Dealing with the Evolution and Spread of *Sorghum halepense* glyphosate resistance in Argentina

A consultancy report to SENASA

by

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Executive Summary

SENASA initiated our consultancy assignment to evaluate the current situation of glyphosate resistance in "sorgo de alepo" (*Sorghum halepense*) and to propose immediate and long term strategies to deal with this problem. Poor performance of glyphosate on *S. halepense* became evident to farmers in Salta province in 2003 but the national phytosanitary authorities were not notified. At the time limited action was taken to prevent the spread of putative resistant populations and to establish a regional or national awareness or policy to eradicate or contain infestations and prevent spread or further evolution of glyphosate resistant *S. halepense*. There were no initiatives to ascertain whether new cases were due to spread or new evolution. The situation is now of national concern once SENASA learned about it at the beginning of 2006. We saw varying degrees of infestation with the resistant biotype from only a few clumps of resistant plants scattered in fields to an area of about 30 ha covered with glyphosate-resistant *S. halepense* already subjected to four applications of graminicides without eradication of the weed. The latter infestation was so critical that the area was being tilled, even though production is totally based on no-till agriculture.

Only few confirmatory studies so far would pass the scrutiny of peer-reviewed scientific publications but the field data leave no doubt that resistance has evolved. Resistance seems widespread in Salta and a focus has been detected in Tucumán. Unconfirmed reports suggest that the situation in Tucumán is much worse and that there are already spreading resistant populations in Rosario.

It is unclear how resistance evolved and what the mechanism(s) of resistance is (are), information sorely needed for predicting spread and designing strategies. The resistance levels and the high dose used (relative to the extremely susceptible wild type) suggest that at least two genes are needed for *S. halepense* resistance to glyphosate, so resistant populations should be rare. It is imperative to rapidly determine the resistance mechanism(s) involved. If mutant transporter genes that limit the herbicide translocation in the plant are involved, there may be low level multidrug resistance (MDR) types of cross resistances to other herbicides due to common transporters. Knowing whether resistance evolved at a single or a few foci or concurrently in different regions is critical as different management strategies would be used in each case. Known and putative resistant populations should be DNA-fingerprinted to determine whether one or concurrent resistance events have occurred in order to ascertain whether there were single or multiple founder effects. Critical information on the extent and spread of the problem can be gained by remote sensing and aerial photography if technically possible. Similarly, careful dose-response curves with all herbicides under consideration for dealing with the resistance problems should be determined using susceptible biotypes that

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have been treated over the years with other herbicides, and pristine biotypes as controls would ascertain whether there are the beginnings of MDR type cross resistance. Special attention should be paid to the likely selection of resistance to graminicides that inhibit the acetyl-coenzyme A carboxylase (ACCase) and to inhibitors of acetolactate synthase (ALS) for which resistant *S. halepense* populations exist elsewhere.

It is necessary to understand how resistance spreads within the fields and for long distances across the country. The role of farm equipment in disseminating vegetative and sexual propagules within the field and across neighboring farms should be ascertained. From our limited observations, farmers have not been successful in limiting spread within fields from resistant clumps despite widely used spot herbicide treatments. Long-distance spread of resistant *S. halepense* is a major concern yet there is insufficient knowledge about the dispersal mechanisms of this weed to predict how and where resistance can travel. We thus advise ascertaining how much *S. halepense* seed is not removed by cleaning equipment, how "bolsa blanca" seed and seed of rotational grain crops such as wheat can spread the weed, if screenings from crop seed cleaning equipment commonly sold in Argentina as animal feed are contaminated with resistant seed, to establish if seed is "high-flying" with potential for long-distance wind dissemination, and whether migratory birds feeding in Salta at the time *S. halepense* is in seed can disseminate a proportion of the seed that remains undigested or stuck to their feathers.

Recommendations

As it is necessary to both deal with the present instance of resistance as well as to prevent and delay further instances of this resistance, and evolution of resistance in other weed species, we recommend the following:

1. We strongly encourage instating a low cost / highly effective monitoring system, based on the excellent eyes of the growers, reporting to marketers, with automated reporting to the phytosanitary authorities. Companies marketing glyphosate should be required to have a SENASA approved rapid-response strategy and trained rapid response teams to deal with resistant outbreaks.
2. An aerial or satellite monitoring system should be deployed to follow the extent and spread of resistance, and as a guidance tool to affected farmers.
3. SENASA should consider requiring that all glyphosate be sold as a premix or as a combi package with mixing spout to prevent separation as part of a national strategy to deal with this resistant weed and others that are sure to evolve under current practices.
4. Herbicide labels should contain information on the need for early discovery of resistance, with an explanation of how resistance may appear to the farmer, and whom to contact if resistance is suspected.
5. Rotation schemes should be devised and promoted that will avoid or delay resistance. These should include rotating soybeans with transgenics bearing other herbicide resistances, rotations with other herbicides used preplant, rotating RR-soybeans with a conventional variety every 3-4 years so that alternative herbicides can delay the

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evolution of glyphosate resistant populations, and requiring that RR-soybeans be rotated only with non-RR crops.

6. Immediate action should be taken by farmers under advice of phytosanitary authorities and the local extension agents and industry field advisors where resistance has not yet appeared, to avoid the evolution of resistance or the introduction of resistant propagules. Putative resistant seed should be prevented from growing into rhizomatous clumps whether arising from a new evolutionary event or from seed brought from resistant fields.

7. Prevention of seed set by *S. halepense* should be both a priority for the farmer as well as a national priority where resistance has already been confirmed, and tactics should be carefully integrated to prevent seed set and further dissemination of the weed.

    a. Affected farmers are attempting to deal with the problem and are testing a variety of pre-glyphosate technologies. (Resistance prone) ACCase-grass killers and ALS herbicides are being used to control resistant clumps and for preplant and in-crop postemergence control of glyphosate-resistant *S. halepense*. Both should also be carefully managed to avoid selection of resistant and multiple-resistant biotypes.

    b. Less resistant-prone herbicides should also be considered (e.g. paraquat/diquat, MSMA, tubulin inhibitors, triazines, and the rare protox herbicides that kill this weed).

    c. Farmers are plowing severely infested fields to desiccate rhizomes in Salta with its long rain-free period, a strategy that cannot be used where rain could cause the pieces to sprout and increase infestation.

    d. Where clumps have spread it is possible to treat with rope wick applicators set above the soybean canopy, even with non selective herbicides. SENASA should review label restrictions for soybeans, and consider allowing their use in soybeans when applied by rope wick.

    e. Precision monitoring with automated digital weed detection and GPS-controlled patch spraying that have been successfully tested elsewhere in the field should be considered.

8. We recommend that SENASA instate biosafety quarantine restrictions for the resistant biotype(s) to ensure that research with the biotype(s) is not a cause of spread.

9. Pertinent research is urgently needed to better design and implement preventative and management strategies for glyphosate resistant *S. halepense*. We propose that SENASA perhaps in consultation /coordination with other interested parties, including possible donors, as soon as possible put out a call for pre-proposals to deal with issues of immediate and longer term concern. SENASA must decide whether the call for pre-proposals should be national or international or national with a possibility to collaborate with outside laboratories. We propose strongly considering international or national with outside collaboration. All pre-proposals should be peer-reviewed by a highly-qualified designated committee. Issues to be addressed are the following:

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a. By DNA fingerprinting of R & S biotypes throughout Argentina ascertain whether there have been multiple evolutionary events in the evolution of resistant *S. halepense*.

b. Has *S. halepense* seed spread through uncleaned and "bolsa blanca" seed?

c. Determine the seasonal migration patterns of seed eating birds found presently in Salta and Tucumán during the period of seed ripening of *S. halepense*.

d. Are there incipient cross resistances of glyphosate resistant *S. halepens*e to other graminicides?

e. Genetics of resistance (Is resistance a result of one gene or additive gene effects?).

f. Determining possible modes of resistance (Is resistance due to mutations in EPSP-S, uptake and transport mechanisms, or glyphosate degradation?).

g. Establishment of a national seed and clonal *S. halepense* repository and database.

h. Development of technologies for rapid-remote aerial sensing of clumps and fields of *S. halepense*.

i. Establishment and maintaining of a *S. halepense* resistance electronic database (with public-domain sections).

j. Intra-field observation of farmers' practices affecting resistance spread.

k. Other subjects deemed important by scientists.

We suggest procedures about the call for pre-proposals and their evaluation. SENASA may want to consider immediate commissioning of groups to conduct research projects that are either inexpensive or quick.

10. It is imperative to increase awareness and understanding of the problem, as already noted by SENASA. A workshop to increase awareness and stimulate finding solutions should be organized, as already agreed with SENASA. We put forward a preliminary program with international and local speakers/panelists some of whom may be chosen from among those submitting pre-proposals.

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Resistant *Sorghum halepense* in Argentina

Discovery and farmers' accounts

Evolution of glyphosate resistance in *Sorghum halepense*, locally known as "sorgo de alepo" and "pasto ruso", first came to the attention of one of us (B. Valverde) at the *Seminario-Taller Iberoamericano de Resistencia a Herbicidas y Cultivos Transgénicos*, held at Centro Politécnico del Cono Sur, Colonia del Sacramento, Uruguay, 6-8 December 2005. A brief description of the problem was presented by Ing. Julio Delucchi from Monsanto Argentina. No written account of the incident was provided with the summary of the presentation (see http://www.inia.org.uy/estaciones/la_estanzuela/webseminariomalezas/index.htm) but further information concerning preliminary research results was obtained by electronic contact with Ing. Julio Delucchi and with Dr. Michelle Starke of Monsanto, St. Louis, USA (information described in detail later in this section) in preparation of a review paper on herbicide-resistant grass weeds in Latin America (Valverde 2006). The problem became notorious and internationally known after the local press gave an account of farmers' complaints and concerns about poor performance of glyphosate in controlling *S. halepense*.[1]

The most valuable information regarding the evolution of resistance was obtained from interviews and field visits with local farmers. At Prograno (Asociación de Productores de Granos del Norte) in Pichanal (Salta province) we held a very productive meeting with ten leading farmers on 21 June 2006. The meeting was complemented by visits to fields (Establecimiento Los Angeles, and campo Quijarro and Cornejo in San José de Pocoy). From the accounts and discussion with farmers, the following aspects relevant to understand the glyphosate-resistance problem can be highlighted.

Evident poor performance of glyphosate on *S. halepense* was first noticed in 2003. Some farmers, however, stated that in the late 1990s they observed some failures of glyphosate to control *S. halepense* before planting beans. If this was the beginning of

[1] Investigan si un biotipo de sorgo de Alepo resiste al glifosato. La Nación, Argentina, 11 de marzo de 2006. Available: http://www.lanacion.com.ar/edicionimpresa/suplementos/elcampo/Nota.asp?nota_id=787567.

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the problem it remained unnoticed as *S. halepense* control in beans was achieved with postemergence selective graminicides.

At Establecimiento Los Angeles an estimated 800 ha of 5000 ha are infested with resistant *S. halepense*, mostly distributed in clumps scattered around fields (Figure 1a). At the time of visit, clumps that had survived and re-sprouted after crop harvest had been treated a week earlier with Roundup®[2] at a dilution of 2:10 v/v using a knapsack sprayer. Lack of control was evident (Figure 1b) and the farmer confirmed that this was the typical response of the newly discovered resistant plants. Some of the fields were planted with safflower and received a postemergence, pre-plant application of a co-formulated mixture of glyphosate plus imazethapyr (177 + 20 g ae L^{-1}, respectively). In other fields, resistant clumps had been already treated with a systemic graminicide (fenoxaprop-P) after having received two previous in-crop applications of the same herbicide. Resistance in Argentina was first noticed at this farm and soon after at neighbors' fields. The clumps were dispersed randomly in the field, not at the edges or entrance to the field, which might be indicative that itinerant farm machinery was not the vector of resistance into the field. In no case were resistant clumps seen to be dispersing from field borders or entrances.

At campo Quijarro, San José de Pocoy, some fields had increasing infestations of glyphosate-resistant *S. halepense*, far more serious than those observed at Los Angeles. Distribution of the clumps suggested involvement of machinery movement in the local dispersal of resistant plants within the field. Because of the spreading, the farmer decided to till the infested strips twice during the dry winter aiming to desiccate the rhizomes (Figure 1c) and to later treat the disturbed area with trifluralin. The cost of each soil disturbance is equivalent to USD 16 ha^{-1}; cost of spraying is USD 3 ha^{-1} plus the cost of the chemical (USD 3 L^{-1} Roundup or USD 7-12 ha^{-1} for graminicides such as haloxyfop). The farmer spot treated a field that had a more severe infestation with asulam in March 2006 (Figure 1d) and late-emerging plants from seeds that escaped the treatment had been re-sprayed with glyphosate ten days before our visit.

[2] Roundup is a trademark of Monsanto for its glyphosate formulations. Mention of herbicide trade names does not imply endorsement by the authors for their use or preference of any particular product over other containing the same active ingredient. Product trade names are only used for illustration purposes where the authors considered it appropriate for increased understanding by the reader.

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Figure 1. Illustration of current field situation of *Sorghum halepense* resistant to glyphosate. (a) Scattered distribution of resistant *S. halepense* clumps, (b) Lack of efficacy of glyphosate one week after spot-application of clumps of *S. halepense* that re-sprouted after harvesting the soybean crop, (c) soil disturbance as a drastic control action taken by a farmer under no-tillage production attempting to control infestation of resistant *S. halepense* by rhizome desiccation, (d) resistant clumps treated with asulam and seedlings escaping through late germination. All photographs taken by B. Valverde in Salta region.

The situation was even worse at Cornejo (90 000 ha under production). There an area of about 30 ha was covered with glyphosate-resistant *S. halepense* already subjected to four applications of graminicides during the previous year without eradication of the weed. The farmer's experience was that the infestation with the resistant population had increased dramatically in only three years resulting in total crop failure in 20 ha. Field history of the site included three seasons planted with beans (*Phaseolus vulgaris*) subjected to a pre-plant application of glyphosate and in-crop graminicide use, three seasons with no-till cotton and six years with no-till Roundup Ready®[3] (RR) soybeans. Glyphosate application in soybeans averaged three sprays of 2.5 L ha^{-1} (900 g ae ha^{-1})

[3] Roundup Ready is a trademark of Monsanto to designate transgenic glyphosate-resistant crop varieties.

each for an estimated total glyphosate use of 27 kg ae ha^{-1} during the 12 year period. The farmer considered the infestation so critical that he decided to till the most severely affected 30 ha. Spot treatments at this farm consist of a mixture of clethodim, ammonium sulfate and crop oil. According to the farm manager, imazethapyr was not effective on tall *S. halepense* (of about 50 cm).

Another area where the problem has been reported is at Las Lajitas, Coronel Mollinedo. A leading farm manager, Mr. Ignacio Pisani from Anta del Dorado stated that in his opinion resistance arouse as a single focus that has spread throughout Tartagal and now to Las Lajitas and possibly to other areas. In Las Lajitas area there are claims of at least two sites with glyphosate resistant *S. halepense*. Little attention was initially paid to uncontrolled clumps and the farmer complained that no effective action was taken because they were mislead by technical advisors who stated that the situation was not problematic. This year, upset with the increasing severity of the resistance problem he decided to talk to the local press to raise awareness and speed up proper action[1].

On 23 June we participated at a meeting with researchers, students, field advisors and local authorities at Estación Experimental Agroindustrial Obispo Colombres, in Tucumán. Ing. Ignacio Olea presented a seminar on the use and derived problems of glyphosate in Tucumán. An estimated 1.3 million kg ae glyphosate are used in the Tucumán area, of which about 65% are used in RR-soybeans, which are planted under no-till (Devani and Perez 2003); lemon and wheat consuming about 12% each. The herbicide has been used in lemon for about 20 years and in other crops for 10-12 years. As a result of glyphosate dependency for weed control, shifts in the weed flora have been documented and, more recently, a glyphosate-resistant *S. halepense* population was detected. Some cases of soil activity of glyphosate resulting in phytotoxicty to maize also have been documented (I. Olea, personal communication). Tucumán has a history of herbicide resistance. ALS-herbicide resistant *Amaranthus quitensis* became a serious problem in soybeans but was mitigated by the introduction RR varieties. Ing. M. de la Vega, Universidad de Tucumán, discussed a paper he presented at the Brazilian Weed Science Society Congress held in Brasilia, 29 May-02 Jun 2006 (De la Vega et al. 2006). He confirmed that a biotype from Salta was resistant to glyphosate (see following section).

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Based on information provided at this meeting and a field visit, there is only one confirmed site in Tucumán with glyphosate-resistant *S. halepense*. The field is located at Estación Araoz, Campo Buenavista, Empresa Melián, S.A., Departamento Cruz Alta. Resistance was suspected when individual plants were only slightly damaged by glyphosate applied commercially at the label dose. With the help of the farmer and collaborators we tried to reconstruct the field history, trying to determine if resistance evolved in this field in Tucumán as an independent event from that of Salta. Three years before our visit lack of glyphosate control was first noticed but blamed on a bad application technique by a contract sprayer. The following year inefficacy of glyphosate was attributed to rain soon after application; the year before, maize was planted. Resistant *S. halepense* is spreading in the field despite efforts to prevent it. Current distribution suggests recent spread from a few clumps in the direction of wheat planting; perhaps no-till planters are able to break rhizomes and the tillering crown, and move them short distances away. Harvesting equipment probably helped in previously disseminating the weed in an opposite direction. Adjacent fields where there is no resistant *S. halepense* differ very little in management from the affected field. In the problem field, RR-soybean was initially planted in 1999/2000 and has been included ever since in the rotation (with maize); in other fields a conventional variety was planted once during the five-year period. Weeds were controlled in conventional soybeans with imazaquin and flumioxazim. Metolachlor was not applied in the problem field; only atrazine. Propaquizafop has been used for spot treatments of resistant *S. halepense*.

Our final visit was to Universidad Nacional de Rosario where we were presented with information about production systems and on-going research related to weed science topics. The current production scheme is dominated by a crop sequence that includes soybeans, a short fallow, wheat, soybeans, a long fallow, and maize. Glyphosate is the main herbicide used as the basis of no-till production as well as post-emergence in RR-soybeans and maize. Major changes in the floristic composition of weed populations have been observed and thoroughly studied but so far glyphosate resistance has not been formally reported. There is suspicion, however, that glyphosate-resistant *S. halepense* populations are already present in the area. *S. halepense* is widely distributed (about 65% of the area) but present at a low frequency (8%). The weed has been a research subject

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for three decades. On the road from Rosario to Buenos Aires we spotted clumps of *S. halepense* in soybean fields that otherwise had good weed control. Considering that most soybean fields are treated with glyphosate, it is important to verify if resistant clumps are already present in these areas and to increase farmer awareness. A critical recommendation of this report is that farmer awareness should be increased; if farmers deal with resistance when the first clumps are seen, and before they set seed, there is a possibility of eradicating new foci. If resistant seed goes into the soil, with the slow release from the prolonged dormancy of *S. halepense*, the farmer will be left with expensive and ineffective long term need for control.

Confirmatory studies carried out by Monsanto and independently

According to Monsanto, the first complaint about poor performance of glyphosate was received in December 2003. In January 2004 a preliminary field trial was conducted at the problem farm using farmer's application equipment and in April 2004 an additional micro-plot test indicated glyphosate control of young plants but not of more mature plants. *S. halepense* was controlled by glyphosate at label dose in a greenhouse test conducted in May 2004 similarly to a reference biotype from Venado Tuerto, Santa Fe. In December 2004 further field tests were conducted (at Pocoy and Gerala) with conflicting results: there was no apparent relationship between plant size and control level obtained with glyphosate; some plants were controlled by glyphosate at field dose whereas others were at least 3.5 times resistant (i.e. survived the application of 4.6 kg ae ha^{-1}). Glyphosate in combination with systemic grass killers defoliated the plants but they quickly re-sprouted from rhizomes.

Rhizomes of putative resistant (R) plants were collected in Tartagal (San José de Pocoy) where glyphosate at 3.5 kg ha^{-1} failed to control *S. halepense* (R-Tartagal) and of susceptible plants (S) from road sides (S-Tartagal) and near Fontezuela experiment station (S-Pergamino). Rhizomes were divided and planted in pots. Emerged plants were treated with glyphosate at increasing doses (0.88, 1.77, 3.54, 7.07, and 14.14 g ae ha^{-1}). Plant size at time of herbicide application was not uniform: susceptible plants were 17-23 cm tall and had 11-13 tillers; resistant plants were taller (57 cm) and had more tillers (18). Additional tests using plants emerging from rhizomes also corroborated

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failure of glyphosate alone and in mixture with ammonium sulfate to control some *S. halepense* biotypes.

