# Peanut Weed Control With and Without Acetolactate Synthase-inhibiting Herbicides[1]

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## ABSTRACT

Field studies were conducted in Florida and Alabama during 2001 and 2002 to compare weed control systems for peanut (*Arachis hypogaea* L.) that included only the herbicides registered on peanut that do not inhibit aceto hydroxyl acid synthase (AHAS). Three non-AHAS systems were identified that consistently preformed equivalent to imazapic, i.e., an AHAS-inhibiting herbicide that is very effective in peanut. These systems were either *S*-metolachlor plus flumioxazin, *S*-metolachlor plus *S*-dimethenamid, or *S*-metolachor plus norflurazon applied preemergence (PRE), followed by paraquat plus bentazon plus 2,4-DB applied postemergence. Greenhouse studies established that tank mixtures of *S*-metolachlor plus flumioxazin and *S*-metolachor plus norflurazon applied PRE were synergistic with respect to yellow nutsedge (*Cyperus esculentus* L.) control. This synergism may contribute to the excellent performance of these *S*-metolachlor-containing tank mixtures in the field. Identification of systems which utilize herbicides with modes of action other than AHAS inhibition could offer rotational alternatives to delay the emergence of AHAS-resistant weed biotypes, or alternatives should such biotypes become problematic.

Key Words: Imazapic, bristly starbur, sicklepod, Florida beggarweed, pitted morningglory, yellow nutsedge, herbicide interactions.

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Since registration in 1996, imazapic {(±)-2-[4,5 dihydro-4-methyl-4-(1 methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} has become established as an excellent weed control option for peanut (*Arachis hypogaea* L.). Imazapic applied early post-emergence (POST) alone at 71 g/ha consistently provides comprehensive weed control, optimum peanut yield, and maximum economic returns (Wehtje *et al.*, 2000b; Brecke *et al.*, 2002). Consequently, imazapic has emerged as a near stand-alone product for the control of most broadleaf and nutsedge species and suppression of annual grasses in peanut in our region.

Imazapic is an imidazolinone herbicide that inhibits acetolactate synthase, also termed aceto hydroxyl acid synthase (AHAS) in susceptible plants. This enzyme catalyzes the first committed step in the synthesis of the branched chain amino acids (Hatzios, 1991). Sulfonylurea, triazolopyrimidine, and pyrimidyl-oxy-benzoic acid herbicides also inhibit the AHAS enzyme, and members of these herbicide groups have become nearly essential for weed control in many agronomic crops, including peanut and the crops that are rotated with peanut (Moberg and Cross, 1990). In addition to imazapic, three other AHAS-inhibitors are registered in peanut: the imidazolinone herbicide imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid}, the sulfonylurea herbicide chlorimuron {ethyl 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]benzoate}, and the triazolopyrimidine herbicide diclosulam [*N*-(2,6-dichlorophenyl)-5-ethoxy-7-fluoro-(1,2,4)triazolo (1,5-c)pyrimidine-2-sulfonamide] (Anon., 2004d,b,e, respectively).

Crop rotation restriction is a current limitation for the use of imazapic in peanut. Due to relatively long soil persistence, imazapic treatment precludes the planting of sensitive crops such as cotton for at least 18 mo after application (Anon., 2004a). Emergence of herbicide resistant biotypes is a potential limitation of imazapic and other AHAS-inhibiting herbicides (Saari *et al.*, 1994). Emergence of AHAS-resistant biotypes has been relatively rapid in some cropping systems (Saari *et al.*, 1994). To date, only one report has been published concerning the occurrence of AHAS-resistance weed biotypes in peanut (Vencill and Prostko, 2002). In this case, two populations of Palmer amaranth (*Amaranthus palmeri* S. Wats.) which were both collected from peanut fields in Jefferson County, GA exhibited resistance to imazapic. These populations were also resistant to pyrithiobac (a pyrimidyl-oxy-benzoic acid herbicide used in cotton), chlorimuron, and diclosulam. Cross resistance among AHAS-inhibiting herbicides from different groups has been previously reported (Saari *et al.*, 1994).

