 0.25% (v/v). Each solution was applied as a single 5-ul droplet to the youngest fully expanded leaf of each plant. There were four single-plant replicates for each species. Small 'O' rings (3 mm diameter), which had been sealed to the leaf surface with lanolin, were used to keep constant the amount of leaf surface areas exposed. All applications were made at 9:00 a.m., and harvested 72 hr. later.

At harvest, the 'O' ring was removed, and a 1-cm diameter cork borer was used to remove the disk of leaf tissue that encompassed the treated site. The disk was rinsed for 30 s with 20 ml H20:MeOH (90:10 v/v) to remove unabsorbed herbicide., A 5-ml aliquot of this rinse was added to scintillation fluid and radioactivity was quantified by liquid scintillation spectrometry (LSS). The remainder of the treated leaflet and the adjacent leaflets were removed. Since paraquat is not subject to extensive translocation, separating the leaf tissue into progressively more distal areas from the site of application was considered an appropriate method to detect subtle differences in paraquat behavior between cultivars. All plant parts were oven dried for 48 hr at 40 C, weighed, and combusted in a biological sample oxidizer[6]. Radioactivity was quantified by LSS. Counts per minute (cpm) were corrected to disintegrations per minute (dpm), based on quenching of an external standard. The range of counting efficiency was 88 to 94%.

The amounts of radioactivity recovered from the rinsate, as well as from each segment of tissue, were expressed as percent of the total applied. Data for each cultivar were analyzed by appropriate multivariate and univariate techniques.

Results and Discussion

Field Studies

Yield varied significantly between years, consequently data are presented on a yearly basis (Tables 1, 2, and 3). Yield was consistently influenced by cultivar. Inspection of the data reveals that NC 7 consistently yielded less (3-yr average of 2210 kg/ha) than the other cultivars. This lower yield

Table 4. Absorption and translocation of paraquat in four peanut cultivars when applied alone and in combination with alachlor [1,2].

	^{14}C-paraquat	^{14}C-paraquat + alachlor	Univariate probability
	---(% of amount applied)----		
Florunner			
Leaf wash	19	19	1.00
1-cm radius around target	72	68	0.40
Remainder of treated leaf	6	11	0.10
Adjacent leaflet	3	2	0.44
NC 7			
Leaf wash	20	11	0.19
1-cm radius around target	61	76	0.03
Remainder of treated leaf	17	11	0.06
Adjacent leaflet	1	2	0.35
Sunrunner			
Leaf wash	20	21	0.98
1-cm radius around target	69	56	0.46
Remainder of treated leaf	9	20	0.05
Adjacent leaflet	2	3	0.32
Southern Runner			
Leaf wash	33	15	0.05
1-cm radius around target	56	60	0.82
Remainder of treated leaf	10	15	0.12
Adjacent leaflet	1	10	0.06

[1]Solutions were applied as a single 5-ul drop. These drops were confined by small "O" rings (3 mm diameter) which were sealed to the leaf surface with lanolin. All plants were 3 weeks old at the time of treatment. Treatment exposure was 72 hr.

[2]Statistical analysis using multivariate techniques indicated that the foliar of paraquat penetration or paraquat + alachlor was not affected by peanut cultivar.

probably reflects the lack of adaptation of this cultivar to the southeastern peanut production area. Similar results were reported by Colvin and Brecke (5). Within the three runner cultivars, the ranking of yield in descending order was as follows: Southern Runner (3-yr average yield of 3490 kg/ha), Sunrunner (3200 kg/ha) and Florunner (2890 kg/ha). This yield ranking of cultivars was consistent across years, while individual significance varied with year. (Insert tables 1, 2, and 3).

Treatment effect, as well as the treatment-by-peanut cultivar interactions were significant only in 1988. Thus, no yield reduction could be attributed to the application of paraquat or paraquat-containing tank mixtures in either 1987 or 1989. Examination of the data from 1988 reveals that the nontreated control frequently had the lowest yield; the next lowest yield was with paraquat applied alone at 0.14 kg/ha. Increasing the rate of paraquat, whether applied alone or tank mixed with alachlor, did not reduce yields, and generally resulted in higher yields. Even though weeds were removed, more successful herbicide treatments tended to have greater yields. This is attributed to less crop distrubance and injury, an inescapable factor when extensive hand weeding is required. The 1988 crop year was relatively droughty compared to the other two years. Cumulative rainfall for April, May and June for 1987, 1988 and 1989 was 31, 13 and 45 cm., respectively. This abnormal rainfall distribution may have been a factor in the anomalies in the 1988 data.

Since there were no major differences in yield resulting from either the application of paraquat or paraquat-containing tank mixtures, none of these cultivars can be identified as uniquely sensitive or tolerant to the treatments evaluated relative to Florunner; the cultivar originally used to demonstrate the utility of paraquat (12). Research in Virginia has reported similar findings with NC 7 and Florigiant cultivars (15).

Absorption and translocation

Multivariate analysis at the 5% level of probability revealed that the distribution of paraquat was influenced by cultivar nor by the addition of alachlor (Table 4). However, inspection of the data reveals that the total amount of paraquat absorped by Southern runner was less than the other cultivars (67% absorbed, compared to an average of 80% for the others). This lack of a pronounced cultivar response with respect to paraquat behavior is in agreement with the field research. Averaged across all peanut cultivars, the distribution of ^{14}C-paraquat applied alone, between the amounts recovered in leaf wash, immediate target area, remainder of the treated leaflet, and adjacent leaflets was 23, 65, 11 and 2%, respectively.

Differential absorption could be a factor in differential sensitivity between species or cultivars with a common species to a herbicide. However, this does not appear to be a factor here since the cultivars were essentially identical with respect to paraquat absorption and subsequent distribution within the plant tissue. In similar experiments, in which ^{14}C-labelled paraquat was applied either to the leaf surface or supplied to the cut ends of perennial ryegrass (*Lolium perene* L.) leaves, herbicide uptake was similar in both paraquat-tolerant and sensitive cultivars (8). Furthermore, neither the amount of paraquat translocated out of the treated leaf, nor the pattern of distribution to other ryegrass tillers and the root system could be related to degree of herbicide tolerance.

Univariate analysis at the 10% level of probability revealed that within individual cultivars, the addition of alachlor frequently altered the distribution of paraquat relative to that observed when applied alone. In these cases, greater amounts were recovered in the target tissue, and/or in tissue adjacent to the target. Averaged across all cultivars, the distribution of ^{14}C-paraquat applied with alachlor, between the amounts recovered in the leaf wash, immediate target area, remainder of the treated leaflet, and adjacent leaflets was 17, 65, 14, and 4%, respectively. This slight enchancement in paraquat absorption and translocation with the addition of alachlor is in agreement with field observations (2), in that the addition of alachlor to paraquat can result in enhanced peanut injury.

The results from the field study demonstrated that none of the peanut cultivars evaluated were significantly sensitive or tolerant of paraquat. This conclusion was supported by the laboratory study, in that the absorption and translocation of paraquat did not vary significantly between peanut cultivars. This study indicated that the herbicide paraquat can be used on different peanut cultivars without a detrimental cultivar response. However, adverse environmental conditions, such as drought stress, or other growth limiting factors may result in a cultivar-by-paraquat interaction.

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