Two sets of bioassay experiments have been conducted by Monsanto in St. Louis (USA) and were reported by Dr. Starke at a meeting we held in Salta (SENASA regional office) on 20 June 2006. For the first bioassay study, seeds produced in Argentina under greenhouse conditions were sent to the USA. These seeds were obtained from the populations described above as having been tested in the greenhouse at Monsanto's Fontezuela research station. [From the discussion with them, it is questioned whether they used appropriate containment of pollen during their US experiments. Inflorescences were not bagged. It is fortuitous that experiments were carried out during the northern winter].

The first bioassay was conducted in November-December 2005 using limited plant material because of poor seed germination. Two putative resistant biotypes, designated as B and G, were compared to susceptible biotypes E and F collected in the same geographical area in Argentina as the alleged resistant ones. A commercially available[4], susceptible *S. halepense* biotype was used as an additional control. Only six plants from each biotype were tested with four glyphosate doses (426, 841, 1260 and 2520 g ae ha^{-1}) using a commercial formulation without further adjustment for surfactant concentration. Glyphosate was applied in 94 L water ha^{-1} at the 2-3-tiller stage and plant mortality was assessed 21 days after application (DAT). Plants of the reference biotype V, the susceptible biotype E and the putative resistant biotype B were killed by glyphosate at all test doses. Erratic results were obtained with the susceptible biotype F and putative resistant biotype G. The limited number of plants and dose range as well as the erratic response to glyphosate precluded obtaining a dose-response curve and proper statistical analysis.

In the second bioassay (April –May, 2006), five Argentinean biotypes (D, J, L, M, and N), all suspected to be glyphosate-resistant, were tested. The seeds were from a second collection from greenhouse-grown plants (Fontezuela research station). Reference biotype V was also included as a control. Four plants of each biotype were treated with glyphosate (426, 841, 1682, 3364, and 6728 g ae ha^{-1}) using technical grade

[4] Azlin Seed Service, 112 Lilac Drive, Leland, MS 38756, USA.

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herbicide and adjusting for surfactant concentration at an application volume of 94 L ha^{-1}, when they had reached the 3-5 tiller growth stage. Plant mortality was assessed at 19 DAT. All Argentinean biotypes were poorly controlled by glyphosate at doses that killed the reference biotype but inadequate use of the same dose range for the susceptible and putative resistant biotypes (Figure 2) did not allow obtaining a dose response curve for the susceptible biotype and thus precluded calculation of a resistance index and the assessment of shifts of the curve slopes.

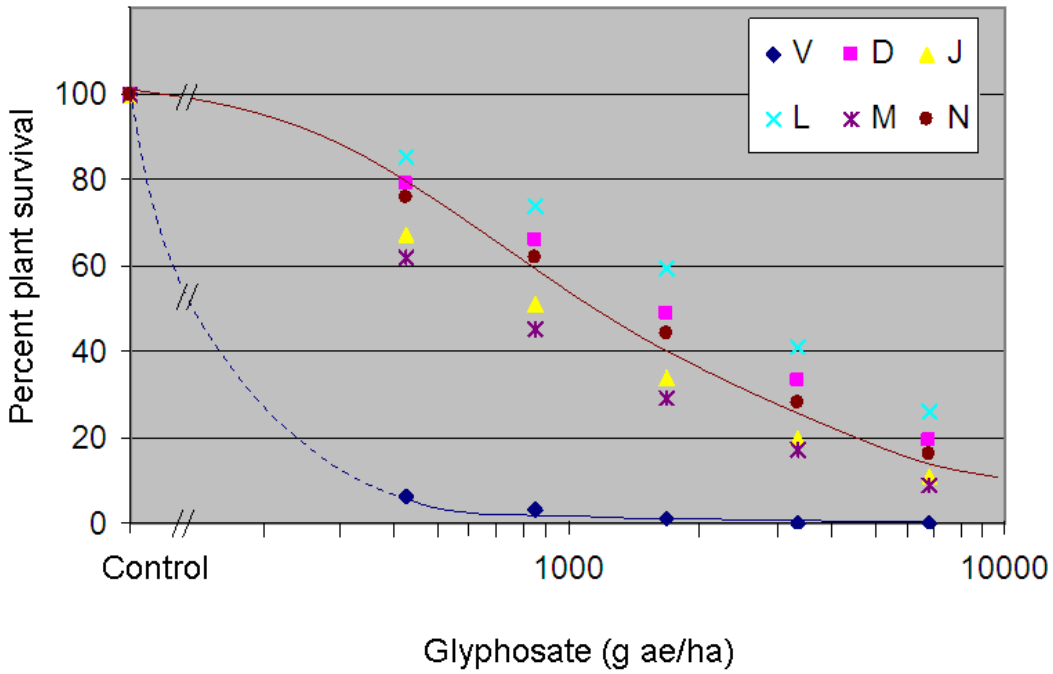

Figure 2. Response of *Sorghum halepense* biotypes to increasing doses of glyphosate. Calculated from information provided by M. Starke, Monsanto. Putative resistant biotypes D, J, L, M, and N were collected in areas where glyphosate resistance is suspected. Reference (susceptible) biotype V was commercially obtained from Azlin Seed Service (USA). Shape of response curve for susceptible biotype is uncertain (dashed line) because of inappropriate herbicide dose range.

De la Vega et al. (2006) confirmed resistance to glyphosate in a biotype from General San Martín, Salta province collected as rhizomes. The putative resistant biotype was compared to a susceptible one (never exposed to glyphosate) collected at Finca El Manantial, Tucumán Province. Glyphosate at a dose range that included 0, 240, 480, 960, 1 920, 3 840 and 7 680 g ae ha^{-1} was applied to *S. halepense* plants in 120 L water ha^{-1}. Above-ground fresh weight of the plants was determined 21 DAT. Based on the

dose response curves obtained, the resistant biotype from Salta was 2.8 times more resistant that the reference biotype (Figure 3). Their extended abstract is appended as Appendix A. Other independent tests also indicate that several populations of *S. halepense* from Salta are resistant to glyphosate (C. Ghersa, personal communication on June 24 of unpublished results).

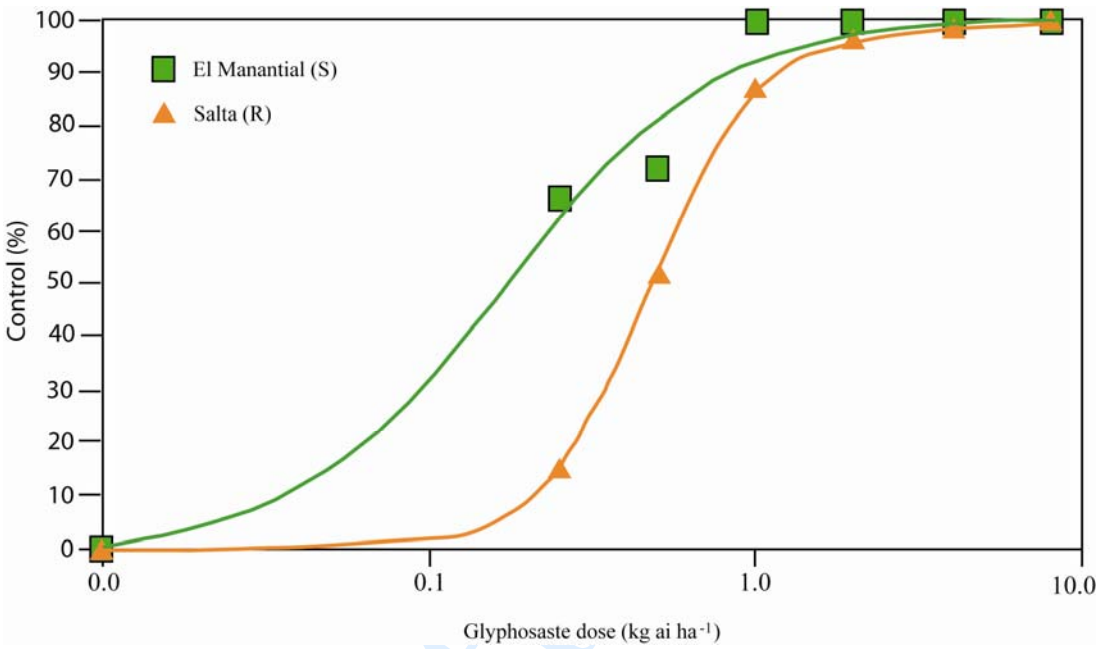

Figure 3. Dose response curve of a putative resistant (Salta) and a susceptible (El Manantial) biotype of *Sorghum halepense* from Argentina. From De la Vega et al (2006) with permission.

Research plots were established to study resistance in the field where resistant *S. halepense* was identified in Tucumán. Three glyphosate formulations (Total plus Speedagro surfactant, RoundUp Full 2, and Atanor plus Tensiowet surfactant) were applied on 12 December 2005 to 4x30 m strips in their first experiment. A second test (applied on 04 January 2006; strips of 4x20 m) included a treatment of haloxyfop plus crop oil and a tank mixture of glyphosate plus haloxyfop. An additional experiment (13 February 2006) was carried out with haloxyfop at increasing doses combined with a fixed amount of crop oil. Glyphosate resistance and haloxyfop efficacy on resistant plants were confirmed (I. Olea, personal communication).

Thus, based on the information we received, resistant *S. halepense* is still mostly concentrated in Salta, where farmers estimate an infestation of about 60 x 20 km (i.e. 120 000 ha), and at a single field in Tucumán (although we heard of rumors of an infestation of some 40 000 ha in Tucumán and of spreading infestation in Rosario). For these reasons, we suggest developing methods of aerial monitoring, as discussed in the section on "monitoring". Unfortunately, even though these outbreaks of resistance may seem to be incipient on the national scale, there are so many foci that the infestations are probably already too large to consider country-wide eradication as an option (Moody and Mack 1988; Thill and Mallory-Smith 1997); eradication can be practiced on new foci, but management and control of infestations and spread are probably the only options in fields where resistance has established. Had there been immediate discussion of the first infestations when they were initially reported to field representatives of the herbicide manufacturers, eradication might have been possible. This is a lesson to be learnt when other species evolve resistance, as inevitably they will.

Management of resistant populations as suggested by Monsanto

As one the major interested parties, Monsanto has been promoting some tactics (wrongly termed as a "strategies") to deal with glyphosate-resistant *S. halepense*. In fields where resistance is detected, Monsanto suggests the following herbicide treatments. Once the field is harvested, wait until sprouts from rhizomes reach 30-40 cm in height and spray with glyphosate tank-mixed with a grass killer (pre-plant or V2). Proceed with the same treatment (in crop) once or twice as required. Their suggested formulation of glyphosate is Roundup® UltraMax (1.8 kg ha^{-1}) and the possible grass killers presented are clethodim (Select 24%, 800 mL ha^{-1}), haloxyfop (Mirage 10.4%, 800 mL ha^{-1}) and fenoxaprop-*p*-ethyl (Isomero, 1600 mL ha^{-1}). The best results have been obtained with clethodim and haloxyfop.

Monsanto also advises monitoring fields after herbicide applications to identify resistant plants and "to take action to prevent these plants from flowering." At harvest time, fields where *S. halepense* has mature panicles (i.e. where the farmer did not "take action to prevent these plants from flowering", or this action was unsuccessful) should be left for last and combines must be cleaned before leaving the field. Only certified

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("fiscalizada") seed free of weed seeds should be planted, and only the recommended dose of the herbicide should be used. If a control failure is noticed, Monsanto requests to be contacted through a field advisor to verify if there is a resistance problem. [We recommend that all suppliers of herbicides be required to immediately report such instances, as described below]. Additionally, Monsanto suggests some general practices such as tillage, crop rotation, delayed planting, burning, modified planting distances but without indication of how they are integrated into a resistant *S. halepense* management strategy.

How did resistance evolve?

It is clear that the evolution of glyphosate resistant populations is a very rare event. Typically resistance evolves quickest to highly persistent herbicides that provide season long control, killing all flushes of weeds that germinate. It was argued on theoretical grounds that resistance to glyphosate was a nigh impossible event (Bradshaw et al. 1997) based on the problems encountered in generating the multi-site mutated genes with modified promoters needed to obtain glyphosate resistant crops, but these arguments were considered specious when they came out (Gressel 1996), and nature proved they were wrong, as there are many glyphosate resistant weeds (Heap 2006). Glyphosate is not at all persistent in the biosphere; it is a systemic herbicide with little residual effect. This lack of biosphere persistence is made up for by farmer persistence to apply glyphosate up to four times a year. Still, persistence is not sufficient; the size of seed rain and the number of seeds germinating per year and the frequency of resistant individuals in the population are also factors that in interaction with the selection pressure determine the likelihood of evolution of resistant populations in a particular species. *S. halepense* can put out 80 million seeds per hectare when not controlled (Martinez-Ghersa and Ghersa 2006), but the amount germinating the following year is much less due to dormancy, predation, and rotting. Assuming that lower amounts of seed were initially in northern Argentinean soils due to at least 4 years of excellent control by glyphosate, there could remain 1 million seeds germinating per hectare per year. The natural frequency of mutations to ALS and ACCase herbicides is about 10^{-6} and 10^{-7}, respectively, so it is no wonder that resistance has evolved to these herbicides in *S. halepense* in other parts of the

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world when there are a million seeds per hectare to choose among. [For this reason, herbicides in these groups should be used sparingly in dealing with glyphosate resistant *S. halepense*].

Clearly, glyphosate resistance is far more rare than resistance to ALS and ACCase. In the cases where genetic or physiological measurements have been possible, resistance has been due to at least two genes having different additive or even synergistic function (some of the mechanisms of glyphosate resistance in weeds have been recently reviewed by Gressel 2002, Pline-Srnic 2006 and Powles and Preston 2006). If there had been under-dosing as had been the case in Australia where 75 g a.e. ha^{-1} were used in the *Lolium* that evolved resistance (Pratley et al. 1996; Pratley et al. 1999), then resistance might have evolved to one of these genes (at a frequency of 10^{-6} to 10^{-8} if dominant at low doses) and then to the second by a process termed "creeping" resistance (Gressel 1995; Gressel 2002). It has been postulated that species that are hard to control with normal rates of glyphosate, such as *Conyza*, naturally have one gene for resistance, and need mutate only a second gene (Lee 2006). The high doses used (relative to the wild type) suggests then that there should be at least two genes involved in *S. halepense.* If two genes are needed, and are each at a frequency each of 10^{-6}, then the frequency of a resistant individual in an untreated population will be 10^{-12}. If the initial frequency of each gene is 10^{-8} each then the frequency of a resistant individual decreases to 10^{-16}. At 1 million seeds germinating per hectare (remember, this is an assumption) then there will be a resistant individual having both genes in a million (at 10^{-12}) to a ten billion (at 10^{-16}) hectares per year. There are ca. 14 million hectares of glyphosate resistant soybean in Argentina of which 0.3 million hectares are in Salta, and 0.2 million hectares are in Tucumán provinces. Thus, there is a chance that few double mutational events bearing resistance evolved in all of Argentina and then spread from a single source. The chance is far less that there were many mutational events evolving in various places in Argentina if indeed resistance is due to selecting for a simultaneous double mutant. There is a converse possibility, that there are two mutations and that one pre-existed in some populations, and the constant use of glyphosate selected for the second mutation. This possibility can lead to much more dire consequences, as will be discussed below.

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Speculation on why glyphosate resistance evolved in northern Argentina

During our discussions, Prof. Claudio Ghersa put forth a hypothesis about why resistance evolved in the north, and why it could not evolve in the south. *S. halepense* could have become resistant to glyphosate because of a combination of herbicide "acclimation" and particular local conditions conducive to the selection of resistant plants. Acclimation refers to the phenotypic responses associated with selecting target plants under recurrent reduced doses of a herbicide. Herbicide acclimation can be expressed as the ability of tillers to produce new vegetative shoots as opposed to normal, susceptible tillers that are incapable of doing it. Vila-Aiub and Ghersa (2005) claim to have shown this type of response in "daughter" ramets of acclimated parent plants of some biotypes of *Lolium multiflorum* recurrently treated with subdoses of diclofop. Acclimated plants were able withstand high doses of diclofop but when their progeny was treated with increasing doses of the same herbicide did not differ from those not recurrently selected, indicating that this is not truly resistance since the trait is not inherited. The notion is that daughter ramets connected through the rhizome to acclimated parents are more likely to survive the application of glyphosate as it has been proposed for plants growing in sites contaminated with heavy metals (Outridge and Hutchinson 1991). Transmission of herbicide resistance as an adaptive change could occur through embryo imprinting, a process that was suggested as relevant in ecotype differentiation in *Sorghum bicolor* (Amzallag 2000). This neo-Lamarkian concept of acclimation is not accepted by the vast majority of scientists dealing with evolution, and the results in their paper can be explained by alternative mechanisms.

In the Pampa, rhizome biomass decreases steadily during the winter and early spring to a minimum around November-December increasing again until foliage is killed by low temperatures in May-June (Ghersa et al 1990; Satorre et al. 1981). Northern Argentina is not subjected to the cold spans that occur in other cropping areas and it is more likely that bud sprouting contributes more to the weed infestation. Additionally, it appears that the contribution of seed production to population growth in *S. halepense* is very limited because of the losses occurring at the soil surface when the seeds are not incorporated (Scopel et al. 1988). Furthermore, the number of rhizomes produced by plants originating from rhizomes was higher than those originating from seed (Vanesso

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and Ghersa 1993). Thus in northern Argentina the continuous plant growth during the winter would facilitate both acclimation and expression of herbicide resistance in ramets attached to acclimated plants as well as the selection of resistant individuals by the selection pressure imposed by the more frequent use of herbicides. These speculations would not preclude spread from the north and establishment in the south of resistant individuals and rather it supports the necessity to diminish resistant seed flow to the south, and to be prepared in the south with management practices that will preclude establishment of resistant individuals. If this is so, then there is a likelihood of one or a few mutational events having occurred on this small area devoted to soybeans in these provinces.

Glyphosate resistance and the risk of multiple and cross resistances

There is a possibility of both multiple and cross resistances evolving (i.e. that new resistances will evolve due to selection by the other herbicides used to control glyphosate resistant *S. halepense*), as well as the possibility that by nature of the genes for glyphosate resistance, that resistant individuals already have a modicum of cross resistance to some other herbicides. Both are dangerous risks.

One species, *Conyza* evolved resistance at multiple foci in the USA. Resistance in *Conyza* is also endowed by genes controlling two separate processes (Dinelli et al. 2006). Does this not contradict what was said above about the extreme rarity of resistance? As mentioned before, Lee (2006) postulates not. He hypothesizes that weeds that are hard to control, such as *Conyza* already possess one of the mutations to resistance, and had to get only the second mutation. This implies that resistance could easily evolve, anywhere in Argentina where glyphosate is heavily used, among the hard to control species. *S. halepense* has large natural variations in response to glyphosate (Fernández et al. 1987; Kintzios et. al. 1999), MSMA (Monaghan and Michael 1981) and other herbicides (Acciaresi and Chidichimo 2005). The lesser response could be due to mutant transporter genes that limit the herbicides in the plants. Similar mutations occur in bacterial, fungal, and mammalian cells where they confer multi-drug resistance (MDR). In such cases selection by a single antibiotic or anti-cancer drug leads to cross resistance to a large variety of drugs, even though the organism had never been exposed

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to the other drugs, all because a transporter that is common to all the drugs had mutated. There is no reason to expect that we do not have similar mechanisms in plants.

Continuous selection with low levels of drugs leads to amplification of the MDR genes leading to higher levels of resistance, which led to using higher doses of drugs. This has happened in some cases in plants, especially with the grass *Lolium rigidum* where low doses of only diclofop methyl in Australia led to cross resistance to all other graminicides that could be used to control this weed in wheat. A similar occurrence happened with another grass weed, *Alopecurus myosuroides* in Britain and on the European continent where the herbicide chlorotoluron was the selector. The same problem is occurring in India in the grass weed *Phalaris minor* with isoproturon as the initial selector, and ALS and ACCase inhibiting herbicides as secondary selectors. In all these cases, the mutation(s) leading to this MDR type cross resistance were in cytochrome P-450's that degrade all these herbicides. For a description of these occurrences, and how they might be overcome see Gardner et al. (1998) and Gressel, (2002).