The non-AHAS-inhibiting herbicides flumioxazin and *S*-dimethenamid have been registered for preemergence (PRE) applications in peanut in recent years (Anon. 2004c,f). Flumioxazin {2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione} inhibits protoporphyrinogen oxidase in sensitive species (Duke *et al.*, 1991; Vencill, 2002b). *S*-dimethenamid {2-chloro-*N*-[(1-methyl-2-methoxy)ethyl]-*N*-(2,4-dimethyl-thien-3-yl)-acetamide}, a chloroacetamide herbicide, inhibits lipid metabolism and thus the formation of long chain fatty acids (Cobb, 1992; Vencill, 2002a). Both flumioxazin and *S*-dimethenamid are effective in controlling problematic broadleaf and grass weeds (Clewis *et al.*, 2002; Johnson and Vencill, 2002; Jordan *et al.*, 2002).

The chloracetamide herbicide *S*-metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] and norflurazon {4-chloro-5-(methylamino)-2-[3-(trifluoromethyl)phenyl]-3(2*H*)-pyridazinone} can also be applied PRE to control certain weeds. These herbicides also have a mode of action other than AHAS inhibition (Cobb, 1992; Wehtje, *et al.*, 2000; Vencill, 2002c).

The potential emergence of AHAS-resistant weed biotypes has increased the need to reevaluate peanut weed management systems. The objective of this research was to determine if weed control equivalent to that which is currently obtained with imazapic could be obtained with herbicide systems that exclude all AHAS-inhibiting herbicides. Such systems could be serve as replacements should AHAS-resistant weed biotypes become problematic. A more likely scenario, though, is that non-AHAS-inhibiting systems could be rotated with the widely used systems that include AHAS-inhibitors so as to retard the onset resistance.

## Materials and Methods

***General Information.*** Field experiments were conducted during 2001 and 2002 at the Wiregrass Substation of Auburn Univ. located at Headland, AL and the Univ. of Florida, West Florida Res. and Educ. Center, located at Jay, FL. Soil at Headland was a Dothan loamy sand (fine-loamy, siliceous, thermic plinthic paleudults) with 1.3% organic matter and pH 6.5. Soil at Jay was a Red Bay sandy loam (fine-loamy, siliceous, thermic rhodic kandiudults) with 2.1% organic matter and pH 5.8. Separate areas were used each year of the experiment. Both locations were infested with sicklepod [*Senna obtusifolia* (L.) Irwin and Barneby], Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.], and pitted morningglory (*Ipomoea lacunosa* L.). In addition, Headland was infested with bristly starbur (*Acanthospermum hispidum* DC.), whereas yellow nutsedge (*Cyperus esculentus* L.) was present at Jay.

Experimental areas were moldboard plowed in the spring followed by disking twice. Annual grasses and small-seeded broadleaf weeds were controlled with ethalfluralin [*N*-ethyl-*N*-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl) benzenamine] applied preplant incorporated at 0.6 kg ai/ha. Peanut cv. Georgia Green was planted at 125 kg/ha during either the 4th wk of April or the 1st wk of May. All other pest management and cultural practices were in accordance with recommendations of either the Alabama or the Florida Coop. Ext. Serv. Individual plots were four rows wide (0.9 m spacing) × 6 m long. Herbicides were applied with a tractor-mounted compressed-air sprayer equipped with flat fan nozzles and discharging 140 L/ha. The nonionic surfactant Induce® (a 90%-active mixture of alkyl aryl poloxykane ethers, free fatty acids, and dimethyl polysiloxane) (Helena Chemical Comp., Colliersville, TN) was included with POST applications at 0.25% v/v.

***Comparison of Herbicide Systems.*** PRE-applied herbicide systems included *S*-dimethenamid (0.73 kg ai/ha), flumioxazin (0.11 kg ai/ha), and *S*-metolachlor (1.40 kg ai/ha), which were applied alone and in all possible two-way combinations. A control with no PRE-applied herbicide was also included. Each of the PRE treatments were followed POST with either a tank mixture of paraquat (0.28 kg ai/ha) plus bentazon (0.56 kg ai/ha) plus 2,4-DB (0.14 ai/ha), or with no POST treatment. Paraquat plus bentazon plus 2,4-DB has been demonstrated to be an economically effective POST treatment in peanut (Wilcut *et al.*, 1990; Wehtje *et al.*, 1992). Treatments consisted of a factorial arrangement of the PRE-applied and POST-applied treatment options arranged in a randomized complete block design with four replications. Imazapic applied early POST at 71 g/ha was included as a comparison treatment. The intent was to identify combinations of the aforementioned PRE- and POST-applied options that could equal the performance of imazapic.