One of the two genes responsible for glyphosate resistance in *Conyza* (Dinelli et al. 2006) and a gene leading to low level resistance in *Lolium* (Wakelin et al. 2004) is a transporter type gene, at least according to the phenotype of restricted glyphosate movement to the growing points. If a similar occurrence happened with *S. halepense*, the result might be a burndown of the above ground portions, but viability of the rhizomes, when glyphosate is used. With 2-4 such burndowns a year, *S. halepense* would seem controlled (albeit poorly), until a second mutation occurs, probably in the target enzyme EPSP-synthase. This scenario could have unfortunate implications in Argentina:

1. There might be low level MDR cross resistances to other herbicides due to a common transporter. Thus, some of the other herbicides being used to control the glyphosate resistant biotype may have less efficacy on it than on the wild type, and their efficacy will decrease as the common transporter genes amplify.
2. Resistance due to first selecting for MDR type resistance and then EPSP-synthase resistance will not be as rare as the selection for a simultaneous double mutation, and concurrent resistance might be evolving in various places throughout Argentina and will continue to do so (unless measures are taken to slow this process).

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Spread from a single source would call for different management strategies than parallel evolutionary events at many sites occurring around the country (as discussed in a later section). To determine whether one or concurrent resistance evolved it is necessary to DNA fingerprint resistant material from various places where resistance appeared to ascertain whether there were single or multiple founder effects. This in turn is necessary in order to predict how / where resistance may evolve and how it may spread, while allowing the design of better preventative management practices. Similarly, to ascertain whether there are the beginnings of MDR type cross resistances in Argentina, it is necessary to perform careful dose-response curves with all herbicides under consideration for dealing with the resistance problem. These should be with resistant biotypes, with glyphosate susceptible biotypes that have been treated over the years with other herbicides, and pristine biotypes that have never been subjected to treatment by any herbicide. These differential diagnostics are critical for planning on how to deal with this resistance, as well as plan ahead to deal with future resistance problems with other weeds.

Which weeds may evolve glyphosate resistance next?

If it is shown that glyphosate resistance evolved in two stages, the first being a MDR-type cross resistance to many herbicides, it might be expected that weeds that are just barely controlled by glyphosate might be the next to upgrade to full resistance by another evolutionary step. There are many hard to control species in Argentina (Table 1). These might be candidates for evolution of resistance similar to *Conyza* spp. in the USA, Spain, Brazil and South Africa.

The reasons for poor control in one species (*Dicliptera chinensis*) have been elucidated as being threefold; a slightly modified target enzyme EPSP-S that provides a small margin of resistance, a physical presence of more enzyme that "titrates" glyphosate by binding to the herbicide, and elevation of enzyme levels when the plants are treated with glyphosate (Yuan et al. 2002). Mutation that raise transcription as well as expression levels are common in plants, and such mutations could push such a species over the threshold to resistant to labeled rates of herbicide. Whether such mechanisms

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Table 1. Weed species increasingly infesting glyphosate-resistant soybean in Argentina due to limited efficacy of glyphosate, which could evolve resistance[1].

Scientific name	Common name	Family	Life cycle	Reference
Anoda cristata (L.) Schltdl.	Malva	Malvaceae	Annual	[A], [B], [F], [I]
Artemisia annua L.	Ajenjo	Asteraceae	Annual	[G], [H]
Clematis montevidensis Spreng	Barba de chivo	Ranunculaceae	Perennial	[F]
Commelina erecta L.	Flor de Santa Lucía	Commelinaceae	Perennial	[A], [D], [E], [F]
Conyza bonariensis (L.) Cronq.[2]	Rama negra	Asteraceae	Annual	[F]
Convolvulus arvensis L.	Correhuela, Campanilla	Convolvulaceae	Perennial	[D], [G], [H]
Eleusine indica (L.) Gaertn[3]	Pie de gallina	Poaceae	Annual	[A], [E], [F], [I]
Hybanthus parviflorus (L.f.) Baill.	Violetilla	Violaceae	Perennial	[D], [E], [F]
Ipomoea purpurea (L.) Roth and other species	Bejuco	Convolvulaceae	Annual	[D], [E], [F]
Iresine diffusa Humb and Bonpl.	Iresine, Pluma	Amaranthaceae	Annual	[D], [E], [F]
Oenothera indecora Cambess.	Flor de la noche	Onagraceae	Annual	[D], [G], [H]
Parietaria debilis G. Foster	Parietaria, Ocucha	Uricaceae	Annual	[C], [D], [E], [F], [G], [H], [I]
Petunia axillaris (Lam.) Britton, Sterns & Pogg.	Coroyuyo	Solanaceae	Perennial	[D], [F]
Rumex crispus L.	Lengua de vaca	Polygonaceae	Perennial	[G], [H], [G], [H]
Sida rhombifolia L.	Afata	Malvaceae	Perennial	[A] , [F]
Solanum chacoense Bitter.	Papa del monte	Solanaceae	Perennial	[E]
Spharalcea bonariensis (Cav.) Griseb.	Malva blanca	Malvaceae	Perennial	[D]
Trifolium repens L.	Trebol blanco	Papilionoideae	Perennial	[A], [D], [F], [G], [H]
Verbena bonaerensis L.	Verbena	Verbenaceae	Perennial	[D], [F]
Viola arvensis Murr	Violeta silvestre	Violaceae	Annual/biennial	[C], [D], [E], [F]
Wedelia glauca Oct. Hoffmann	Sunchillo	Asteraceae	Perennial	[F]

[1]Compiled from the following references [A] De la Fuente et al. 2006, [B] Puricelli and Faccini 2005, [C] Puricelli and Tuesca 2005, [D] Rodríguez 2005, [E] Vitta et al. 2004, and personal communications from [F] Ignacio Olea, [G] Eduardo Puricelli, [H] Daniel Tuesca, and [I] Eduardo Leguizamón.

[2]Reported as glyphosate resistant in Brazil, Spain and South Africa.

[3]Reported as glyphosate resistant in Malaysia, Taiwan, and Bolivia.

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exist in any Argentinean hard-to-control species (Table 1) has not been checked, but such experiments are recommended.

Other cases of herbicide resistant S. halepense

Resistance to graminicides was confirmed in Mississippi, USA. *S. halepense* populations treated once or twice per year with fluazifop-P and/or sethoxydim from 1983 to 1991 evolved resistance to fluazifop-P, quizalofop-P and sethoxydim but not to clethodim when applied at recommended doses to either seedling or rhizome plants. At sublethal clethodim doses, however, low levels of cross-resistance were observed. Both seedling and rhizome plants were adequately controlled with glyphosate and glufosinate (Smeda et. al. 1997). Resistance in at least one of these biotypes is conferred by an insensitive form of ACCase, the target enzyme (Marles et al. 1993). Similarly, a biotype from Virginia (USA) treated with quizalofop consecutively for three years was confirmed to be resistant to the same herbicides and remained susceptible to clethodim (Bradley and Hagood 2001). The mechanism of resistance in the Virginia biotype appears to be related to an overproduction of the target enzyme ACCase. Absorption, translocation, differential metabolism, and target site mutations are not involved in resistance (Bradley et al. 2001). Based on these cases of resistance it appears that clethodim could be a herbicide of choice to control glyphosate-resistant *S. halepense*. Monsanto Argentina, in fact, is currently recommending mixtures of glyphosate plus clethodym to spray resistant clumps in Northern Argentina. [If spot treating, it is not clear to us why glyphosate is needed in the mixture]. But caution must be exercised since a differential response between the resistant and susceptible biotypes from the USA to clethodim was detected and also because clethodim resistant biotypes have already appeared in the same state in the USA. A new biotype of *S. halepense* was identified in Mississippi that is cross resistant to clethodim, sethoxydim, quizalofop-P, and fluazifop-P because of an altered ACCase enzyme (Burke et al. 2006a, 2006b). Three *Sorghum* weedy species, *S. sudanense*, *S. saccharatum* and *S. verticilliflorum* evolved resistance to ACCase herbicides in Bolivia (Valverde 2006). Resistance to nicosulfuron in *S. halepense* has now been confirmed in Venezuela (A. Ortiz, personal communication).

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Implications of multiple genes for resistance

One of the genes for partial resistance is often EPSP synthase, the target of glyphosate. This can be either a single mutation in the gene (which does not confer resistance to high doses), doubling of gene expression, as seen with *Lolium* (Gruys et al. 1999), or control of gene expression (as naturally found in *Lotus corniculatus*) (Boerboom et al. 1990, 1991).

The additive gene(s) is/are less apparent. They could control plant metabolism of glyphosate, as found in legumes, including soybean (Komossa et al. 1992) or could control glyphosate transport (Dinelli et al. 2006).

The possibility of impairment of herbicide transport has dual implications vis a vis *S. halepense*:

(1) if movement is specifically impaired to the rhizomes, then the top and even crown could be controlled, but systemic movement to the rhizomes would not occur allowing regrowth;

(2) transporter proteins, the type that would control movement, are typically multi-substrate in animal, microbial and fungal systems where they are well studied, and transporter gene mutations confer multiple drug resistances in these organisms, i.e. confer cross resistances to other pesticides, poisons and anti-cancer drugs, despite chemical dissimilarity and different modes of action (Ambudkar et al. 2006; Piddock 2006). Plant transporters are genomically similar to those of other organisms, but are less well characterized physiologically (Windsor et al. 2003).

In the case of Argentinean *S. halepense* it is necessary to perform careful dose response curves with all herbicides used to control this species, using pristine *S. halepense* that never was treated with any herbicide as a control. It may be difficult to find this type of material but in the course of our visit we were told that the reference biotype used by De la Vega et al. (2006) and others kept by University of Buenos Aires have never been treated with herbicides (M. de la Vega and C. Ghersa, respectively, personal communications). Other material that received treatments by other herbicides to ascertain whether there is any low dose cross resistances that would be indicative of a multi-drug resistance type mechanisms should be used as well. Even though *S. halepense* is considered to be easily controlled by glyphosate, quite a bit of variability has been

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found in response to low doses of glyphosate among Greek biotypes (Kintzios et. al. 1999). Differential responses of the *S. halepense* biotypes to aromatic amino acids known to reverse the effect of glyphosate suggested the possibility of multiple mechanisms involved in the expression of glyphosate tolerance *in vitro* (Kintzios et al. 2003). It is not known whether this is the case in Argentina but we found a reference that would support it actually could be. The response of two *S. halepense* biotypes from Buenos Aires province (La Plata and Salto) to glyphosate and fluazifop was determined under field conditions (Fernández et al. 1987). Rhizome sections bearing a single bud were planted in groups of 50 individuals and emerged plants were sprayed with either herbicide at increasing doses (from 0.25X to 4X, where X = 6 L ha^{-1} of formulated glyphosate or 4 L ha^{-1} of formulated fluazifop) using a logarithmic sprayer at the booting stage (about 80 cm tall). Herbicide efficacy was assessed by determining the chlorophyll content of the flag-leaf blades at 72 h after application and the re-sprouting ability of the plants using a subsample of eight individuals. To determine re-sprouting, plants were cut at the crown 30 days after application (DAP) and the re-sprouted plants were counted 60 days and eight months later. Chlorophyll content and re-sprouting ability decreased with increasing doses of glyphosate; the biotype from Salto was more affected by glyphosate that that from La Plata (Figure 4). Interestingly, the biotype from La Plata was more susceptible to fluazifop that the biotype from Salto. After eight months no major differences in re-sprouting were observed between the two biotypes regardless of the herbicide used.

Morphologically distinct *S. halepense* biotypes from Australia also differed in their intrinsic response to glyphosate and MSMA (Monaghan and Michael 1981).

Seven *S. halepense* populations from subhumid and humid areas of Argentina (Provinces of La Pampa, Córdoba, Buenos Aires and Entre Ríos) were treated with nicosulfuron at increasing doses at the 3-4 leaf growth stage. Those from subhumid regions were significantly less affected by nicosulfuron especially at low doses and required more time for a 50% reduction of photosynthesis rate and stomatal conductance. Sixteen-week old untreated plants from the humid regions produced more above-ground biomass, total rhizome length and seeds per plant that those from the subhumid regions, except a biotype from Laboulaye (Cordoba, subhumid) that was intermediate (Acciaresi

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and Chidichimo 2005). The shifts in the slopes of these populations when treated with increasing doses up to only 1.5 times the recommended commercially could be taken as an indication of the potential of local *S. halepense* biotypes to evolve resistance to nicosulfuron through mechanisms other than a target site mutation, and which could be related to transport, because of the differential response on rhizome control. Given that the vegetative material used for these experiments was collected in 1999, it would be very interesting, if still available as seed or rhizomes, to test it with glyphosate to determine if there are also differential responses to this herbicide.

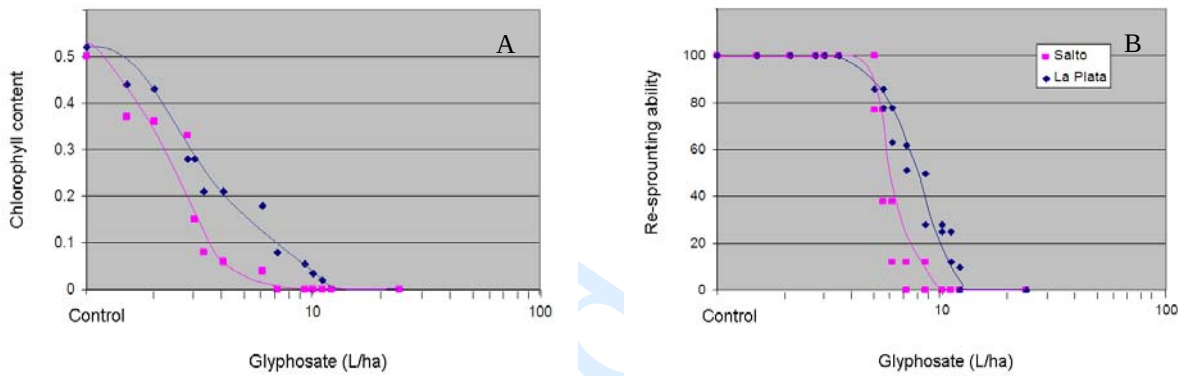

Figure 4. Response of two Argentinean biotypes of *S. halepense* to glyphosate. (A) Chlorophyll content of flag leaf (mg ml^{-1}) 72 h after application; (B) Re-sprouting ability 60 days after the foliage was cut (foliage cut 30 days after application). Adapted from Fernandez et al. 1987.

Knowing which herbicides (if any) have a modicum of cross resistance, and which do not will help guide designing best management practices. Likewise, herbicides that cause negative cross resistance (control the resistant biotype(s) at lower concentration than the susceptible) may be found. Such instances have been especially useful in controlling herbicide resistant weeds in the past (Gadamski et al. 2000; Gressel and Segel 1990).

To further refine management practices it is necessary to have genetic studies initially using the most resistant and the most susceptible material, to complement modes of resistance studies.

Is evolution of resistance a function of glyphosate dose or formulation?

Many cases of herbicide resistance, including resistance to glyphosate, have been a function of using low doses. Low doses can allow selection for incremental levels of resistance controlled by quantitative genes – either multigenes, sequentiate allelic mutations within a gene or gene amplification (=creeping resistance).

Low doses can be obtained by:

(1) Using less than recommended dose

(2) Treatment at times when the weed is less susceptible

(3) Using poor formulations

(4) Removal of herbicide by rain, stress conditions, high wind resulting in drift, too low relative humidity and other functional problems.

All the farmers we visited with the problem claimed to have used recommended doses. Glyphosate had been used in years when it was inexpensive, so there was no reason to underdoseing the northern areas affected, which had previously been pasture. All farmers and researchers interviewed claimed that wild type *S. halepense* is extremely susceptible to glyphosate at all growth stages including the pre-plant application stage where *S. halepense* plants can already be a meter tall. [We propose that this latter observation be rechecked with accurate dose-response curves at various stages].

If this is the case, then it is doubtful that the evolution of resistance is a function of poor management on the part of the farmers or of the use of any particular formulation on the market.

Spread of glyphosate resistant *S. halepense*

If indeed there has been a single or a few mutational events that are the "founder(s)" of glyphosate resistance, there should be just a few "metapopulations" (spatially separated identical or closely related populations linked by dispersal) in Argentina, and one must ascertain how they disperse to develop meaningful management strategies. Long distance seed dispersal is inherently hard to measure, with few datasets. Clearly rare and unusual events move seeds long distances (Cain et al. 2000). Ecologists have developed a whole subject around theories that long distance dispersal of seeds is brought about by non-standard means, and have a propensity to model such events

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(Higgins et al. 2003). Basically, because of their being so rare, it is hard to predict where it will happen – just that it will. According to the literature (Holm et al. 1977) *S. halepense* seed can be blown short distances by wind, float in water and can be carried on fur and feathers, and a proportion pass through birds and animals undigested.

Movement within fields

It is clear from infestation patterns near older clumps that farm equipment plays a part in movement of *S. halepense*. When no-till seed drills pull through clumps they may both chop and drag crown buds, and pull, chop and drag rhizome pieces. Harvesting equipment can separate the *S. halepense* seeds and blow them long distances with the trash. Technologies were developed in similar instances of resistance in Australia, either with baffles that forced trash to fall immediately behind harvesters, limiting spread, or collecting trash in separate containers for burning. Rodents and birds could move seed within the field.

It is imperative to have studies of the situation in Argentina, to ascertain responsibility for intra-field movement, so that propagules do not disperse from the initial problem clumps, while efforts are underway to control the initial clumps. From what we have seen (a limited amount), farmers have not been overly successful in limiting spread within fields, try as they may.

Crop seed

Certified seed must come from weed-free fields and must be free of weed seeds. According to various sources, *ca* 20% of seed planted is certified and the rest farmer-saved and "bolsa blanca" seed. If such seed comes from an infested field, it is unclear if cleaning equipment can remove all *S. halepense* seed. If there is one remaining seed per sack, then this is sufficient to be the focus of a new infestation. We thus advise ascertaining how much weed seed is not removed by cleaning equipment.

Birds and mammals

Birds and mammals can eat and pass a portion of seed undigested (Holm et al. 1977). Birds can be responsible for long distance movement as well. *S. halepense* seeds

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have been detected in gizzards of birds elsewhere (Goddard 1969). Rodents are reported to eat *S. halepense* seed in Argentina (Ellis et al. 1998). Both birds and rodents could be responsible for the dispersion of a single clump to widely dispersed clumps as we saw in some of the fields. Cattle feeding on *S. halepense* plants maturing seed can disseminate the seed through their feces as a proportion of them maintain their viability after passing through the digestive tract (Ghersa and Martinez 1985).

Movement throughout the country

The best way to determine whether dispersed populations are meta-populations from a single or a few founders is through markers and genetic fingerprinting, now through DNA and a few decades ago via polymorphic electrophoretic patterns of proteins or specific enzymes (Cain et al. 2000). Despite the importance of this to know how to deal with the problem, there are very few instances where founder effects had been studied. It is important to ascertain whether there were single or multiple founders early, especially in out-crossing species, as there are often rapid evolutionary changes in the founding population after they begin sexual interactions with the local populations (Lambrinos 2004). Of course in continuous soybeans with glyphosate such interactions are kept to a minimum because glyphosate controls the local susceptible populations, and founders will evolve less quickly in a perennial (at least underground) such as *S. halepense*.

Using enzyme electrophoretic markers it was possible to show that within a field of triazine-resistant *Chenopdium album* (Gasquez and Compoint 1981) or *Amaranthus retroflexus* (Warwick and Black 1986) the resistance emanated from a single founder, with little genetic diversity compared to the great diversity of the wild type individuals still in or near the field. The resistant *Chenopdium* biotypes differed from one another in different regions of France, suggesting concurrent evolution of resistance in each locale to this exceedingly high selection pressure herbicide. Triazine resistance in *Poa annua* (Darmency and Gasquez 1981) and with other herbicides in *Avena fatua* (Mengistu et al 2005) seems to be different, and was highly divergent by the time experimentation was performed with these outcrossing species. The genetic divergence of ACCase resistant *Alopecurus myosuroides* individuals (measured by sequencing the ACCase gene itself)

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was indicative of multiple evolutionary events at the field level (Menchari et al. 2006). This would be expected, as the frequency of mutant alleles within populations is quite high, unlike what we suspect with *S. halepense.*

Founder effects have not been researched for most instances of resistance, some very relevant to the spread of *S. halepense* because evolution of resistance is considered to be rare. This includes *Kochia scoparia* that evolved resistance to highly persistent simazine along railroad rights of way that are kept ultra-clear of weeds by many applications. The first case was reported after 13 years of selection pressure, and eventually lined thousands of km of track in 7 USA states five years later (Bandeen et al. 1982). Was it all from a single founder? The experiments were not performed, but we can guess a single founder. It would have been easy to measure, as susceptible *Kochia* biotypes are highly genetically variable (Mengistu and Messersmith 2002). The triazine resistance was never found in the *Kochia* in adjacent maize fields (where another triazine was often used), so one can assume that a single founder was spread by moving trains. An even more cogent case is glyphosate-resistant *Conyza canadensis* that first evolved resistance in eastern USA states, and later in the Midwest (Heap 2006). Is this all from a single event that somehow crossed the intervening mountains, did it evolve once each on either side of the mountains, or in many places?

There is one case, where the studies were professionally performed that is very cogent to *S. halepense*. *Echinochloa phyllopogon* evolved multiple resistance to a group of disparate herbicides in monoculture California rice paddies. AFLP fingerprinting "established that resistance moved [from paddy to paddy] by spikelet dispersal, not independent mutational events, most likely defined the geographical distribution of resistance in California" (Tsuji et al 2003). The authors conclude: "Prevention and control of this dispersal combined with elimination of seed producing survivors after herbicide treatment should be relevant components of the integrated management of resistance". Easier said than done, as it is not clear how the seeds were dispersed from the single founder, and they suggest it could be due to "birds, irrigation channels, farm machinery and as contaminants of rice seed" (Tsuji et al 2003).

Glyphosate resistance itself is the first marker for following resistant *S. halepense*. In order to simplify such fingerprinting, it has been suggested to use only maternal tissue

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(pericarp), which worked successfully on one recent case (Grivet et al. 2005). If indeed DNA fingerprinting shows that a single evolutionary event in Salta province is found at distances within Salta and JuJuy and to Tartagal and possibly elsewhere, it is necessary to elucidate the culprit(s) responsible for the spread.

DNA finger-printing must be done correctly, and be able to distinguish polymorphisms: In an unsuccessful study to ascertain founder effects of ALS-resistant *Bidens* spp., the 26 RAPD primers used could not even distinguish between the two *Bidens* species (Vidal et al 2006).

Additional information can be gained from surveying the distribution of resistant populations or clumps by remote sensing and aerial photography. Light reflectance from *S. halepense* leaves allows distinguishing it from other weeds and crops, including grain sorghum, by remote sensing or aerial photography (Gausman et al. 1981; Menges et al 1985). Low cost digital equipment also has been tested for distinguishing among weed species, including *S. halepense* (Thomson et al. 2005), and perhaps could be evaluated and adapted to help in mapping the distribution of resistant populations. It also would be worth determining if analysis of aerial or satellite photographs taken before the onset of the resistance problem can provide additional detail of the historical spread of resistance.

There are a variety of possibilities that need to be elucidated, as management strategies are predicated on knowledge.

Migratory farm equipment

If farm machinery has been the vector of dispersal in Argentina, one would expect field colonization along roadsides, which has not been reported. *S. halepense* is an excellent colonizer of roadsides, with further "corridor" dispersal by the wind currents generated by passing vehicles. Such very long (up to 8 km long) infestation corridors of *S. halepense* have been reported in Austria, with little colonization of fields (Essl 2005). Mowing once of twice per year does not limit the rapid spread of the species, and mowing is more tolerated by *S. halepense* than by the other ruderal species, which it rapidly replaced.

Weed seeds are often carried by farm equipment, but the large distances between sites puts this into question as a dispersal vector in Argentina. Harvesting equipment is

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usually moved short distances in a continuous pattern, and resistance has not followed such patterns.

One could institute a requirement to fully inspect and steam clean migratory equipment, but this does have a great cost. We advise first ascertaining whether there are other major causes of movement or whether equipment is the major cause before instituting such regulations.

Wind

We have not found in the literature any quantitative assessment of wind dispersal of *S. halepense* seeds other than the statement in Holm (1977) that seeds can be borne by wind. Air turbulence and uplift can carry seed to high altitudes and the hairs and awns can act as sails keeping some airborne, and lighter seeds fall slowly. There is a high degree of uncertainty in predicting long distance movement, but estimates of tens of km for a small proportion of seed have been made (Nathan et al. 2002). When seed gets caught up in a wind, the vast majority falls to the ground with a typical exponential decay curve; most seeds fall closest to the mother plant, less further on. Some seed gets caught in turbulences and can go far, with a small proportion traveling very far; coming down in unpredictable places. Models can predict how far the tiniest amounts can go, and the maximum distance depends on seed morphology and weight, and meteorological factors (Nathan and Casagrandi 2004). The seed factors are ascertained in a special apparatus that measures the rate of fall, without wind, down a cylinder. This gives an estimate of the drag that keeps seeds airborne, and continually kept up - like a glider plane. These data, for many seeds are put in a model with meteorological data, and can predict maximum distances. Thus, the first experiment is to establish if *S. halepense* seed is "high-flying" with potential to travel. Ecologists have problems in verifying the accuracy of such models because most of the few seed that land do not establish, due to competition with other species; few fall in an empty niche. Glyphosate resistant *S. halepense* presents a unique system for those working on long distance dispersal. Thanks to the continued use of glyphosate, the *S. halepense* has only to compete with the crop (and it has always been adept at that), the herbicide has killed off all competing weeds.

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Water

S. halepense seeds are often dispersed by water (Holm et al. 1977), especially irrigation water. The national water carrier scheme in Israel is considered to be the vector that brought this species hundreds of km from the source water of the Lake of Gallilee (with banks infested by this species) to the Negev desert, where this species had been unknown (S. Kleifeld, personal communication, 2006). When better maps of Argentinean infestations are available, it would be wise to see if infestations follow rivers or arroyos.

Migratory birds

As stated above, birds have been reported to be vectors of *S. halepense* seed (Holm et al. 1977), and long distance movement of seeds is known by birds, which have carried the seeds to vegetate new volcanic islands in the oceans. In one well-documented case, it was shown how the radius of herbicide-resistant populations of *Solanum nigrum* increased 20 km per year due to bird dispersal (Stankiewicz et al. 2001) of this laxative species, which causes birds to defecate more quickly (Wahaj et al. 1998). The eared dove (*Zenaida auriculata*) is claimed to be a migratory bird in Argentina, and it does eat the seeds of *S. halepense* (Murton et al. 1974), but there is no mention of the patterns and distance of migration of this species. It is necessary to ascertain whether migratory birds feed in Salta at the time *S. halepense* is in seed, and whether they can disseminate a proportion of the seed that remains undigested or whether they carry seed stuck to their feathers. Burns (2002) provides a meta-analysis of how one correlates phenology of seed formation with bird abundance. In contrast to Holm et al (1977), Ghersa (personal communication) claims that *S. halepense* seeds do not pass through birds, but such results have not been published. Conversely, Darwin (1859) already reported that a proportion of seeds could pass through the digestive systems of birds unharmed. The glumes may be hard to remove in the gizzard of birds, just as they are hard to remove to facilitate breaking of dormancy. Concentrated sulfuric acid is used in the laboratory to digest away the seed coating, suggesting that it too may prevent digestion in birds. Indeed, passage of seeds through bird guts often assists in breaking dormancy (Traveset et al. 2001).

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Migratory birds forage *S. halepense* rhizomes following plowing or discing (Taylor and Smith 2005) and birds could easily gather seeds on their feathers at such times due to the beards and awns on the seeds.

Migration of bolsa blanca seed

The possible contamination of bolsa blanca seed with a low level of weed seed is possible, as described in the previous section. Because of the daylength specificities of soybeans, the north-south movement of such seed may not be as great as the east-west movement. Seed of rotational grain crops such as wheat are even more likely to be contaminated with *S. halepense* seed facilitating its dispersal.

Movement of seed cleaning screenings

Screenings from crop seed cleaning equipment is commonly sold in Argentina as animal feed (C. Ghersa, personal communication). If such material is marketed at long distances, it could be a vector for weed seed movement. We heard at the meetings that transport of such material is illegal, and if so, there are plenty of good reasons to bring about farmer awareness of the dangers of such material, along with adequate enforcement of the law. Such screenings in affected areas should be checked for viable glyphosate resistant *S. halepense* and the results should be reported to farmers as a warning.

Possible solutions to alleviate the problem

Where resistance has not yet appeared

In such places it is necessary to prevent resistant seed from growing into rhizomatous clumps. It is immaterial whether this is to prevent new evolutionary events from establishing, or to prevent seed being brought from resistant fields.

1. Require that all glyphosate sold be mixed as a premix or as a combi package with mixing spout to prevent separation with:

(a) a graminicide and a broad leaf killer for preplant applications. This will not only deal with *S. halepense* but also resistant-prone weeds such as *Conyza* species and *Amaranthus* species;

(b) be mixed with a post-emergence graminicide for soybeans and;

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(c) be mixed with a broad leaf killer for use in grain rotations, and if there is a strong possibility resistant seed coming in, with a selective graminicide that controls *S. halepense* without affecting the grain (e.g. selective chloroacetamides such as alachlor, metolachlor and other chloracetamides in glyphosate resistant maize).

It may be useful if SENASA makes it clear to manufacturers that such mixtures are desirable and if the registration packages are clear, they will be dealt with expeditiously. Knowing of the market may get mixed products developed.

2. Consider rotating soybeans with transgenics containing other resistances than glyphosate, presently available (such as glufosinate-resistant varieties, with events already registered in the USA) and to be developed. Such rotations will help conserve glyphosate resistant soybeans even though glufosinate appears to be less effective in controlling *S. halepense* than ALS and ACCase herbicides (Johnson et al. 2003).

3. Consider requiring rotations with other herbicides used preplant. This includes compounds such as paraquat or paraquat diquat mixtures and preplant materials currently available and yet to be developed.

4. Consider requiring rotating RR-soybeans with a conventional variety every 3-4 years to force the use of alternative herbicides with different modes of action and degradation to delay the evolution of resistance to glyphosate in other weeds and to promote pre-emergence control of *S. halepense*.

5. Consider requiring that RR-soybeans be rotated only with non-RR crops to decrease selection pressure imposed by the persistent use of glyphosate.

It would be worthwhile to have economic studies, based on local costs, of using the above "insurance" tactics to prevent the establishment of resistance vs. the costs of dealing with the problem once it has established. These studies should include the advantage conferred by controlling the hard to control weeds. While hard to economically calculate, such tactics will delay the evolution of resistant populations of other weeds.

Dealing with the problem once it has established

As we mentioned before, farmers in the affected areas were already attempting to deal with problem and were testing a variety of old technologies from the days before

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glyphosate. Many of these older technologies are described in the literature appearing in Appendix B. The farmers are attempting to deal with two problems: the prevention of seed set and the killing of the rhizomes. The prevention of seed set is both a priority for the farmer as well as a national priority. We visited fields where herbicides were used to prevent seed set, but the treatment may have been too late; a few plants bore some viable seed. *S. halepense* can produce 8000 seeds per m^2. Clearly 95% reduction of seed output, leaving 40 seeds per m^2 is insufficient.

Few herbicides have the systemic affect of glyphosate, which accumulates in rhizomes, killing them. These include the ALS inhibiting herbicides and to a lesser extent the ACCase inhibiting herbicides. Both imazethapyr and haloxyfop controlled *S. halepense* in conventional and vertical-tilled soybeans in Argentina but to significantly reduce population levels at least two consecutive years of herbicide application are required (Tassara et al. 1996). As noted above, both of these groups are prone to the evolution of resistance. The killing of rhizomes typically involves 3 or 4 applications during a season. The farmers we met were using the same herbicides for each of these applications. This is "asking for it". Clearly herbicides of other groups should be tested, whether as mixing partners or as separate herbicides. Part of killing the rhizomes is in starving them by killing new sprouts by contact herbicides. Thus, less resistant-prone herbicides can be considered (e.g. paraquat/diquat, MSMA, tubulin inhibitors, triazines, the few protox herbicides that kill *S. halepense*, etc.).

Specific systems being used or that could be considered:

(1) Plowing during the dry season. This is done to desiccate the rhizomes. This must be done at a time where there will be no wetting of the soil or it can actually increase the infestation due to the fragmentation of the rhizomes.

(2) The use of selective herbicides. This is somewhat easier in the soybean phase of rotation where more options are available than with wheat or maize. Efficacy of both nicosulfuron and primisulfuron to control *S. halepense* and eliminate rhizomes with applications for a few consecutive seasons in maize has been demonstrated elsewhere (Tweedy and Kapusta 1995). But care must be exercised as nicosulfuron resistant *S. halepense* has evolved resistance to nicosulfuron in Venezuela (A. Ortiz, personal communication).

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(3) Use of non-selective herbicides.

In early incipient infestations, where clumps have not spread, it is possible to spot-treat with selective or non-selective herbicides. It is immaterial that such treatments will kill soybeans as the *S. halepense* also competes with the soybeans. Some farmers expressed concern about the possibility of some of these non-selective herbicides to be released to the soil through the rhizome system. Indeed it has been demonstrated that foliarly applied nicosulfuron in *S. halepense* translocates to its roots/rhizomes and also into the rooting medium. More than half of the radiolabeled exudates found in the rooting medium a month after treating the foliage with ^{14}C-nicosulfuron was the unmetabolized herbicide that was available for crop root uptake (Gubbiga et al. 1996). Exudation of dalapon to the soil by *S. vulgare* also has been documented (Foy 1961).

Where clumps have spread it is possible to treat with rope wick applicators set above the soybean canopy. There has been local experience with this technique (Alvarez et al. 1983) and farmers indicate they still have some of the old equipments available. Rope wicks can also be used for selective and non-selective herbicides to save herbicide and expense. SENASA should review label restrictions on the use of such herbicides in soybeans, and allow their use in the crop when applied as a rope wick application, if such is not allowed. Is a rope wick application above a crop considered by regulatory authorities to be an application to that crop? SENASA should also consider how to stimulate chemical companies to register the maximum number of herbicides for this purpose, especially those that are not prone to the evolution of resistance.

Herbicide application optimization for site specific weed management using advanced technologies can help in controlling resistant clumps and in reducing costs of resistance management. Automated weed detection systems using digital image analysis, computer-based decision making, and GPS-controlled patch spraying have been developed and successfully tested under field conditions (Gerhards and Oebel 2006) in other cases and we recommend that such systems be developed for at least detection in Argentina.

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Monitoring

Our experience in viewing monitoring programs that have been instated in various instances has been that a huge financial and human input is instituted after an initial release, and as nothing happens in a few years, support peters out as nothing of worry is found. It is only years later that there is a problem that initially goes undetected. This leads to a situation that quickly gets out of hand. We propose considering a low cost / highly effective system, based on the excellent eyes of the growers, who are highly motivated and understand of the gravity of problems not being dealt with early and quickly. The monitoring system is predicated on two items.

1. Each company marketing glyphosate must have a SENASA approved rapid-response strategy and trained rapid response teams of existing personnel or contractors to deal with resistant outbreaks.

2. An electronic report system should be instated based on Internet reporting and/or 24h phone reporting through a toll-free number. There should be directions on the herbicide label explaining how resistance may appear to be.

Rapid Response Plans

Each marketer of glyphosate, alone or together with other marketers must propose to, and work out with SENASA a rapid response strategy to deal with farmer based electronic reports of incidences of putative resistance. This must include elements of rapidly contacting the farmer with complaints of putative resistance, visits to the farmer, taking tissue samples for analysis, reporting on field status, providing the farmer with information / material for immediate prevention of seed set and discussing with farmers the need to eradicate/prevent seed set, rhizome movement, and strategies to prevent further spread based on local agro-ecosystems and the intensity of infestations, with reports back to SENASA and INTA on standardized electronic forms, in close to real time on the disposition and later follow-up of each incident.

On each label must appear information on the need for early discovery of resistance, with an explanation of how resistance may appear to the farmer. The farmer is to be given the choice of using the Internet to report resistance or a 24h toll free

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number with a recorded digitalized questionnaire. Reports coming in by phone must be transcribed to digital Internet form within one working day.

The beginning of the digitalized forms must include in standard form.

1. Automated time / date – Automated Incident Accession Code
2. Farmers name
3. Address
4. Phone Cell Phone
5. email address
6. GPS or other coordinates of problem area
7. Name of uncontrolled weed (choose from Pull Down menu in internet reporting)
8. Formulation of glyphosate used (choose from Pull Down menu in internet reporting)
9. Was certified seed plant in each of the last three years? __ yes; ___ no
10. Were other weed species normally susceptible to glyphosate controlled by the herbicide? ___ yes; ___ no
11. Were the uncontrolled plants of the weed surrounded by others of the same species properly controlled by glyphosate? ___ yes; ___ no

12 If the uncontrolled weed appears to be distributed in patches, are those patches located where control problems were also observed in the previous cropping/fallow season? ___ yes; ___ no

If the answers to questions 10 - 12 are yes, the above information must be automatically forwarded to SENASA and INTA designated web sites.

Additional questions may be asked that are of interest to the chemical supplier and are optional in reporting, SENASA and INTA must receive a follow up report on disposition within 5 working days.

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Biosafety for studying glyphosate resistant *Sorghum halepense*

This resistance is still rare, yet poses an immense risk if spread, and the little known about it must be augmented by considerable knowledge. This knowledge must be obtained without abetting the spread of resistance. Many laboratories in Argentina and the world may be interested in obtaining material and this should be viewed positively, as the more knowledge available, the more intelligent the strategies that can be developed to staunch the spread.

Qualified scientists wishing to study this weed should be encouraged to do so, while being aware of the problems. Thus, we recommend that SENASA instate biosafety quarantine restrictions for the resistant biotype. The simplest system is that those collecting seed in affected areas be required to do so with the permission of their institutional biosafety officer and that a pre-requisite for any shipment out of the area must be that a Material Transfer Agreement (MTA) is executed. In addition to any restrictions the sender may have in such an MTA, we suggest that the following be included:

1. Recipient scientists, together with their institutional biosafety officers, will work out a biosafety protocol ensuring that biosafety procedures should be ready prior to beginning experiments, along the lines of P2 level for transgenics.
2. All flowering stalks should be removed, or must be bagged before anthesis if to be used for seed collection or genetic crossing.
3. All soil with rhizomes, seeds or plant material must be autoclaved before removal.

A copy of the executed MTA must be filed with SENASA and must accompany any shipment of plant or seed material and any request for export permits.

Needed research – A Call for pre-proposals

We propose that as soon as possible SENASA, perhaps in consultation / coordination with other interested parties, including possible donors that could provide

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the necessary funding, put out a call for pre-proposals to deal with issues of immediate and longer term concern. These pre-proposals should contain 3-5 pages of text explaining how research groups plan to deal with the subject, citing the known literature and any preliminary findings each group has.

The subject areas on a call for Round 1 - pre-proposals might include.

(1) Have there been multiple evolutionary events in the evolution of resistant *S. halepense* by DNA fingerprinting of R & S biotypes throughout Argentina?

The group should provide techniques for collection and shipment of putative resistant material (e.g. live buds from rhizomes, seed, and tissue), DNA extraction and quick tests for new biotypes. Procedures to determine relatedness among materials and determination of presence or absence of a founder effect should be briefly explained.

(2) *Can *S. halepense* seed spread through uncleaned and bolsa blanca seed?

This study can be based on measuring removal of seed by various cleaning machinery. To be performed with susceptible seed. Complementary information can be obtained by sampling already processed commercial seed.

(3) Seasonal migrational patterns of seed eating birds found presently in Salta and Tucumán during the period of seed ripening of *S. halepense.* Part of study can be based on existing knowledge of migrational patterns and part should be 24h / day ornithological observations at the time of ripening. Individuals of those species suspected of being involved in the dissemination of *S. halepense* should be captured to verify presence of seed in feathers and excreta.

(4) *Are there incipient cross resistances of glyphosate resistant *S. halepense* to other graminicides?

Careful dose response curves at various stages of growth of resistant vs. pristine susceptible (never treated with any herbicide) material to measure possibility of MDR (multiple drug resistant) type mechanisms having evolved. Group must design experiments dealing both with seeds and rhizomes.

(5) Genetics of resistance. Is resistance a result of one gene or additive gene effects? Such proposals must be from groups capable of studying both quantitative genetics and

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performing the careful dose-response studies necessary for studying quantitative herbicide effects.

(6) Determining possible modes of resistance. Is resistance due to mutations in EPSP-S, uptake and transport mechanisms, or glyphosate degradation?

(7) Establishment of a national clonal database.

A group with P2 level greenhouse or screen house (if in right climatic zone) capable of cultivating hundreds of accessions in large containers for production of seed. This group will be paired with group 1 doing the fingerprinting to allow elimination of identical clones. This group may consider charging for providing clonal material and seeds to partially offset costs. The proposed charges should appear in the pre-proposal. This group will be responsible for seed production for any group needing material (subject to a material transfer agreement containing biosafety elements – see corresponding section of report).