Visual estimates of percent weed control, based upon relative density and vigor of surviving weeds, where 0 = no control and 100 = complete control, were recorded within 2 wk of harvest. The center two rows of each plot were harvested in Sept. using conventional harvesting equipment. Peanut yield was adjusted to 11% moisture. All data were subjected to analysis of variance using the general linear models procedures of SAS® (SAS, 2000). In the first step of statistical analysis, data sets of a common response variable were tested for treatment consistency across locations and/or years. Data were pooled across locations and years provided that no interactions were detected. The factorial treatment arrangement of the none-AHAS inhibiting treatments (i.e., imazapic treatment data excluded) was addressed in the next step of analysis. Individual treatment means were compared using Fisher's protected LSD value (P = 0.05) in the final step of the analysis. For each response variable, the treatments that were included within the first statistical grouping were identified. Imazapic was consistently included in the most efficacious and highest yielding group. Any non-AHAS-inhibiting treatments also included in this group were therefore equivalent to imazapic.

***Greenhouse Study.*** A greenhouse study was conducted to test for possible interactions among the non-AHAS-inhibiting treatments. This study was conducted in a glass-glazed greenhouse equipped with evaporative cooling. Day/night temperatures were set to 28/22 C, with a photoperiod day length of 11.5 to 12.6 hr. Soil was collected from both the Headland and Jay locations. Soil was air dried and passed through a 4-mm wire screen. Processed soil was placed into 0.5-L styrofoam cups with perforated bottoms for drainage. Four previously germinated yellow nutsedge tubers were planted 2 cm below the soil surface. Soil in the cups was saturated and allowed to drain for 1 d prior to treatment application. Treatments consisted of *S*-metolachor, flumioxazin, and *S*-dimethenamid applied alone at the use rates described in the field study, and at one-half (0.5×) and one-fourth (0.25×) this rate. *S*-metolachor was also applied alone at twice (2×) its normal use rate. The next series of treatments consisted of *S*-metolachlor tank mixed with flumioxazin, norflurazon, or *S*-dimethenamid with a) both components at their normal use rate, b) components at 0.5× rate and c) components at 0.25× rate. A nontreated control was also included.

Treatments were applied with an enclosed-cabinet spray booth calibrated to deliver 190 L/ha. Cups were covered with black polyethylene after treatment to limit evaporation loss, and remained covered until yellow nutsedge shoot emergence was evident in the nontreated control (approx. 3 d). Subsequently, cups received approximately 0.5 cm irrigation on a daily basis. Yellow nutsedge foliage was harvested and weighed 3 wk after treatment. Percent reduction for each cup was then determined by comparing its weight to that of the nontreated control of the respective soil type. A completely random experimental design was used, and the experiment was repeated over time.

Data were subjected to analysis of variance. Preliminary statistical analysis detected no treatment × experimental repetition interaction. Consequently, data were pooled across experimental repetitions for further analysis. Subsequent analysis, other calculations, and data presentation were on an individual soil series basis since control was influenced by soil series. Fisher's protected LSD values (P = 0.05) were used to separate between treatment means. The procedure described by Colby (1967) was used to determine whether the herbicide mixtures were synergistic, antagonistic, or additive. Interactions were considered significant if the difference between the observed and expected values exceeded the appropriate LSD.

## Results and Discussion

***Weed Control.*** Excluding imazapic and focusing only on the non-AHAS-inhibiting herbicides, control of all weed species was influenced by the main effects of both the PRE- and the POST-applied treatments, and by the interaction thereof. The single-herbicide PRE-applied treatments were relatively ineffective. However, flumioxazin applied alone controlled Florida beggarweed and pitted morningglory 80 and 77%, respectively (Tables 1 and 2). The two-herbicide PRE treatments were generally more effective than single herbicide treatments. Several of the two-herbicide PRE treatments controlled bristly starbur, Florida beggarweed, pitted morningglory, and yellow nutsedge at least 77%. However, sicklepod control did not exceed 66% with any of the two-herbicide PRE treatments. The addition of the POST treatment improved weed control at least 20% (pitted morningglory), and up to 47% (sicklepod; data set 1) compared to PRE treatments alone, as averaged over all PRE treatments (data not shown).