(8) Development of technologies for rapid- remote aerial sensing of clumps and fields of *S. halepense* and determination of whether retro-analysis of various aerial or satellite photographs can provide data on spread.

(9) Establishment and maintaining of a *S. halepense* resistance electronic database containing parts that are open to all:

a. Description of the problem, maps with proven and putative resistance reports.
b. Links to INTA and company websites where possible solutions are described.
c. Chat line for growers discussing problems and solutions.
d. Other sections to be suggested

and a closed section for SENASA and INTA and their approved users that compiles the automated information from growers provided by the glyphosate marketers web and hotline reporting systems (see Monitoring section of the report).

(10) *Intrafield observation of farmers' practices – movement of rhizomes and seeds from established clumps or populations under standard agronomic procedures.

(11) Other subjects deemed important by scientists, both conventional proposals and those that are "out of the box".

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Groups submitting pre-proposals where live resistant material will be studied, i.e. subjects 1 and 4-7 must append a declaration from the group's institutional biosafety officer that adequate facilities are available to the group to carry out the research.

We recommend that SENASA decide whether the call for pre-proposals should be national or international or national with a possibility to collaborate with outside laboratories. We propose strongly considering international or national with outside collaboration.

*SENASA may want to consider immediate commissioning of groups to perform the experimentation of projects with a * as they are either inexpensive, or quick.

Preproposals should contain a

(1) One paragraph description of the facilities of the group – demonstrating that those needed are available.
(2) A timetable. All except 5, 6, and7 should be less than 6 months, including final report.
(3) A one page curriculum vitae of all scientific personnel
(4) A list of proposers' publications relative to the proposal.
(5) A tentative budget.

Proposals must be submitted electronically to: _____ by ____date___ as pdf files of no more than 2 megabytes.

In the call for pre-proposals there could be a statement that the call is for pre-proposals to understand the phenomenon and to develop short and long term strategies. Within nine months there will be call for longer term proposals based on these findings.

We recommend that all preproposals be peer-reviewed by a committee composed of a representative each of: SENASA, INTA, SECyT, CONABIA, growers groups, industry groups, one national and one international consultant with no conflict interest.

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As preproposals come in, the members of the group should nominate an outside academic peer-reviewer. The committee should rate the pre-proposals numerically and the two with highest averages in each category should be asked to write a proposal by September 10, and also to present the proposal to the committee orally at the meeting. The committee may then ask the groups to make changes in the proposal and may ask whether they are willing/how they could split the task with other groups based on best expertise.

A workshop to increase awareness – stimulate finding solutions

Awareness is imperative if resistance is to be dealt with efficiently. We have seen the results of delaying and obfuscating before in dealing with epidemic like problems such as HIV, SARS, mad cow, etc. Even in Argentina, the battle in dealing with glyphosate resistant *S. halepense* has been rendered much harder due to the three years that have elapsed since the first farmer complaints. *S. halepense* is a problem weed in most places in the world where glyphosate resistant crops are cultivated, so there may be considerable international interest in being aware to the problem, so that information can be gathered so that effective strategies can be designed. Thus, we suggest that others outside of Argentina be made aware of the problem. An added advantage is that many will begin studying the issues, and it may well be that others will find solutions applicable to Argentina.

This is a proposed preliminary program for the open workshop to be organized by SENASA in September 2006 (some speakers/panelists may be chosen from among those submitting pre-proposals).

The Threat of Glyphosate Resistant *S. halepense* to Argentinean Agriculture

Day one (Sept. 20)

I. Setting the scene – the magnitude of the threat of *S. halepense.*

A. Opening remarks by SENASA representatives (Chair: Silvia Passalacqua)

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B. Panel discussion with representatives of growers groups in Salta and Tucumán (and elsewhere?) describing the present situation and future as they see it (Panel chair: representative from ProGrano).

C. Ignacio Olea (Sección Manejo de Malezas, Estación Experimental Agroindustrial "Obispo Colombres", Tucumán) – Have other weeds poorly controlled by glyphosate filled the ecological vacuum?

D. Ag economist (Eduardo Trigo?) Economic implications to Argentinean agriculture.

II. How does resistance evolve? The need to know to develop long term management strategies.

A. J. Gressel - "Classical" target site resistance.

B. J. Gressel - New modes of resistance evolving.

C. B. Valverde/J. Gressel Evolution of glyphosate resistance world wide

Day 2 Sept. 21

D. Eduardo Leguizamón – Biology of *S. halepense*

E. Claudio Ghersa – Hypothesis: Resistance can evolve only in northern Argentina.

F. Gressel/Valverde. How might glyphosate resistance evolved in Argentina.

G. E. Satorre?????. Lessons learned from National *Sorghum halepense* Action Plan of the 1970s: implications for prevention and management of herbicide resistance

III. Why *Sorghum halepense?* Panel discussion (Possible panel chair: Federico Trucco)

IV. How might resistance have spread

A. Ornithologist – Migratory patterns of seed eating birds in Argentina.

B. Vertebrate Ecologist - Mammal movement and eating patterns in fields.

C. Seed specialist – the bad seed – problems of cleaning seed for planting.

D. ???? Use and distribution of seed screenings

E. ??? Machinery as a vector of weed seed movement

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Panel – Chair (Esteban Hoop?) Possible interim recommendations for preventing seed and rhizome spread.

Day III Sept. 22

V. Dealing with the problem

A. J. Gressel – Strategies that have worked elsewhere

B. B. Valverde/A. Fischer – synergists to overcome resistance

C. Valverde /Gressel. Possible preventative "immunizations" and possible cures by "chemotherapy" and "surgery".

D. Regulator. Options for emergency temporary registration of chemicals in affected and the most vulnerable areas.

E. Valverde/Fischer – Why research is needed to develop the most cost effective strategies.

F. Discussion of volunteer posters (Moderator: A. Fischer)

Panel – Tactics that work and haven't worked (short presentations by researchers and growers).

Panel. B. Valverde / J. Gressel/ A. Fischer – implications / long term limitations of each strategy.

Panel (Growers / Industry / Government) – What would be the implications of requiring that glyphosate be used only with approved mixtures?

M. Burachak- CONABIA's role in preventing future problems.

J. Gressel- Long term biotech solutions to the problem.

Day 4 (closed)

Panel – Presentations of Proposals to the committee.

15 minutes presentation – 15 minutes discussion.

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A CD containing Power Point presentations and relevant papers or abstracts will be handed to all participants with the registration package.

Posters on topics relevant to the workshop will be accepted for display during the event. A discussion session of the most relevant posters will be held on day III. Summaries of posters and/or a PDF file of the entire poster should be submitted in advance to be included in the CD to be distributed to all participants

Contacts

Our main contact at SENASA was Ing. Silvia Passalacqua, Dirección Nacional de Protección Vegetal, passalac@senasa.gov.ar.

The following people/organizations provided very useful information and thoughful discussions about *S. halepense* during our visit to Argentina.

Farmers and their organizations

- Prograno (Asociación de Productores de Granos del Norte), prograno@prograno.org.ar
  Presidente Fernando Fortuny: ffortuny@lajitas.com.ar
  Secretaria Ana Lorenzo: of.salta@prograno.org.ar

Prograno associates:
- Jose León, Las Lajitas S.A., Attn.: ffortuni@lajitas.com.ar
- Fernando Varela, Desdelsur, S.A., fernandovarela@desdelsur.com
- Mariano Musari, Estancia Rio Colorado, S.A., riocolorado@arnet.com.ar
- Javier Elizalde, San Jose de Pocoy, S.A., jepocy@arnet.com.ar (Quijano, field visit)
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Appendix A

Extended abstract by De la Vega et al. 2006

De la Vega MH, Fadda D, Alonso A, Argañaraz M, Sánchez Loria JY, García A (2006) Curvas dose-resposta em duas populações de *Sorghum halepense* ao herbicida glyphosate no Norte Argentino. Resumos do XXV Congresso Brasileiro da Ciência das Plantas Dañinas. Brasilia, 29 May-02 Jun 2006, Brazil, 4p.

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CURVAS DOSE-RESPOSTA EM DUAS POPULAÇÕES DE *Sorghum halepense* AO HERBICIDA GLYPHOSATE NO NORTE ARGENTINO

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RESUMO: A resistência é um fenômeno que ocorre em condições de monocultura, ou monoherbicida pelo que o plantio direto e a utilização de culturas transgênicas resistentes ao glyphosate proven as condições ótimas para o mencionado fenômeno. No presente trabalho tentou-se verificar se a ocorrença na falha de controle de *S. halepense* no campo trata-se de um caso de resistência para o qual foi feito um ensaio de curva dose- resposta em casa de vegetação. Trabalhou-se com plantas amostradas na região problema no Departamento General San Martín na provincia de Salta e outra população obtida do Manantial na provincia de Tucumán. Esta última não tem relatos de aplicação do herbicida. O experimento foi desenvolvido na casa de vegetação da Facultad de Agronomía, onde as doses avaliadas foram: 0, 240, 480, 960, 1 920, 3 840 y 7 680 g do princípio ativo por ha e um volume de aplicação de 120 l/ha. O delineamento experimental utilizado foi em blocos inteiramente casualizado com cinco repetições. Após a aplicação, os vasos foram irrigados para permitir a absorção e translocação do produto. As avaliações ocorreram 21 dias após a aplicação do herbicida, extraiu-se as partes verdes das plantas e obteve-se o peso fresco. Os dados obtidos foram submetidos à análise da variância, com o objetivo de verificar se existe diferenças entre as populações e procedeu-se a análise da regressão não linear dos dados utilizando o modelo log-logístico proposto por Seefeldt *et al*. (1995). O ANOVA para dose recomendada demostrou diferenças significativas ao 1% de probabilidade pelo teste F, entre as populações. Na população problema a dose necessária para reduzir em 50% do crecimento (GR_{50}) foi de 460,8 g p.a/ha para a população de Salta e de 163,2 g p.a/ ha para a população susceptível. A relação dos GR_{50} resistente / GR_{50} suscetível deu um valor de 2,82. A equipe de trabalho esta tentando determinar os alelos especificos pelo PCR. O controle insatisfatório das populações de *S. halepense* no Norte de Salta pelo herbicida Glyphosate são devidas a uma maior GR_{50} em dita população o que leva a concluir que para obter sucesso no manejo do biótipo resistente debe visar a minimização da pressão de seleção pela utilização de mixturas e rotações de produtos.

Palavras-chave: resistência, glyphosate, capim massambará (*Sorghum halepense* (L.) Pers.)

DOSE-RESPONSE CURVES FOR TWO POPULATIONS OF *Sorghum halepense* (L.) Pers. TO THE HERBICIDE, GLYPHOSATE, IN NORTHERN ARGENTINA

ABSTRACT: Resistance generally arises under conditions of monoculture and the continuous use of the same herbicide. As such, no-tillage and the use of transgenic crops resistant to Glyphosate provide optimal conditions for the appearance of such phenomena. With the objective of verifying whether the observed failures in the control of *S. halepense* in the field have been due to herbicidal resistance, a greenhouse dose-response trial was performed. The plants used came from a problem area located in the Department of General San Martín in Salta province; the second population was collected from El Manantial, in Tucumán province where there was no recorded use of the aforementioned herbicide. The trial was performed in the greenhouse of the Faculty of Agronomy and the doses evaluated were 0, 240, 480, 960, 1 920, 3 840 y 7 680 gms of active ingredient per hectare with an application volume of 120 L/h. A randomized block experimental design was used with five replications per dose. The pots were watered after each application to favor absorption and translocation of the product. After 21 days, all the green parts were extracted to evaluate fresh weight. Data obtained were subjected to an ANOVA analysis to determine whether differences existed between the two populations and then were fitted to the non-linear regression model proposed by Seefeldt *et al.* (1995). The ANOVA showed that for the recommended doses the populations were significantly different at the P=0.01 level. The doses at which growth was reduced by 50% (GR_{50}) were 460.8 gms a.i./h for the problem population and 163.2 gms a.i./h for the susceptible population. The resistance ratio (obtained by comparing the GR_{50}'s) was 2.82. In addition to this trial, we are performing genetic PCR studies to amplify the specific alleles involved. It can be said that the repeated failure to control *S. halepense* with the herbicide Glyphosate in populations from northern Salta is due to a higher GR_{50} present in this population. This fact enables one to conclude that the successful control of this weed will require reducing the genetic selection pressure by using herbicide mixtures and product rotation.

Keywords: resistance, glyphosate, Johnsongrass.

INTRODUÇÃO

O uso repetitivo de herbicidas com o mesmo mecanismo de ação, exerce uma pressão de seleção que incrementa a resistência das espécies que antes eram susceptível. Desde a ocorrência do primeiro caso de resistência de plantas daninhas ao herbicida, *Senecio vulgaris* a Simazina, são numerosas as espécies que apresentam este fenômeno (Holt, 1992). Foram registradas ocorrências de 306 biótipos resistentes ao herbicida que involvem 182 espécies (Heap, 2006). Esta resistência de tipo genética é heredável e se apresenta em condições de monocultura e monoherbicida desta manera o plantio direto e a utilização de culturas transgênicas resistentes ao Glyphosate proven as condições ótimas para o presente fenômeno. No Noroeste Argentino a superfície cultivada com soja é de 700.000 ha (Devani *et al.* 2003) onde mais do 90% da superfície é feita sob plantio direto e com cultivares resistentes ao Glyphosate. *Sorghum halepense* (L.) Pers. é uma das plantas daninhas mais importantes no EEUU, ela compite de uma maneira forte pela água, luz e nutrientes. Perdas no campo de 40 % pela maleza não é inusual, além de ser uma planta perene é capaz de desemvolver em 15 semanas 250 m de rizomas, atingindo entre 600 e 900 m de rizomas (Koch, 1982). Durante 1997 publicou-se o primeiro caso de resistência ao Glyphosate em *Eleusine indica* (L) Gaertn; no 2000 apareceu em *Conyza canadiensis* (L.) Cronq e na atualidade se citam oito biótipos que apresentam resistência a este herbicida entre as seguintes espécies: Lolium rigidum, Gaudin, *Lolium multiflorum* Lam., *Conyza bonariensis* (L.) Cronq., *Plantago lanceolata* L., *Amaranthus palmeri* S. Wats. y *Ambrosia artemisiifolia* L. (Heap 2006).

A relação entre a dose do herbicida e a resposta da planta é de fundamental importância para avaliar a eficiência do herbicida e a curva dose-resposta é recomendada para quantificar a sensibilidade da planta ao herbicida e assim determinar casos de resistência Seefeldt *et al.* (1995).

O objetivo do presente trabalho foi determinar a relação entre as doses que causam o 50 % da diminuição no crecimento de dos biótipos de *S halepense*.

MATERIAL E MÉTODOS

O experimento foi desenvolvido na casa de vegetação da Finca El Manantial da Facultad de Agronomía da Universidad Nacional de Tucumán. Para o trabalho usaram-se duas populações de *S. halepense*. Uma delas foi coleitada no Departamento General San Martín, Provincia de Salta onde existem falhas no controle pelo herbicida Glyphosate. A outra foi obtida da Finca El Manantial na Provincia de Tucumán, ela nunca esteve sob pressão de seleção pelo herbicida por ende ela foi considerada o biótipo suscetível. Os rizomas de 5 cm de comprimento foram colocados em vasos plásticos e deixados em casa de vegetação. O delineamento estatístico adotado foi de blocos ao acaso com 5 repetições. As doses testadas foram: 0, 240, 480, 960, 1 920, 3 840 y 7 680 g do princípio ativo por ha e um volume de aplicação de 120 l/ha usando-se uma equipe de pressão constante provisto de bicos de jato plano (tipo “leque”) 8002. Após a aplicação do produto os vasos foram mantidos em casa de vegetação e irrigados para permitir a translocação do herbicida. As avaliações ocorreram 21 dias após aplicação (DAA) do herbicida, sendo as plantas daninhas coletadas por corte ao nivel do colo e determinou-se o peso fresco considerando o peso da testemunha (0 princípio ativo) como 0% de control e das plantas mortas como 100 % de control. Os dados obtidos foram submetidos à análise da variância, e logo ajustou-se a equação inversa do modelo de regressão não linear log-logístico proposto por Seefeldt *et al* 1995, sendo a expressão matemática que relaciona a resposta *y* (porcentajem de control) a dose x é a seguinte:

$$y = C + (D - C)/1 + \exp [b (\log(x) - \log (GR_{50}))]$$

Em que: C: limite superior da curva, D: limite inferior da curva, GR_{50} dose necessária para reduzir 50% do crecimento e b: declividade da curva. El limite superior de la curva se fija en 100% de control y el limite inferior en 0% de control.

RESULTADOS E DISCUSSÃO

Exceto para as doses de 7 680 gr p.a/ha (16 l do produto comercial ao 48%), verificou-se em todas as demais doses o controle meio aos 21 DAA e ele foi maior nas plantas do Manantial (Tabela 1). O experimento de dose-resposta mostrou diferenças entre os biótipos testados ao Glyphosate (Figura 1). As curvas dose–resposta mostraram um declinio semelhante para ambas populações, sendo que o biótipo do Manantial, população suscetível, teve uma maior redução da biomasa fresca em comparação á população de Salta com a mesma dose. A análise da variância mostrou que houve diferenças significativas das doses e populações, verificou-se então que ambos biótipos apresentaram uma resposta diferencial ás diferentes doses do herbicida. Com os dados obtidos pela análise da regressão não linear se definem os parâmetros da equação log-logístico. Tais parâmetros da equação encontram-se na tabela 2.

Ng et al 2004 trabalhou com quatro biotipos de *E. indica* resistentes ao Glyohosate em Malasia, ele encontrou declinios semelhantes nas curvas resposta-dose e coeficientes de resistência com valores de 2,1; 2,8; 2,9 e 3,3 para os quatro biótipos. Os valores apresentam um nivel similar ao valor obtido no presente trabalho (2,82 vezes). Pérez e Kogan, 2003 obtiveram valores em *L. multiflorum* que indicaram que

as populações desta espécie coleitada em San Bernardo e Olivar, Chile são resistentes ao Glyohosate e com uma relação de resistência duas a quatro vezes maior em relação ao biótipo suscetível.

Tabela 1. Controle médio em porcentagem dos dois biótipos de *Sorghum halepense* as diferentes doses testadas 21 DAA.

Biótipos	Doses						
	0	240	480	960	1 920	3 840	7 680
El Manantial	0	66	72	99	100	100	100
Salta	0	15	52	87	96	99	100

Tabela 2. Parâmetros C, D, b, GR_{50} do modelo matemático obtidos através da aplicação da equação inversa do modelo log-logístico e relação de resistência (RR) para os dois biotipos de *S. halepense* a os 21 dias após aplicação.

Biótipos	Parâmetros				
	C	D	b	GR_{50}	RR
El Manantial	0	100	1.3946	0.17	
Salta	0	100	2.5781	0.48	2.82

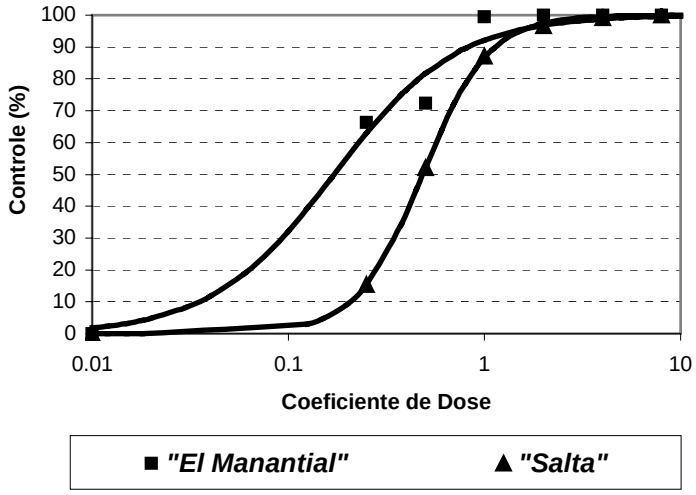

Figura 1. Valores percentuais de controle aos 21 DAA para as dois populações, quando submetidas à aplicação de Glyphosate

CONCLUSÕES

A introdução do plantio direto e logo os cultivares transgênicos resistentes ao Glyphosate trouze uma mudança no manejo das plantas daninhas além de uma mudança nas comunidades das mesmas. O uso repetitivo de um único herbicida com o mesmo mecanismo de ação, resultou na surgimento de espécies resistentes. Ao serem estas plantas perenes o problema torna-se mais grave ainda. Os valores da relação de resistência encontrados neste trabalho para uma população no Norte Argentino de *S. halepense* constitue o primeiro caso para esta espécie, que é considera uma das principais plantas daninhas ao nivel mundial. Os produtores deverão compriender que não pode continuar exercendo tal pressão de seleção ja que desta manera permite o surgimento das plantas resistentes e de seguir aumentando isto ocasionaria graves perdas. É necesario por conseguinte por ênfase em modificar o manejo das plantas daninhas para evitar a porpagação destes biotipos e a aparição de novos casos de resistência .

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Appendix B

Bibliography of Glyphosate and *S. halepense*

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Bibliography of Glyphosate and *S. halepense*

Record 1 of 48
Author(s): Arai, K; Hirase, K; Moriyasu, K; Molin, WT
Title: Herbicidal efficacy of 4-ethyl-3-(3-fluorophenyl)-1-(3-trifluoromethylphenyl)pyrrolidin-2-one (MT-141) in the control of graminaceous and broad-leaved weeds in cotton
Source: JOURNAL OF PESTICIDE SCIENCE, 31 (1): 29-34 2006
Abstract: The herbicidal activity and properties of a diphenylpyrrolidinone, MT-141 [4-ethyl-3-(3-fluorophenyl)-1-(3-trifluoromethylphenyl)pyrrolidin-2-one], were examined. MT-141 controlled barnyardgrass (Echinochloa crusgalli),johnsongrass (Sorghum halepense), green foxtail (Setaria viridis), large crabgrass (Digitaria sanguinalis), fall panicum (Panicum dichotomiflorum), goosegrass (Eleusine indica), and broadleaf signalgrass (Brachiaria platyphylla) at 300g a.i./ha when applied pre-emergence (PRE), and provided greater than 90% control of these weed species at 500g a.i./ha when applied post-emergence (POST). MT-141 was less effective against broad-leaved plants such as velvetleaf (Abutilon theophrasti) and ivyleaf morningglory (Ipomoea hederacea), but two other broad-leaved plants, hemp sesbania (Sesbania exaltata) and prickly sida (Sida spinosa), were slightly susceptible to MT-141. MT-141 applied PRE at 500g a.i./ha did not injure cotton. The most significant herbicidal symptom for this compound was bleaching. Residual activity of MT-141 applied PRE to barnyardgrass and johnsongrass lasted at least 5 weeks. Planting depth or soil type did not affect the herbicidal activity of MT-141 at 300g a.i./ha. MT-141 applied PRE increased the herbicidal activity of glyphosate against hemp sesbania and morningglory without injuring glyphosate-resistant cotton. Also several surfactants increased the herbicidal efficacy of this compound on POST application. MT-141 seems to be an effective herbicidal compound for controlling graminaceous weeds when applied PRE in cotton production. (c) Pesticide Science Society of Japan.
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Record 2 of 48
Author(s): Molin, WT; Hirase, K
Title: Effects of surfactants and simulated rainfall on the efficacy of the Engame formulation of glyphosate in johnsongrass, prickly sida and yellow nutsedge
Source: WEED BIOLOGY AND MANAGEMENT, 5 (3): 123-127 2005
Abstract: The effects of surfactants and simulated rain were investigated on the efficacy of Engame and Roundup Ultramax formulations of glyphosate on johnsongrass (Sorghum halepense L.), prickly sida (Sida spinosa L.) and yellow nutsedge (Cyperus esculentus L.), Flame surfactant provided the greatest enhancement of Engame efficacy and the effect was species-dependent. Flame enhanced the activity of Engame on johnsongrass and yellow nutsedge but not on prickly sida. Engame and Engame plus Flame were more active than Roundup Ultramax on a glyphosate acid-equivalent basis on johnsongrass without rain, and on yellow nutsedge with or without rain. The Engame and Roundup Ultramax activities on johnsongrass were similar with rain, and rain occurring between five and 30 min after treatment diminished their activities to <38% of the control. With the addition of Flame surfactant, Engame activity on johnsongrass increased, such that 50% and 80% of the control were realized, even with rain occurring between five and 15 min after treatment, respectively. Engame and Roundup Ultramax provided better control of prickly sida than of johnsongrass following a rain

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event. The addition of Flame surfactant to Engame did not enhance the activity on prickly sida. Yellow nutsedge control with Engame and Engame plus Flame was greater than with Roundup Ultramax and rain had little effect on control regardless of the length of the rain-free period. These results demonstrated that the activities of Engame, Engame plus Flame and Roundup Ultramax were species-dependent and surfactant-dependent.

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Record 3 of 48

Author(s): Scroggs, DM; Miller, DK; Griffin, JL; Geaghan, JP; Vidrine, PR; Stewart, AM
Title: Glyphosate efficacy on selected weed species is unaffected by chemical coapplication
Source: WEED TECHNOLOGY, 19 (4): 1012-1016 OCT-DEC 2005
Abstract: A study was conducted in 2004 to determine the effect of coapplication of the insecticides acephate, acetamiprid, bifenthrin, cyfluthrin, cypermethrin, dicrotophos, dimethoate, emanectin benzoate, imidacloprid, indoxacarb, lambda-cyhalothrin, methoxyfenozide, spinosad, thiamethoxam, and zeta-cypermethrin; the plant growth-regulator mepiquat pentaborate; a foliar sodium calcium borate micronutrient solution; and a foliar nitrogen fertilizer solution with glyphosate on the efficacy of weeds that commonly infest cotton. Barnyardgrass, hemp sesbania, johnsongrass, pitted morningglory, and sicklepod were grown in outdoor containers and treated with glyphosate at 1,120 g ai/ha alone or in coapplication at the three-to four- or seven-to eight-leaf growth stage. Glyphosate efficacy, based on visual control ratings at 7, 14, and 28 d after treatment (DAT) and fresh weight reduction of weed biomass at 28 DAT, was unaffected by chemical coapplication or application timing. Averaged across application timing and visual rating interval, glyphosate alone controlled barnyardgrass 97%, hemp sesbania 68%, johnsongrass 98%, pitted morningglory 68%, and sicklepod 89%. These results indicate that glyphosate coapplications evaluated offer producers the ability to combine pest and crop management strategies and reduce application costs without sacrificing control of weeds evaluated.

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Record 4 of 48

Author(s): Flint, SG; Shaw, DR; Kelley, FS; Holloway, JC
Title: Effect of herbicide systems on weed shifts in soybean and cotton
Source: WEED TECHNOLOGY, 19 (2): 266-273 APR-JUN 2005
Abstract: Field studies were conducted from 1998 through 2000 to compare weed population shifts in soybean and cotton using a total glyphosate system, preemergence (PRE) herbicides followed by glyphosate, and a conventional herbicide program. In the first year of the soybean study, populations of hemp sesbania were highest for treatments of PRE herbicides followed by either glyphosate or the conventional herbicide program because of better control from the total glyphosate system. Barnyardgrass populations in the first year of the study for the nontreated plots were 0 plants/m(2) but increased in the third year to 61 plants/m(2). Flumetsulam plus metolachlor followed by glyphosate at the lower rates and the nontreated check were the only

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treatments in which there was an increase in barnyardgrass over the 3-yr study. Broadleaf signalgrass populations increased in the third year with 0.1 kg ai/ha flumetsulam plus 2.1 kg ai/ha metolachlor followed by 0.84 kg ae/ha glyphosate, primarily because of reduced competition from lower populations of other weeds such as hemp sesbania. Pitted morningglory populations for all treatments decreased in the third year because of good control of this species and the high level of interference from other weed species in the first 2 yr. Johnsongrass populations decreased in the third year with 0.4 kg ai/ha flumetsulam plus 1.1 kg ai/ha metolachlor followed by 0.84 kg/ha glyphosate. Johnsongrass populations decreased with timely glyphosate sequential applications, with 5 plants/m(2) in 1998 and 0 plants/m(2) in 2000. Yields increased from the first year to the second year, corresponding to reduced weed pressure, and yields varied from 710 to 1,420 kg/ha. Because of weed pressure, soybean yields were not different in any of the treatments, including the nontreated, although treatments changed the species present. In the cotton study, weed populations over the 3 yr decreased, with the most significant reductions from the treatments of fluometuron plus prometryn plus metolachlor followed by either pyrithiobac or glyphosate. Weeds that showed the most significant decline were barnyardgrass and hemp sesbania, whereas johnsongrass increased, with 27 plants/m(2) in treatments of 0.6 kg ai/ha fluometuron plus 0.3 kg ai/ha prometryn plus 0.7 kg ai/ha metolachlor followed by 0.84 kg/ha glyphosate. Lint cotton yields varied from 0 to 128 kg/ha. Because of the weed pressure, cotton yields were not different in any of the treatments, although treatments changed the species present. This research has shown that weed species can decrease over time with the continued use of any of these herbicide programs.
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Record 5 of 48
Author(s): Koger, CH; Price, AJ; Reddy, KN
Title: Weed control and cotton response to combinations of glyphosate and trifloxysulfuron
Source: WEED TECHNOLOGY, 19 (1): 113-121 JAN-MAR 2005
Abstract: Greenhouse and field studies were conducted to evaluate potential interactions between glyphosate and trifloxysulfuron on barnyardgrass, browntop millet, hemp sesbania, seedling johnsongrass, pitted morningglory, prickly sida, sicklepod, and velvetleaf control as well as cotton injury and yield. In the greenhouse, glyphosate at 840 g ae/ha controlled all weed species 62 to 99%, which was better than trifloxysulfuron at 2.5 or 5 g ai/ha. Control of four-leaf pitted morningglory and hemp sesbania was 80 to 88% when glyphosate and trifloxysulfuron were mixed compared with 62 to 66% control with glyphosate alone. Mixing trifloxysulfuron with glyphosate did not affect control of other species compared with glyphosate alone. In the field, glyphosate controlled barnyardgrass, prickly sida, sicklepod, seedling johnsongrass, and velvetleaf 68 to 100%. Trifloxysulfuron controlled hemp sesbania, seedling johnsongrass, and sicklepod 65 to 88%. All other species were controlled 36 to 72% with glyphosate and 10 to 60% with trifloxysulfuron. Combinations of glyphosate (840 g/ha) and trifloxysulfuron (5 g/ha) were applied postemergence over-the-top and postemergence directed to three-, six-, and nine-leaf glyphosate-resistant cotton in the field. Cotton injury at 2 wk after treatment (WAT) was less than 13% for all herbicide treatments and less than 5% by 3 WAT. Herbicides did not affect the percent of open bolls or nodes per plant. Seed cotton yield ranged from 1,430 to 1,660 kg/ha, and only the sequential over-the-top applications of trifloxysulfuron reduced cotton yield compared with the weed-free, nontreated cotton.
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Record 6 of 48
Author(s): Koger, CH; Reddy, KN
Title: Role of absorption and translocation in the mechanism of glyphosate resistance in horseweed (Conyza canadensis)
Source: WEED SCIENCE, 53 (1): 84-89 JAN-FEB 2005
Abstract: Greenhouse and laboratory experiments were conducted to investigate mechanisms of glyphosate resistance in horseweed populations from Mississippi, Arkansas, Delaware, and Tennessee. A nondestructive leaf-dip bioassay was developed to confirm resistance and susceptibility in individual test plants. A single leaf was excised from each plant, and the petiole and bottom one-fourth of leaf was dipped in a 600 mg ae L-1 glyphosate solution for 2 d followed by visually estimating the injury on a scale of 0 to 10. Plants were classified as resistant (R) if the score was 2 to 3 and susceptible (S) if the score was 5 to 6. C-14-glyphosate solution was applied on the adaxial surface of a fully expanded leaf of the second whorl of four-whorl rosette plants. Plants were harvested 48 h after treatment and radioactivity was determined in treated leaf, other leaves, crown, and roots. Absorption of C-14-glyphosate was similar (47 to 54%) between R and S plants from within and among the four states, suggesting absorption is not involved in glyphosate resistance. The amount of radioactivity translocated from the treated leaf was reduced in R plants compared with S plants. The reduction in translocation of 14C-glyphosate ranged from 28% in Mississippi-R biotype to 48% in Delaware-R biotype compared with their respective S biocypes. Epicuticular wax mass ranged from 6 to 80 mug cm(-2) among horseweed biotypes, with no differences between R and S biotypes within each state. Treating two leaves with glyphosate solution at the field use rate (0.84 kg ae ha(-1)) killed S plants but not R plants (38 to 58% control) regardless of state origin. These results suggest that a simple bioassay can be used to screen biotypes for suspected resistance and that reduced translocation of glyphosate plays a major role in glyphosate resistance in R biotypes of horseweed.
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Record 7 of 48
Author(s): Ivany, JA
Title: Comparison of glyphosate formulations with and without sequential herbicides for no-till soybean in narrow rows
Source: PHYTOPROTECTION, 85 (2): 95-100 AUG 2004
Abstract: Effective control of weeds during early stages of soybean (Glycine max) growth is critical to minimize crop yield reduction. Experiments were conducted to compare weed control and crop yield with two glyphosate formulations (trimethylsulfonium and isopropylamine salts) applied in the fall or spring, either alone or in combination with sequential pre-or post-ememergence herbicides in soybean cv. 'Maple Glen' no-till planted in narrow rows into grain stubble. In six experiments where glyphosate was applied (three in the fall and three in the spring), there was no difference in weed control or in soybean yield between the two glyphosate formulations. Crop yield was improved over glyphosate used alone by addition of metribuzin in

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all fall experiments and in two of three spring experiments and by addition of linuron in two of three experiments in both fall and spring. An herbicide that controlled annual broadleaf weeds was needed after fall-applied glyphosate in all experiments to achieve maximum soybean yield. Addition of an effective sequential herbicide after spring applied glyphosate improved yields but not to the same extent as noted with the fall applied glyphosate. A pre-emergence residual herbicide, such as metribuzin or linuron, that controls a broad spectrum of weeds is recommended after fall or spring applied glyphosate to maximize soybean yield.
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Record 8 of 48
Author(s): Tingle, CH; Chandler, JM
Title: The effect of herbicides and crop rotation on weed control in glyphosate-resistant crops
Source: WEED TECHNOLOGY, 18 (4): 940-946 OCT-DEC 2004
Abstract: Field studies were conducted from 1998 through 2000 to determine the influence of crop rotation and level of herbicide system for johnsongrass, entireleaf morningglory, and smellmelon control in glyphosate-resistant cotton and corn. Three different crop rotation schedules were used including cotton-cotton-cotton, cotton-corn-cotton, and corn-cotton-corn. Herbicide systems involving various degrees of input levels (low, medium, and high) were compared with a conventional standard program. In 1998, weed control ranged from 80 to 95% for all herbicide systems when the rotation was corn-cotton-corn. In 1999 and 2000, the low-input herbicide system controlled entireleaf morninglory 76 to 78% late in the season. Decreased smellmelon control (78%) was also observed with the conventional standard during this same period. In the cotton-corn-cotton rotation, late-season entireleaf morningglory control decreased each year in the low-input system, regardless of crop. In 2000, late-season evaluations indicated lower weed control of all three species with the conventional standard program compared with the other input systems. Yield data from 2000 suggested that corn and seed cotton yields were influenced by crop rotation.
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Record 9 of 48
Author(s): Barnes, JW; Oliver, LR
Title: Cloransulam antagonizes annual grass control with aryloxyphenoxypropionate graminicides but not cyclohexanediones
Source: WEED TECHNOLOGY, 18 (3): 763-772 JUL-SEP 2004
Abstract: Field, greenhouse, and laboratory studies were conducted to examine the potential for antagonism of postemergence graminicides when tank-mixed with cloransulam and to determine the role of herbicide absorption and translocation in observed antagonistic responses. Cloransulam antagonized annual grass control with aryloxyphenoxypropionate herbicides fluazifop-P, quizalofop, and the prepackaged formulation of fluazifop-P plus fenoxaprop. Cloransulam did not affect annual grass control with the cyclohexandiones clethodim and sethoxydim. In the greenhouse, increasing the rate of the graminicides was a more effective strategy for overcoming antagonism for quizalofop than for fluazifop-P or

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fluazifop-P plus fenoxaprop, and success was species dependent. Annual grass control with clethodim, sethoxydim, and glyphosate was not adversely affected by tank mixtures with cloransulam. Control of large rhizome johnsongrass was initially reduced when cloransulam was mixed with sethoxydim, fluazifop-P plus fenoxaprop, or quizalofop. By 6 wk after treatment, control of rhizome johnsongrass was antagonized only when cloransulam was mixed with sethoxydim. Rainfall within 1.5 h of application reduced johnsongrass control with glyphosate and sethoxydim but did not affect activity of the other herbicides. Absorption of C-14-fluazifop-P and C-14- quizalofop into broadleaf signalgrass was not affected by cloransulam 6 or 24 h after treatment. Translocation of C-14-fluazifop-P to broadleaf signalgrass shoot tissue above and below the treated leaf was decreased when fluazifop-P was combined with cloransulam. Translocation of quizalofop was not affected by cloransulam.
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Record 10 of 48
Author(s): Corbett, JL; Askew, SD; Thomas, WE; Wilcut, JW
Title: Weed efficacy evaluations for bromoxynil, glufosinate, glyphosate, pyrithiobac, and sulfosate
Source: WEED TECHNOLOGY, 18 (2): 443-453 APR-JUN 2004
Abstract: Thirteen field trials were conducted in 1999 and 2000 to evaluate postemergence (POST) weed control with single applications of bromoxynil at 420 or 560 g ai/ha, glufosinate at 291 or 409 g ai/ha. glyphosate at 1,120 g ai/ha, pyrithiobac at 36 or 72 g ai/ha, or sulfosate at 1,120 g ai/ha. Additional treatments evaluated included two applications with glufosinate at both rates in all possible combinations, two applications of glyphosate, and two applications of sulfosate. Weeds were 2 to 5 cm or 8 to 10 cm tall for annual grass and broadleaf weeds whereas yellow nutsedge and glyphosate-resistant corn were 8 to 10 cm tall. All herbicide treatments controlled 2- to 5-cm common cocklebur, Florida beggarweed, jimsonweed, ladysthumb smartweed, Pennsylvania smartweed, pitted morningglory, prickly sida, redroot pigweed, smooth pigweed, and velvetleaf at least 90%. All herbicide treatments except pyrithiobac at either rate controlled 2- to 5-cm common lambsquarters, common ragweed, and tall morningglory at least 90%; pyrithiobac at the lower rate was the only treatment that failed to control entireleaf and ivyleaf morningglory at least 90%. Bromoxynil and pyrithiobac at either rate controlled 2- to 5-cm sicklepod 33 to 68% whereas glufosinate, glyphosate, and sulfostate controlled greater than or equal to99%. Glyphosate and sulfosate applied once or twice controlled hemp sesbania less than 70% and volunteer peanut less than 80%. Bromoxynil and pyrithiobac were the least effective treatments for control of annual grass species and bromoxynil controlled Palmer amaranth less than 80%. Glufosinate controlled broadleaf signalgrass, fall panicum, giant foxtail, green foxtail, large crabgrass, yellow foxtail, seedling johnsongrass, Texas panicum, and glyphosate-resistant corn at least 90% but controlled goosegrass less than 60%. Glyphosate and sulfosate controlled all grass species except glyphosate-resistant corn at least 90%. In greenhouse research, goosegrass could be controlled with glufosinate POST plus a late POST-directed treatment of prometryn plus monosodium salt of methylarsonic acid.
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Record 11 of 48
Author(s): Heatherly, LG; Spurlock, SR; Reddy, KN
Title: Weed management in nonirrigated glyphosate-resistant and non-resistant soybean following deep and shallow fall tillage
Source: AGRONOMY JOURNAL, 96 (3): 742-749 MAY-JUN 2004
Abstract: Management inputs that maximize economic return from the early plantings of soybean [Glycine mar (L.) Merr.] in the midsouthern USA have not been evaluated fully. The objective was to compare perennial weed control in and yields and economic returns from plantings of maturity group (MG) IV and V soybean cultivars grown in the field under different weed management systems (WMS) following shallow (ST) and deep (DT) fall tillage. Adjacent experiments were conducted on Tunica clay (clayey over loamy, smectitic, nonacid, thermic Vertic Haplaquept) near Stoneville, MS (lat. 33degrees26'N). Weed management systems were (i) glyphosate [N-(phosphonomethyl)glycine]-resistant (GR) cultivars with preemergent (PRE) nonglyphosate herbicides followed by postemergent (POST) glyphosate; (ii) GR cultivars with POST glyphosate; (iii) non-GR cultivars with PRE plus POST nonglyphosate herbicides; and (iv) non-GR cultivars with POST nonglyphosate herbicides. Control of perennial redvine [Brunnichia ovata (Walt.) Shinners] declined in the ST environment when non-GR cultivars were used, but this did not result in a yield decline. Control of perennial johnsongrass [Sorghum halepense (L.) Pers.] at the end of the study period averaged <40% when non-GR cultivars were used and >93% when GR cultivars were used regardless of tillage treatment, and this was associated with lower yield. Use of PRE + POST vs. POST-only weed management sometimes resulted in lower profits regardless of fall tillage treatment. The fall tillage treatment x WMS interaction was not significant for yield or net return, which indicates that use of DT for perennial weed management is not economical.
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Record 12 of 48
Author(s): Baig, MN; Darwent, AL; Harker, KN; O'Donovan, JT
Title: Preharvest applications of glyphosate affect emergence and seedling growth of field pea (Pisum sativum)
Source: WEED TECHNOLOGY, 17 (4): 655-665 OCT-DEC 2003
Abstract: Field experiments were conducted in 1994 and 1995 at Vegreville, Legal, and Lacombe, AB, to determine the effects of a preharvest application of glyphosate on seedling emergence and growth of field pea. Glyphosate was applied at 0.9 kg ai/ha at each of the three crop development stages, as determined by seed moisture content (SMC), to determinate ('Ascona' and 'Radley') and indeterminate ('Miko' and 'Trapper') cultivars. Applying glyphosate when the SMC was less than 30% had little to no effect on seedling emergence but reduced seedling shoot fresh weight in two of six experiments. Applying glyphosate at SMC above 40% reduced seedling emergence and shoot fresh weight in two and three of the six experiments, respectively. Reductions in seedling emergence and shoot fresh weight were greater from seeds collected from the top than from seeds collected from the bottom one-third of sprayed plants. Differences in response between determinate and indeterminate cultivars occurred, but there was no consistent trend. Given the variable maturity in most fields and on individual pea plants, applications of preharvest glyphosate to peas destined for seed production may decrease seed germination and biomass accumulation.