As expected, imazapic was always among the most effective treatments for control of all weed species (Tables 1 and 2). Weed control with imazapic ranged from 80% (Florida beggarweed; Table 1) to 94% (pitted morningglory; Table 2). The non-AHAS systems which were equivalent to imazapic varied with weed species. The POST treatment alone controlled bristly starbur 90%, which was equivalent to imazapic (Table 1). All PRE

**Table 1. Peanut weed control with systems that used either non-AHAS-inhibiting herbicides or imazapic.**

| Herbicide system | | Weed control | | |
|---|---|---|---|---|
| PRE-applied[a] | POST-applied[b] | Bristly starbur[c] | Florida beggarweed[d] | Sicklepod[e] |
| | | ----------- | % | ----------- |
| None | no | 0 | 0 | 0 |
| Dim | no | 55 | 35 | 20 |
| Flu | no | 57 | 80*[f] | 48 |
| Met | no | 15 | 47 | 19 |
| Nor | no | 38 | 58 | 36 |
| Dim + flu | no | 80* | 89* | 66 |
| Dim + met | no | 70 | 70 | 30 |
| Dim + met | no | 0 | 62 | 33 |
| Flu + met | no | 71 | 89* | 59 |
| Flu + nor | no | 38 | 82* | 63 |
| Met + nor | no | 60 | 69 | 55 |
| None | yes | 90* | 76* | 84* |
| Dim | yes | 92* | 88* | 90* |
| Flu | yes | 85* | 69 | 85* |
| Met | yes | 81* | 80* | 84* |
| Nor | yes | 85* | 78* | 86* |
| Dim + flu | yes | 86* | 90* | 89* |
| Dim + met | yes | 78* | 78* | 81* |
| Dim + nor | yes | 64 | 85* | 91* |
| Flu + met | yes | 90* | 91* | 88* |
| Flu + nor | yes | 85* | 92* | 86* |
| Met + nor | yes | 90* | 87* | 87* |
| Imaz | no | 92* | 80* | 85* |
| LSD$_{(0.05)}$ | | 15 | 18 | 23 |

[a] Dim = *S*-dimethenamid at 0.73 kg ai/ha; Flu = flumioxazin at 0.11 kg ai/ha; Met = *S*-metolachlor at 1.40 kg ai/ha; Nor = norflurazon at 1.34 kg ai/ha; and Imaz = imazapic at 70 g ai/ha.

[b] A tank mixture of paraquat at 0.28 kg ai/ha plus bentazon at 0.56 kg ai/ha and 2,4-DB at 0.14 kg ai/ha.

[c] Pooled over Headland 2001 and 2002.

[d] Pooled over Jay 2001, Headland 2001 and 2002.

[e] Pooled over Jay 2002, Headland 2001 and 2002; referred to as data set 1 in text.

[f] * indicates values that were included in the first statistical grouping according the LSD$_{(0.05)}$ comparison.

**Table 2. Peanut weed control with systems that used either none AHAS-inhibiting herbicides or imazapic.**

| Herbicide system | | Weed Control | | |
|---|---|---|---|---|
| PRE-applied[a] | POST-applied[b] | Sicklepod[c] | Pitted morningglory[d] | Yellow nutsedge[e] |
| | | ----------- | % | ----------- |
| None | no | 0 | 0 | 0 |
| Dim | no | 20 | 56 | 44 |
| Flu | no | 20 | 77*[f] | 24 |
| Met | no | 15 | 69 | 37 |
| Nor | no | 5 | 62 | 25 |
| Dim + flu | no | 16 | 84* | 38 |
| Dim + met | no | 10 | 82* | 62 |
| Dim + nor | no | 24 | 71 | 34 |
| Flu + met | no | 36 | 76* | 77* |
| Flu + nor | no | 25 | 85* | 20 |
| Met + nor | no | 22 | 64 | 53 |
| None | yes | 53 | 72 | 64 |
| Dim | yes | 63* | 89* | 70* |
| Flu | yes | 50 | 76* | 61 |
| Met | yes | 46 | 87* | 84* |
| Nor | yes | 66* | 82* | 67 |
| Dim + flu | yes | 65* | 93* | 73 |
| Dim + met | yes | 62* | 82* | 78* |
| Dim + nor | yes | 60 | 79* | 74 |
| Flu + met | yes | 65* | 92* | 70* |
| Flu + nor | yes | 61 | 88* | 39 |
| Met + nor | yes | 69* | 88* | 91* |
| Imaz | no | 88* | 94* | 93* |
| LSD$_{(0.05)}$ | | 26 | 23 | 26 |