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Record 13 of 48
Author(s): Johnson, WG; Li, JM; Wait, JD
Title: Johnsongrass control, total nonstructural carbohydrates in rhizomes, and regrowth after application of herbicides used in herbicide-resistant corn (Zea mays)
Source: WEED TECHNOLOGY, 17 (1): 36-41 JAN-MAR 2003
Abstract: Greenhouse and field experiments were conducted to evaluate the efficacy of nicosulfuron, primisulfuron, glyphosate, glufosinate, imazethapyr plus imazapyr, and quizalofop, on johnsongrass biomass reduction, rhizome total nonstructural carbohydrate (TNC) content, and subsequent regrowth from rhizomes. In the greenhouse, johnsongrass plants originating from rhizome segments were controlled 88 to 97% with quizalofop, glyphosate, imazethapyr plus imazapyr, nicosulfuron, and primisulfuron and 56% with glufosinate 3 wk after treatment (WAT). Johnsongrass treated with quizalofop, glyphosate, and nicosulfuron did not regrow 6 WAT, whereas plants treated with primisulfuron, imazethapyr plus imazapyr, and glufosinate regrew from the rhizome of the treated plant. Rhizome TNC levels 3 WAT were not reduced by glufosinate or nicosulfuron, but they were reduced 64% by quizalofop, 32% by primisulfuron, 61% by glyphosate, and 29% by imazethapyr plus imazapyr. When rhizome TNC was reduced by 60% or more compared with nontreated plants, johnsongrass did not regrow from the treated rhizomes. In field experiments, nicosulfuron and glyphosate controlled johnsongrass 94 and 99%, respectively, whereas imazethapyr plus imazapyr (79%) and glufosinate (85%) provided less control 6 WAT.
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Record 14 of 48
Author(s): Armel, GR; Wilson, HP; Richardson, RJ; Hines, TE
Title: Mesotrione combinations in No-till corn (Zea mays)
Source: WEED TECHNOLOGY, 17 (1): 111-116 JAN-MAR 2003
Abstract: Field studies were conducted in 1999, 2000, and 2001 to determine the effectiveness of mesotrione applied preemergence (PRE) or postemergence (POST) in no-till corn. Also, a proposed prepackage mix of mesotrione plus acetochlor (1: 11 ratio of mesotrione-acetochlor) in combinations with the trimethylsulfonium salt of glyphosate (glyphosate-TMS), paraquat, and 2,4-D was investigated. Mesotrione PRE at 235 g ai/ha or greater controlled common lambsquarters, smooth pigweed, and common ragweed at least 80%. POST mesotrione at 35 g/ha and higher controlled common lambsquarters 91% or greater. Mesotrione applied POST at 140 g/ha controlled smooth pigweed greater than 97%. Common ragweed control from POST mesotrione was inconsistent, ranging from 56 to 97%. PRE and POST applications of mesotrione did not adequately control goosegrass, giant foxtail, fall panicum, johnsongrass, or cutleaf eveningprimrose. The mesotrione plus acetochlor prepackage mix plus glyphosate-TMS or paraquat controlled field pansy and ivyleaf morningglory similar to or better than did the prepackage mixture of the isopropylamine salt of glyphosate (glyphosate-IPA) plus atrazine plus acetochlor. But common ragweed control by mesotrione plus acetochlor plus glyphosate-TMS or paraquat was occasionally lower than control by the prepackage mixture of glyphosate-

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IPA plus atrazine plus acetochlor. Corn injury was generally less than 10% with PRE and POST mesotrione applications.
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Record 15 of 48
Author(s): Shaw, DR; Arnold, JC
Title: Weed control from herbicide combinations with glyphosate
Source: WEED TECHNOLOGY, 16 (1): 1-6 JAN-MAR 2002
Abstract: Greenhouse studies were initiated to evaluate glyphosate alone and tank-mixed with acifluorfen, CGA 277476, chlorimuron, cloransulam-methyl, fomesafen, imazaquin, or pyrithiobac on seedling johnsongrass, broadleaf signalgrass, pitted morningglory, and hemp sesbania. Johnsongrass and broadleaf signalgrass control by glyphosate was not affected by the selective herbicides applied in mixtures. Pitted morningglory control by glyphosate ranged from 0% with 280 g ai/ha to 67% with 840 g/ha. There was an additive effect when selective herbicides were added to 280 g/ha glyphosate 2 wk after treatment (WAT). When acifluorfen was added to 560 g/ha glyphosate, pitted morningglory control 2 WAT increased to 100% compared with 55% with glyphosate alone. Similarly, the addition of fomesafen or acifluorfen to 840 g/ha glyphosate controlled pitted morningglory 2 WAT by 90 and 98%, respectively, compared with 67% with glyphosate alone. Only tank mixtures of acifluorfen, CGA 277476, or fomesafen, and 840 g/ha glyphosate reduced fresh weight compared with glyphosate alone 4 WAT. Acifluorfen, CGA 277476, and fomesafen controlled pitted morningglory by 85 to 100% when added to 1,120 g/ha glyphosate. Both acifluorfen and fomesafen effectively controlled hemp sesbania without the addition of glyphosate 2 WAT. Chlorimuron and pyrithiobac added to 1, 120 g/ha glyphosate increased hemp sesbania control to 88 and 99%, respectively, compared with 45% with glyphosate alone 2 WAT. CGA 277476, cloransulam-methyl, imazaquin, and pyrithiobac were antagonistic to hemp sesbania fresh weight reduction when compared with the expected response, but fresh weights were still reduced more than with the same rate of glyphosate alone.
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Record 16 of 48
Author(s): Damalas, CA; Eleftherohorinos, IG
Title: Dicamba and atrazine antagonism on sulfonylurea herbicides used for johnsongrass (Sorghum halepense) control in corn (Zea mays)
Source: WEED TECHNOLOGY, 15 (1): 62-67 JAN-MAR 2001
Abstract: Field experiments were carried out during 1997 and 1998 in northern Greece to investigate the effects of tank mixing rimsulfuron and primisulfuron with atrazine or dicamba against johnsongrass in corn. Sequential applications, where the johnsongrass herbicides were applied 5 d after the broadleaf herbicides, were also evaluated. Rimsulfuron applied alone at 10 g ai/ha gave very good control (91%) of johnsongrass, which was significantly higher than that provided by 30 g ai/ha of primisulfuron (43%). Rimsulfuron applied in tank mixture with atrazine (1.0 kg ai/ha) or dicamba (0.28 kg ai/ha) gave 12 and 17% lower johnsongrass control, respectively, than of rimsulfuron applied alone, whereas the corresponding reduction for primisulfuron was 18 and 43%. Efficacy of rimsulfuron applied 5 d after the application of

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atrazine or dicamba was similar to that applied alone; however, this was not the case for primisulfuron, where reduced antagonism was observed compared to that produced by its tank mixture treatments. Again, primisulfuron was affected more by dicamba than by atrazine. Corn yield with rimsulfuron and primisulfuron applied alone was more than double that of the untreated control and similar to that of the weed-free control. Also, rimsulfuron applied with atrazine or dicamba (in tank mixture or sequentially) produced similar corn yield to that applied alone. However, primisulfuron applied in tank mixture or sequentially with dicamba gave 22 and 14% lower yield, respectively, than when applied alone, and slightly lower when applied with atrazine.
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Record 17 of 48
Author(s): Norris, JL; Shaw, DR; Snipes, CE
Title: Weed control from herbicide combinations with three formulations of glyphosate
Source: WEED TECHNOLOGY, 15 (3): 552-558 JUL-SEP 2001
Abstract: Greenhouse studies were conducted to evaluate weed control from various formulations of glyphosate alone and in combination with postemergence herbicides. Tank mixtures did not increase barnyardgrass control 2 wk after treatment (WAT) when compared with glyphosate alone; however, tank mixtures did reduce barnyardgrass fresh weight 4 WAT when compared with glyphosate alone in several instances. Antagonism was observed when chlorimuron was combined with all formulations of glyphosate 4 WAT, but control was not reduced when compared with glyphosate alone. Selective herbicides added to glyphosate had an additive or antagonistic effect on prickly sida fresh-weight reductions. Antagonism of pitted morning glory fresh-weight reductions occurred when glyphosate was combined with all herbicides except acifluorfen, which had an additive effect. Fomesafen or lactofen effectively controlled hemp sesbania 2 WAT without the addition of glyphosate. Acifluorfen and chlorimuron combined with glyphosate Cheminova, Monsanto, or Zeneca reduced hemp sesbania fresh weight nearly twofold more than glyphosate alone.
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Record 18 of 48
Author(s): Chandramohan, S; Charudattan, R; Sonoda, RM; Singh, M
Title: Field evaluation of a fungal pathogen mixture for the control of seven weedy grasses
Source: WEED SCIENCE, 50 (2): 204-213 MAR-APR 2002
Abstract: In citrus, weedy grasses compete for moisture, nutrients, and light and can inhibit the growth of young trees and delay fruit production. These weeds are difficult to control, either because of their tolerance to available herbicides or due to growth habits that enable them to resist other control practices. Control of seven such weedy grasses (southern sandbur, large crabgrass, crowfootgrass, guincagrass, Texas panicum johnsongrass, and yellow foxtail) with a mixture of three fungal pathogens, termed the multiple-pathogen strategy, was field tested in 1996 and 1998. Three fungi indigenous to Florida, Drechslera gigantea, Exserohilum longirostratum, and E. rostratum, isolated from large crabgrass, crowfootgrass, and johnsongrass respectively, were used. Two separate field studies were conducted: one study with seven grasses trans.. planted and grown within each plot (grass mixture field trial) and

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another study on, a population of guineagrass alone present in a naturally infested field (guineagrass field trial). The objectives of this study were to (1) evaluate the field performance of D. gigantea, E. longirostratum, and E. rostratum individually and in a mixture to control the seven transplanted weedy grasses (grass mixture) and a population of guineagrass in naturally infested field, respectively, and (2) compare the effectiveness of three carriers (water, Metamucil(R), and an invert emulsion) on the bioherbicidal efficacy under field conditions. The fungi were applied as foliar sprays, each pathogen alone or in a mixture of the three fungi (1:1:1, v/v/v, for a total of 5 X 105 spores ml(-1)) in water, 0.5% aqueous Metamucil(R), or an emulsion containing Sunspray(R) 6E. During the 14-wk experimental period, one or two additional sprays of all treatments were applied. Disease severity was recorded weekly for 4 to 6 wk after the initial spray (WAI). Maximum disease severities were obtained in emulsion-inoculum treatments, and were higher than those in the water-inoculum and the Metamucil-inoculum treatments. The pathogen mixture was equally effective as the individual pathogens in controlling the weeds tested. In the 1996 trial, 6 WAI, disease severity on grasses inoculated with D. gigantea spore suspensions in emulsion ranged from 78 to 100%, with E. longirostratum 90 to 100%, E. rostratum 79 to 100%, and the mixture 74 to 100%. In the 1998 trial, 4 WAI, disease severity on grasses inoculated with D. gigantea spore suspensions in emulsion ranged from 45 to 98%, with E. longirostratum 45 to 98%, E. rostratum 34 to 98%, and the mixture 32 to 98.5%. Thus, it was possible to manage all seven weedy grasses under field conditions using an emulsion-based inoculum preparation with the individual pathogens as well as the mixture of pathogens. The same three fungal pathogens were field tested for their ability to manage populations of guineagrass in a naturally infested field. The experimental design and treatments were identical to the field testing with the seven transplanted grasses. Two applications of an emulsion-based inoculum preparation of each pathogen or the mixture of pathogens effectively controlled guineagrass for up to 10 wk, with no regrowth.

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Record 19 of 48

Author(s): Culpepper, AS; York, AC; Batts, RB; Jennings, KM

Title: Weed management in glufosinate- and glyphosate-resistant soybean (Glycine max)

Source: WEED TECHNOLOGY, 14 (1): 77-88 JAN-MAR 2000

Abstract: An experiment was conducted at six locations in North Carolina to compare weed-management treatments using glufosinate postemergence (POST) in glufosinate-resistant soybean, glyphosate POST in glyphosate-resistant soybean, and imazaquin plus SAN 582 preemergence (PRE) followed by chlorimuron POST in nontransgenic soybean. Prickly sida and sicklepod were controlled similarly and 84 to 100% by glufosinate and glyphosate. Glyphosate controlled broadleaf signalgrass, fall panicum, goosegrass, rhizomatous johnsongrass, common lambsquarters, and smooth pigweed at least 90%. Control of these weeds by glyphosate often was greater than control by glufosinate. Mixing fomesafen with glufosinate increased control of these species except johnsongrass. Glufosinate often was more effective than glyphosate on entireleaf and tall morningglories. Fomesafen mixed with glyphosate increased morningglory control but reduced smooth pigweed control. Glufosinate or glyphosate applied sequentially or early postemergence (EPOST) following imazaquin plus SAN 582 PRE often were more effective than glufosinate or glyphosate applied only EPOST Only rhizomatous johnsongrass was controlled more effectively by glufosinate or glyphosate treatments than by imazaquin plus SAN 582 PRE followed by chlorimuron POST. Yields and

net returns with soil-applied herbicides only were often lower than total POST herbicide treatments. Sequential POST herbicide applications or soil-applied herbicides followed by POST herbicides were usually more effective economically than single POST herbicide applications.
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Record 20 of 48
Author(s): McKinley, TL; Roberts, RK; Hayes, RM; English, BC
Title: Economic comparison of herbicides for johnsongrass (Sorghum halepense) control in glyphosate-tolerant soybean (Glycine max)
Source: WEED TECHNOLOGY, 13 (1): 30-36 JAN-MAR 1999
Abstract: Returns to land, management, and risk were compared where glyphosate and four graminicides (quizalofop-P, fluazifop-P, sethoxydim, and clethodim) were used for johnsongrass control in glyphosate-tolerant soybean. In 1994 and 1995, returns to land, management, and risk for glyphosate-tolerant soybean were highest using glyphosate and lowest using sethoxydim. Break-even analysis showed that yields needed for equivalent returns with any nontransgenic soybean cultivar treated with any of the graminicides could range from 67 kg/ha less to 202 kg/ha more than the yields achieved with glyphosate. Based on this methodology, farmers would increase their return to land, management, and risk by planting glyphosate-tolerant soybean if expected yield from a standard cultivar treated with a standard herbicide program were less than the break-even yield.
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Record 21 of 48
Author(s): Bariuan, JV; Reddy, KN; Wills, GD
Title: Glyphosate injury, rainfastness, absorption, and translocation in purple nutsedge (Cyperus rotundus)
Source: WEED TECHNOLOGY, 13 (1): 112-119 JAN-MAR 1999
Abstract: Greenhouse and laboratory experiments were conducted to study activity, rainfastness, absorption, and translocation of glyphosate with and without a nonionic organosilicone surfactant in purple nutsedge. Purple nutsedge responded differently to glyphosate depending on growth stage. Glyphosate at 2.24 k g ai/ha in 17-d-old and at 4.48 kg/ha in 10-wk-old plants controlled purple nutsedge at least 96%. Regrowth of plants and tuber resprouting were greatly reduced in these treatments. Organosilicone surfactant did not increase efficacy of glyphosate. A simulated rainfall of 2.5 cm (7.5 cm/h intensity) at 1 and 24 h after glyphosate application reduced efficacy by one-half and one-third, respectively, compared with no simulated rainfall. A rain-free period of 72 h prevented loss of glyphosate activity. Absorption of C-14-glyphosate increased from 2.8% at 1 h after application to 21.4% at 168 h after application and translocation increased from 0.43% at 1 h after application to 5.18% at 168 h after application. Organosilicone surfactant did not affect absorption and translocation of glyphosate in purple nutsedge.
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Record 22 of 48
Author(s): Monks, CD; Vencill, WK; Hatton, JP; McFarland, ML; Delaney, DP