[a] Dim = *S*-dimethenamid at 0.73 kg ai/ha; Flu = flumioxazin at 0.11 kg ai/ha; Met = *S*-metolachlor at 1.40 kg ai/ha; Nor = norflurazon at 1.34 kg ai/ha; and Imaz = imazapic at 70 g ai/ha.

[b] A tank mixture of paraquat at 0.28 kg ai/ha plus bentazon at 0.56 kg ai/ha and 2,4-DB at 0.14 kg ai/ha.

[c] Pooled over Jay 2001 and Headland 2002; referred to as data set 2 in text.

[d] Pooled over Jay 2001, Headland 2001 and 2002.

[e] Pooled over Jay 2002, Headland 2001 and 2002.

[f] * indicates values which were included in the first statistical grouping according to the LSD$_{0.05}$ comparison.

treatments that included flumioxazin controlled Florida beggarweed at least 80%, which was also equivalent to imazapic (Table 1). In contrast, the other PRE treatments controlled Florida beggarweed no more than 70%. The POST treatment alone controlled Florida beggarweed 76%, which was equivalent to imazapic.

None of PRE-applied treatments alone controlled sicklepod more than 66% (Tables 1 and 2). Effectiveness of the POST treatment varied with year and location, probably reflecting differences in degree of infestation. At Headland in 2001 and 2002, and at Jay 2002 (sicklepod; data set 1, Table 1) sicklepod was controlled at least 84% by either the POST treatment alone or by any of the PRE treatments that were also followed by the POST treatment. The POST treatment was much less effective at Headland 2002 and Jay 2001 (sicklepod; data set 2, Table 2). Only the following six PRE treatments, provided they were followed by the POST treatment, were equivalent to imazapic: *S*-dimethanamid, norflurazon, *S*-dimethanamid plus flumioxazin, *S*-dimethanamid plus *S*-metolachlor, flumioxazin plus *S*-metolachlor, and *S*-metolachlor plus norflurazon.

Pitted morningglory control with flumioxazin, *S*-dimethenamid plus flumioxazin, *S*-dimethenamid plus *S*-metolachlor, flumioxazin plus *S*-metolachlor, and flumioxazin plus norflurazon was at least 76% and equivalent to imazapic (Table 2). The POST treatment alone controlled pitted morningglory only 72%, which was less than imazapic. However, all PRE treatments that were followed by the POST were equivalent to imazapic with respect to pitted morningglory control.

Imazapic controlled yellow nutsedge 93%. Equivalent control was obtained with only five non-AHAS systems (Table 2). The first four systems were *S*-metolachlor, *S*-dimethenamid plus *S*-metolachlor, and *S*-metolachlor plus norflurazon, all followed by the POST treatment; and the last two systems were flumioxazin plus *S*-metolachlor, either alone or followed by the POST treatment.

Among the PRE treatments applied alone, the most effective with respect to yellow nutsedge control were flumioxazin plus *S*-metolachlor (77% control), *S*-dimethenamid plus *S*-metolachlor (62%), and *S*-metolachlor plus norflurazon (53%). In contrast, none of the components of these combinations applied alone provided more than 45% control. This observation led to the hypothesis that the superior yellow nutsedge control of the *S*-metolachlor-containing mixtures may be the result of synergistic herbicide interactions. Testing this hypothesis was the intent of greenhouse study as described below.

***Peanut Yield.*** Only the Jay 2001 and Jay 2002 data could be pooled (Table 3). At Jay (2001 and 2002), flumioxazin plus *S*-metolachlor was the only PRE treatment applied alone that was equivalent to imazapic. However, all PRE treatments that were followed by the POST-applied treatment, as well as the POST treatment alone, were equivalent to imazapic. At Headland 2001, *S*-metolachlor, norflurazon, *S*-dimethenamid plus flumioxazin, *S*-dimethenamid plus *S*-metolachlor, flumioxazin plus norflurazon, and *S*-metolachlor plus norflurazon applied alone, and all PRE treatments that were followed by the POST treatment yielded equivalent to imazapic. Similar results were observed at Headland in 2002 where *S*-metolachlor, flumioxazin plus *S*-metolachlor, flumioxazin plus norflurazon, *S*-metolachlor plus norflurazon alone, and all treatments with the POST treatment yielded equivalent to imazapic.

**Table 3. Peanut yield with weed control systems that used either non AHAS-inhibiting herbicides or imazapic.**

| Herbicide system | | Yield | | |
|---|---|---|---|---|
| PRE-applied[a] | POST-applied[b] | Jay[c] | Headland 2001 | Headland 2002 |
| | | kg/ha | | |
| None | no | 1190 | 3852 | 3517 |
| Dim | no | 844 | 5427 | 3537 |
| Flu | no | 2301 | 5570 | 4198 |
| Met | no | 151 | 6180*[d] | 3678* |
| Nor | no | 603 | 6668* | 3527 |
| Dim + flu | no | 1539 | 6912* | 3415 |
| Dim + met | no | 1245 | 6911* | 3568 |
| Dim + nor | no | 1670 | 5692 | 3700 |
| Flu + met | no | 2654* | 6017 | 3568* |
| Flu + nor | no | 1968 | 6729* | 3376* |
| Met + nor | no | 1748 | 6424* | 3537* |
| None | yes | 3430* | 6098 | 4096* |
| Dim | yes | 3625* | 6708* | 4330* |
| Flu | yes | 3281* | 6324* | 3984* |
| Met | yes | 3798* | 6586* | 3801* |
| Nor | yes | 3368* | 7196* | 3740* |
| Dim + flu | yes | 4081* | 6383* | 4198* |
| Dim + met | yes | 3444* | 6220* | 3954* |
| Dim + nor | yes | 3839* | 6566* | 3913* |
| Flu + met | yes | 3759* | 6993* | 4086* |
| Flu + nor | yes | 3851* | 6139* | 3679* |
| Met + nor | yes | 3222* | 6667* | 3862* |
| Imaz | no | 3508* | 6912* | 3902* |
| $LSD_{(0.05)}$ | | 875 | 1123 | 801 |

[a] Dim = *S*-dimethenamid at 0.73 kg ai/ha; Flu = flumioxazin at 0.11 kg ai/ha; Met = *S*-metolachlor at 1.40 kg ai/ha; Nor = norflurazon at 1.34 kg ai/ha; and Imaz = imazapic at 70 g ai/ha.

[b] A tank mixture of paraquat at 0.28 kg ai/ha plus bentazon at 0.56 kg ai/ha and 2,4-DB at 0.14 kg ai/ha.

[c] Pooled over Jay 2001 and 2002.

[d] * indicates values which were included in the first statistical grouping according to the $LSD_{(0.05)}$ comparison.

Three non-AHAS systems preformed equivalent to imazapic across all weed species evaluated. The systems were the three *S*-metolachlor-containing tank mixtures applied PRE (i.e., *S*-metolachlor plus flumioxazin, *S*-metolachlor plus *S*-dimethenamid, and *S*-metolachlor plus norflurazon), with each followed by the POST treatment. Therefore, we conclude that the non AHAS-inhibiting herbicides that are currently registered in peanut can be combined into systems that can preform equivalent to imazapic. While the more recently-introduced herbicides were included among these systems, they did not replace the older herbicides. *S*-dimethenamid and flumioxazin are the more recent registrants in peanut; *S*-metolachlor, norflurazon, paraquat, bentazon, and 2,4-DB are older herbicides. The non-AHAS imazapic-equivalent systems required two applications during the growing season, i.e., a PRE-applied followed by the POST-applied treatment. This two-application requirement for adequate weed control has been demonstrated in previous research (Wehtje *et al.*, 2000a).

***Greenhouse Study.*** *S*-metolachlor applied alone at 2.8 kg/ha (2× rate) controlled yellow nutsedge at least 99% in both soils (Table 4). Control decreased from 99 to 94% in the Red Bay sandy loam; and from 95 to 76% control in the Dothan sandy loam as the *S*-metolachlor rate was reduced from 1.40 to 0.35 kg/ha (i.e., from 1× to 0.25×). *S*-dimethenamid was generally equal to *S*-metolachlor for controlling yellow nutsedge. Control decreased from 100 to 89% as the *S*-dimethenamid rate was reduced from 0.73 to 0.18 kg/ha (i.e., from 1× to 0.25×). Control decreased from 90 to 79% in the Dothan sandy loam.

*S*-metolachlor was sufficiently active against yellow nutsedge, even at the lowest rate tested, so that any potential interactions in the Red Bay sandy loam were masked. However, in Dothan sandy loam soil, the 0.25× rate combinations of *S*-metolachlor plus flumioxazin and *S*-metolachlor plus norflurazon were deemed synergistic (Table 4). In contrast, the 1×-rate combination of *S*-metolachlor and *S*-dimethenamid was deemed antagonistic. However, control from both components, as well as from the combination, was at least 90%. *S*-metolachlor and *S*-dimethenamid are both chloracetamide herbicides with the same mode of action. In contrast, only the two combinations that brought together different modes of herbicide action were deemed to be synergistic. These results suggest that the superior yellow nutsedge control of these *S*-metolachlor-containing mixtures observed in the field may be the result of synergistic interactions.

In the field study described above, only systems that included *S*-metolachlor in the PRE-applied treatment were equivalent to imazapic. The weed-control ability of these particular combinations may in part be due to synergistic interaction(s), as was demonstrated with yellow nutsedge in the greenhouse study. Assuming that synergism is involved, the respective application rates of the tank mixed components may be reduced without sacrificing control. Testing this hypothesis will be the objective of a subsequent field study.

**Table 4. Yellow nutsedge control with selected soil-applied herbicides applied alone and in combination with *S*-metolachlor in two sandy loam soils.**

| Herbicide | Rate | Red Bay | Dothan |
|---|---|---|---|
| | kg/ha | -- % control[a] -- | |
| *S*-metolachlor | 2.80 | 100 | 99 |
| *S*-metolachlor | 1.40 | 99 | 95 |
| *S*-metolachlor | 0.70 | 97 | 89 |
| *S*-metolachlor | 0.35 | 94 | 76 |
| Flumioxazin | 0.11 | 34 | 1 |
| Norflurazon | 1.34 | 31 | 1 |
| *S*-dimethenamid | 0.73 | 100 | 90 |
| Flumioxazin | 0.06 | 30 | 21 |
| Norflurazon | 0.67 | 20 | 21 |
| *S*-dimethenamid | 0.37 | 89 | 80 |
| Flumioxazin | 0.03 | 28 | 14 |
| Norflurazon | 0.34 | 24 | 7 |
| *S*-dimethenamid | 0.18 | 85 | 79 |
| *S*-metolachlor + flumioxazin | 1.40+0.11 | 100 | 100 |
| *S*-metolachlor + norflurazon | 1.40+1.34 | 100 | 97 |
| *S*-metolachlor + *S*-dimethenamid | 1.40+0.73 | 100 | 90 - |
| *S*-metolachlor + flumioxazin | 0.70+0.06 | 97 | 91 |
| *S*-metolachlor + norflurazon | 0.70+0.67 | 98 | 93 |
| *S*-metolachlor + *S*-dimethenamid | 0.70+0.37 | 100 | 92 |
| *S*-metolachlor + flumioxazin | 0.35+0.03 | 98 | 86 + |
| *S*-metolachlor + norflurazon | 0.35+0.34 | 99 | 84 + |
| *S*-metolachlor + *S*-dimethenamid | 0.35+0.18 | 99 | 100 |

[a] Control equals percent reduction in foliar fresh weight relative to the nontreated control for the respective soil at 3 wk after treatment. Interaction of the herbicide combinations were evaluated by the method described by Colby (1967), '-' and '+' indicate antagonistic and synergistic responses, respectively; no marking indicates an additive effect. Interactions were considered significant if the difference between the observed and expected values exceeded the $\text{LSD}_{(0.05)}$ value which was 6.2%.

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