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Title: Johnsongrass response to postemergence herbicides applied the previous year
Source: JOURNAL OF PRODUCTION AGRICULTURE, 11 (4): 507-509 OCT-DEC 1998
Abstract: Field experiments were conducted in West Virginia (1992-1994) and Georgia (1995-1996) to evaluate the effects of glyphosate, imazameth [2-[4,5-dihydro-4-methyl-4-(1-methyl-ethyl)-5-oxo-1 (H) under bar-imadazol-2-yl]-5)-methyl-3-pyridinecarboxylic acid], nicosulfuron [2- [[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]-<(N,N)under bar>-dimethyl-3-pyridine-carboxamide], and primisulfuron [methyl 2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl] sulfonyl]benzoate] applied postemergence to johnsongrass (Sorghum halepense L.) the previous year. Glyphosate at 0.75 Ib ae/acre, nicosulfuron at 0.031 Ih ai/acre, primisulfuron at 0.035 Ib ai/acre, nicosulfuron (0.016 Ib/acre) tank-mixed with primisulfuron (0.018 Ib/acre), nicosulfuron (0.031 Ib/acre) tank-mixed with primisulfuron (0.035 Ib/acre), or imazameth at 0.064 Ib ai/acre were applied postemergence to 18- to 20-in. johnsongrass regrowth 2 to 3 wk after mowing. Glyphosate provided the most consistent johnsongrass control (85% or greater) 8 wk after treatment (WAT). Tank-mixing nicosulfuron and primisulfuron did not increase control when compared to nicosulfuron applied alone. Imazameth and primisulfuron did not control johnsongrass over 81% in 1993 or 1995 at 8 WAT. Glyphosate and nicosulfuron applied alone the previous year gave greater than 70% control of johnsongrass regrowth in two out of three experiments. Stem counts and fresh weights indicated that treatments reduced regrowth in 1993 but not in 1994 at 53 WAT. Glyphosate reduced stem counts and fresh weight in two out of three experiments. Most treatments reduced johnsongrass regrowth the following year when applied to nonstressed johnsongrass; however, treatments applied to moisture stressed johnsongrass did not provide control the following year.
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Record 23 of 48
Author(s): de Ruiter, H; Meinen, E
Title: Influence of water stress and surfactant on the efficacy, absorption, and translocation of glyphosate
Source: WEED SCIENCE, 46 (3): 289-296 MAY-JUN 1998
Abstract: Black nightshade was subjected to two degrees of water stress by adding polyethylene glycol 20,000 (PEG) to the nutrient solution 5 d before treatment with glyphosate. The ED50 values for glyphosate, determined from dose-response curves, demonstrated that both degrees of water stress strongly increased the ED50, with and without the surfactant Ethomeen T/25 in the spray solution. The surfactant reduced the ED50 5-, 4.6-, and 6.9-fold at 0, 15, and 20% PEG, respectively. A C-14 study demonstrated that unstressed plants absorbed 22% of applied glyphosate. Without surfactant, water stress reduced foliar absorption 2.2-fold at 15% PEG and 4.5-fold at 20% PEG. With surfactant, the foliar absorption was 35% of the applied amount in unstressed and water-stressed plants. The surfactant and PEG reduced the translocation efficiency of glyphosate. The surfactant had the most pronounced influence and reduced the translocation efficiency 1.5-fold at 0% PEG, 2.2-fold at 15% PEG, and 1.8-fold at 20% PEG. Induction or removal of water stress 24 h after glyphosate treatment indicated that plant growth rate is positively correlated with glyphosate efficacy. It was concluded that the surfactant can overcome the adverse influence of water stress on foliar absorption of glyphosate but not the adverse, post application influence of water stress on glyphosate efficacy.
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Record 24 of 48
Author(s): Scott, R; Shaw, DR; Barrentine, WL
Title: Glyphosate tank mixtures with SAN 582 for burndown or postemergence applications in glyphosate-tolerant soybean (Glycine max)
Source: WEED TECHNOLOGY, 12 (1): 23-26 JAN-MAR 1998
Abstract: Field experiments were conducted to evaluate postemergence (POST)-applied tank mixtures of 560, 1,120, and 1,680 g ai/ha glyphosate with or without 1,120 g ai/ha SAN 582 (proposed name, dimethenamid) as burndown treatments or POST in glyphosate-tolerant soybean. SAN 582 was not antagonistic with glyphosate at the glyphosate rates evaluated. In the burndown study, glyphosate controlled horseweed 98% or more and curly dock 82% or more with or without SAN 582. However, broadleaf signalgrass emerged after the burndown treatments were applied. All tank mixtures that included SAN 582 controlled broadleaf signalgrass 84 to 96%, 6 wk after treatment. In the glyphosate-tolerant soybean study, glyphosate controlled barnyardgrass and johnsongrass present at the time of application 89% or more, regardless of rate. Tank mixtures of SAN 582 with glyphosate controlled late-season flushes of barnyardgrass through residual activity of the SAN 582. Applying SAN 582 with glyphosate improved soybean yield 500 kg/ha over glyphosate applied alone.
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Record 25 of 48
Author(s): Richard, EP
Title: Johnsongrass (Sorghum halepense) control in fallow sugarcane (Saccharum spp. hybrids) fields
Source: WEED TECHNOLOGY, 11 (3): 410-416 JUL-SEP 1997
Abstract: Soil-and foliar-applied herbicide treatments were evaluated for the control of seedling johnsongrass in the interim between row formation and the planting of fallowed sugarcane fields approximately 90 d later. Soil-surface applications of metribuzin at 1,680 g ai/ha, pendimethalin plus atrazine each at 2,240 g ai/ha, terbacil at 1,680 g ai/ha, and sulfometuron at 35 and 70 g ai/ha and an incorporated application of trifluralin at 2,240 g ai/ha followed by a surface application of atrazine at 2,240 g/ha did not consistently control seedling johnsongrass until the crop was planted. Rhizome johnsongrass populations originating from seedling johnsongrass that escaped the fallow treatments were lowest in the newly planted crop when sulfometuron at 140 to 280 g/ha was applied to the soil surface and when glyphosate was applied POST at 2,240 g ai/ha, particularly as a sequential treatment alone or as a spot treatment at 2% by volume following applications of metribuzin, terbacil, and pendimethalin or trifluralin with atrazine. Sugarcane shoot populations in the fall after planting and sugar yields at the end of the crop's first growing season were highest where fallow treatments minimized johnsongrass development. These treatments also provided broad spectrum control of other seedling weeds, the residues of which influenced crop development.
Reprint Address: Richard, EP, USDA ARS,SUGARCANE RES UNIT,POB 470,HOUMA,LA 70361.

Record 26 of 48
Author(s): Smeda, RJ; Snipes, CE; Barrentine, WL
Title: Identification of graminicide-resistant johnsongrass (Sorghum halepense)
Source: WEED SCIENCE, 45 (1): 132-137 JAN-FEB 1997
Abstract: Resistance to fluazifop-P and quizalofop-P (aryloxyphenoxypropionates) and

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sethoxydim (cyclohexanedione) was identified in 2 populations of johnsongrass in both field and greenhouse studies. The cropping history (1983-1991) of the sites indicated 1 or more annual applications of a graminicide (primarily fluazifop-P) since the early 1980s. Under field conditions, control of resistant seedling and rhizome johnsongrass (R91F) with fluazifop-P quizalofop-P fenoxaprop-ethyl, and sethoxy-dim was less than 35%. Clethodim provided up to 80% control of R91F. Under greenhouse conditions, ratios (R/S) of the I-50 values (amount of herbicide required to inhibit plant growth by 50%) of resistant (2 sites: R91F and R91S) to susceptible (S91H) seedling (20-30-cm height) plants were > 388 (fluazifop-P), > 15 (quizalofop-P), and from 2.3 (R91S) to 3.4 (R91F) (both sechoxydim). For rhizome (30-45 cm height) plants, the R/S ratios were > 388 (fluazifop-P), > 16 (quizalofop-P), and 2.8 (R91S) to 8.5 (R91F) (both sethoxydim). Labeled rates (in kg ai ha(-1)) of fluazifop-P (0.10 and 0.21), quizalofop-P (0.039 and 0.08), and sethoxydim (0.21 and 0.21) were applied on seedling and rhizome plants, respectively, and resulted in little or no control of resistant johnsongrass. Greenhouse studies indicated registered rates of clethodim (0.10 and 0.14 kg ai ha(-1) for seedling and rhizome plants, respectively) effectively controlled the resistant populations, but tolerance was measured for both seedling and rhizome plants at sublethal doses (down to 0.007 and 0.009 kg ai ha(-1), respectively), with I-50 ratios ranging from 1.5 (R91S) to 2.1 (R91F) for seedling plants and 4.5 (R91S) to 4.8 (R91F) for rhizome plants. Control of resistant seedling and rhizome johnsongrass under field conditions was adequate with glyphosate at 0.84, glufosinate at 0.84, and sulfosate at 0.84 kg ai ha(-1), indicating no cross-resistance.
Reprint Address: Smeda, RJ, USDA ARS,MAFES DELTA BRANCH EXPT STN,STONEVILLE,MS 38776.

Record 27 of 48
Author(s): Reddy, KN; Locke, MA
Title: Imazaquin spray retention, foliar washoff and runoff losses under simulated rainfall
Source: PESTICIDE SCIENCE, 48 (2): 179-187 OCT 1996
Abstract: Spray retention and foliar washoff of imazaquin in smooth pigweed (Amaranthus hybridus L.) and sicklepod (Senna obtusifolia (L.) Irwin and Barneby) were investigated. Imazaquin (70 g AI ha(-1)) was applied alone, with nonionic surfactant 'X-77' or organosilicone-based nonionic surfactant 'Kinetic' to plants at two- to five-leaf stage and subjected to 2 . 5 cm rainfall in 20 min either 1 or 24 h after application. Imazaquin spray retention was higher with adjuvants than without. Retention was similar between adjuvants in smooth pigweed but 'Kinetic' retained twice as much imazaquin as 'X-77' in sicklepod. Rainfall 1 h after application washed off three-quarters of foliar residues regardless of plant species or adjuvant. However, at 24 h after application, foliar washoff was lowest with 'Kinetic' followed by 'X-77' in both species. Imazaquin washoff ranged from 33 to 88% in the two species at 24 h after application. Overall, imazaquin activity was similar with either adjuvant in smooth pigweed but 'Kinetic' was more effective than 'X-77' in sicklepod. Runoff losses from the surface of a Bosket sandy loam (Mollic Hapludalfs) soil in runoff trays (1 . 2% slope) were also studied. Imazaquin was applied as above to trays with and without smooth pigweed canopy. A 2 . 5-cm rainfall was applied in 20 min at 24 h after application. Runoff samples collected in one-litre fractions were analyzed by enzyme-linked immunosorbent assay. Sediment (but not water) in runoff was greatly reduced (56%) by pigweed cover as compared to bare trays. Imazaquin in the first litre of runoff was higher than in subsequent runoff fractions regardless of pigweed cover. Total imazaquin lost in runoff was higher in pigweed cover (23%) than bare trays (16% of applied). Imazaquin concentration in 10-20 cm soil depth in pigweed cover trays was higher than in bare trays. These results suggest that imazaquin is vulnerable to foliar washoff and the herbicide washed off could move in the aqueous phase due to shorter contact time with soil for sorption.

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Reprint Address: Reddy, KN, USDA ARS,SO WEED SCI LAB,POB 350,STONEVILLE,MS 38776.

Record 28 of 48
Author(s): Gubbiga, NG; Worsham, AD; Corbin, FT
Title: Root/rhizome exudation of nicosulfuron from treated johnsongrass (Sorghum halepense) and possible implications for corn (Zea mays)
Source: WEED SCIENCE, 44 (3): 455-460 JUL-SEP 1996
Abstract: Experiments were conducted to evaluate the occurrence and significance of release of herbicide through subterranean parts of nicosulfuron-treated johnsongrass. In a bioassay, the rooting medium of johnsongrass treated foliarly with 50 or 100 mu g nicosulfuron plant(-1) was inhibitory to the radicle elongation of sorghum and corn indicating the increased toxicity of the rooting medium of nicosulfuron-treated johnsongrass. The study with C-14-nicosulfuron indicated a basipetal translocation of foliarly applied nicosulfuron in johnsongrass to its roots/rhizomes and also into the rooting medium. By 30 DAT, around 23% of the C-14-label absorbed by johnsongrass was found exuded into the rooting medium. Radiochromatogram scans of thin layer chroma tography plates of rooting medium indicated unmetabolized nicosulfuron as the major C-14-labeled compound (56%). The study also revealed a subsequent uptake of exuded C-14 by corn roots sharing the medium. On the whole, the amount of C-14-label recovered from untreated corn amounted to 4.3% of the total applied to johnsongrass. In another experiment, the presence of nicosulfuron in the rooting medium was detrimental to corn growth. Reductions in corn growth occurred at concentrations of 10(-8) M nicosulfuron or greater in the rooting medium. The sensitivity of corn to root uptake was attributed to greater accumulation of nicosulfuron at a faster rate in the growing parts.
Addresses: N CAROLINA STATE UNIV,DEPT CROP SCI,RALEIGH,NC 27695

Record 29 of 48
Author(s): Gubbiga, NG; Worsham, AD; Corbin, FT
Title: Investigations into the growth suppressing effect of nicosulfuron-treated johnsongrass (Sorghum halepense) on corn (Zea mays)
Source: WEED SCIENCE, 44 (3): 640-644 JUL-SEP 1996
Abstract: Greenhouse and growth chamber experiments were conducted to determine the reasons for stunted growth and yield suppression of corn noticed sometimes in nicosulfuron-treated corn fields infested with heavy population of johnsongrass. Results indicated that in the absence of johnsongrass, nicosulfuron applied broadcast POST at 35 g ai ha(-1) had no effect on corn. However, growth reduction of corn occurred when nicosulfuron-treated johnsongrass and corn were allowed to share the same rooting medium with their root systems intermingled. The reduction in growth was even greater when corn foliage or the soil surface were also treated with johnsongrass. The extent of growth reduction of corn growing with nicosulfuron-killed johnsongrass depended on weed density and herbicide application rate, Greater growth reductions occurred at four johnsongrass plants per pot compared to two and at a higher application rate of 100 mu g nicosulfuron per plant. In general, johnsongrass killed by nicosulfuron appeared to be more phytotoxic to corn than plants killed by paraquat, Nicosulfuron provided excellent control of johnsongrass and improved corn growth by two to three times that of not controlling johnsongrass, but it could not elevate corn growth to the level obtained when johnsongrass was controlled by paraquat or in the absence of interference from johnsongrass.
Reprint Address: Gubbiga, NG, N CAROLINA STATE UNIV,DEPT CROP SCI,RALEIGH,NC 27695.

Record 30 of 48
Author(s): Reddy, KN; Locke, MA; Howard, KD
Title: Bentazon spray retention, activity, and foliar washoff in weed species
Source: WEED TECHNOLOGY, 9 (4): 773-778 OCT-DEC 1995
Abstract: Greenhouse studies were conducted to investigate the effects of adjuvant and rainfall on bentazon spray retention, efficacy, and foliar washoff in hemp sesbania, sicklepod, smooth pigweed, and velvetleaf. Bentazon was applied at 0.28 to 2.24 kg ai/ha with Agri-Dex, a crop oil concentrate (COC) or Kinetic, an organiosilicone-nonionic surfactant blend (OSB) when weeds were at the three- to five-leaf stage. Plants were subjected to 2.5 cm simulated rainfall for 20 min at 1 and 24 h after application of bentazon. Shoot fresh weight reduction assessed 2 wk after treatment was similar with either adjuvant on velvetleaf and smooth pigweed. OSB enhanced bentazon efficacy in hemp sesbania and sicklepod as compared to COC. Rainfall at 1 h after application generally reduced bentazon activity in all weeds. OSB maintained bentazon activity in hemp sesbania when subjected to rainfall at 1 h after application as compared to COC. Overall, bentazon spray retention on plants was 9 to 550% higher with OSB as compared to COC among the species at 1 h after application. Amount of bentazon residue washed off from the foliage by rainfall within a weed species was relatively similar for both adjuvants except in smooth pigweed and ranged from 39 to 98% among the four weed species at 1 h after application. OSB exhibited specificity for certain weed species and the potential to minimize bentazon spray reaching the soil by increasing deposition.
Reprint Address: Reddy, KN, USDA ARS,SO WEED SCI LAB,POB 350,STONEVILLE,MS 38776.

Record 31 of 48
Author(s): ELMORE, CD; HEATHERLY, LG; WESLEY, RA
Title: WEED-CONTROL IN NO-TILL DOUBLECROP SOYBEAN (GLYCINE-MAX) FOLLOWING WINTER-WHEAT (TRITICUM-AESTIVUM) ON A CLAY SOIL
Source: WEED TECHNOLOGY, 9 (2): 306-315 APR-JUN 1995
Abstract: Weed control was evaluated in no-till planted soybean in both burned and standing wheat stubble for 3 yr. High, intermediate, low, and no weed management following no-till planting of soybean were compared with a tilled treatment with high weed management. Herbicides for the high weed management were metribuzin plus metolachlor PRE followed by POST applications, as needed, of bentazon, acifluorfen, and fluazifop or quizalofop. Intermediate management included all of the above except metolachlor, plus the as-needed use of chlorimuron or lactofen POST. Low management had no PRE herbicide applications but included the above POST herbicides. Glyphosate was used as a preplant foliar applied desiccant in the stubble-planted soybean of all weed management levels. Yield of soybean was not affected by standing, burned, or tilled wheat stubble. Soil organic matter in the 0 to 2.5 cm of soil was not significantly affected at the end of the 3 yr. Yield of wheat was reduced by standing wheat stubble in the first year of the study. Total POST weed control was sufficient for maximum soybean yields in the second and third years of the study. The weed spectrum changed during the experiment for the no-weed-control treatment in soybean and in wheat. The major weeds present in soybean after 3 yr of no-till were southern crabgrass, nodding spurge, redvine, prickly sida, barnyardgrass, and johnsongrass; in wheat they were Italian ryegrass, little barley, mayweed chamomile, and hairy buttercup. Nomenclature: Acifluorfen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid; bentazon, 3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide; chlorimuron, 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid; fluazifop, (+/-)-2-[4-[[5-

(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid; glyphosate, N-(phosphonomethyl)glycine; lactofen, (+/-)-2-ethoxy-1-methyl-2-oxyethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate; metolachlor, 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide; metribuzin, 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one; quizalofop, (+/-)-2-[4-[(6-chloro-2-quinoxalinyl)-oxy]phenoxy]propanoic acid; wheat, Triticum aestivum L., soybean, Glycine max (L.) Merr., southern crabgrass, Digitaria ciliaris (Retz.) Keel. #(3) DIGSP; nodding spurge, Euphorbia nutans Lag. # EPHNU; redvine, Brunnichia ovata (Walt.) Shinners # BRVCI; prickly sida, Sida spinosa L. # SIDSP; barnyardgrass, Echinochloa crus-galli (L.) Beauv. # ECHCG; johnsongrass, Sorghum halepense (L.) Pers. # SORHA; Italian ryegrass, Lolium multiflorum Lam. # LOLMU; little barley, Hordeum pusillum Nutt. # HORPU; mayweed chamomile, Anthemis cotula L. # ANTCO; hairy buttercup, Ranunculus sardous Crantz # RANSA.
Reprint Address: ELMORE, CD, USDA ARS,APPL & PROD TECH RES UNIT,POB 36,STONEVILLE,MS 38776.

Record 32 of 48
Author(s): LANIE, AJ; GRIFFIN, JL; VIDRINE, PR; REYNOLDS, DB
Title: HERBICIDE COMBINATIONS FOR SOYBEAN (GLYCINE-MAX) PLANTED IN STALE SEEDBED
Source: WEED TECHNOLOGY, 8 (1): 17-22 JAN-MAR 1994
Abstract: Barnyardgrass 7 to 25 cm tall was controlled 48 to 74% with paraquat (420 g/ha), 83 to 87% with glyphosate (1120 g/ha), and 85 to 91% with glufosinate (840 g/ha). In most cases barnyardgrass control was not enhanced with addition of residual herbicides metribuzin plus chlorimuron, metribuzin, or imazaquin. Barnyardgrass and seedling johnsongrass no more than 13 cm tall was controlled at least 90% regardless of herbicide treatment. When rhizome and seedling johnsongrass were present, control with glyphosate was 96% compared with 55% for paraquat and 86% with glufosinate. Tank-mixtures of non-selective and residual herbicides generally enhanced control of entireleaf and pitted morningglory, hemp sesbania (15 to 30 cm), and prickly sida (15 to 18 cm). Soybean yields in most cases were not increased with addition of residual herbicides. Yield following glufosinate applied alone was 25% higher than following paraquat, and for all herbicide treatments yields were at least 45% greater than when a non-selective herbicide was not applied.
Reprint Address: LANIE, AJ, DEPT PLANT PATHOL CROP PHYSIOL,302 LIFE SCI BLDG,BATON ROUGE,LA 70803.

Record 33 of 48
Author(s): HYDRICK, DE; SHAW, DR
Title: EFFECTS OF TANK-MIX COMBINATIONS OF NONSELECTIVE FOLIAR AND SELECTIVE SOIL-APPLIED HERBICIDES ON 3 WEED SPECIES
Source: WEED TECHNOLOGY, 8 (1): 129-133 JAN-MAR 1994
Abstract: Greenhouse experiments were established to investigate the effects of tank-mixing glyphosate, paraquat, or glufosinate with metribuzin plus chlorimuron, imazaquin, or metribuzin on entireleaf morningglory, sicklepod, and johnsongrass control. Antagonism was the most frequent interaction, and usually occurred when the lower rates of non-selective foliar-active herbicides were used in tank mixtures with selective soil-active herbicides. Antagonism occurred on all species when 180 g ai/ha paraquat was tank-mixed with 90 g ai/ha metribuzin plus 15 g ai/ha chlorimuron. When the rates of non-selective herbicide were increased, antagonism was usually overcome. Antagonism also occurred on entireleaf morningglory control when 210 g ai/ha glyphosate was tank-mixed with 90 g/ha metribuzin plus 15 g/ha

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chlorimuron or 36 g ai/ha imazaquin. When lower rates of paraquat or glufosinate were tank-mixed with 210 g/ha metribuzin, antagonism also occurred. Less antagonism was noted with glufosinate.
Reprint Address: HYDRICK, DE, MISSISSIPPI STATE UNIV,DEPT PLANT PATHOL WEED SCI,MISSISSIPPI STATE,MS 39762.

Record 34 of 48
Author(s): FRANS, RE; MCCLELLAND, MR; HORTON, DK; CORBIN, BR; TALBERT, RE
Title: CROP AND HERBICIDE ROTATIONS FOR JOHNSONGRASS (SORGHUM-HALEPENSE) CONTROL
Source: WEED SCIENCE, 39 (4): 660-666 OCT-DEC 1991
Abstract: Four-year cropping sequences of continuous cotton, cotton-soybeans-soybeans-cotton, continuous soybeans, soybeans-grain sorghum-soybeans-grain sorghum, and cotton-rice-cotton-rice were treated each year with high and low levels of herbicides to control johnsongrass. High levels of herbicide were necessary to control johnsongrass in continuous cotton, cotton-soybeans-soybeans-cotton, continuous soybeans, and the soybeans-grain sorghum rotation. Johnsongrass was not eradicated, however, after 4 years of cropping sequences with high herbicide inputs. Both low and high levels of herbicide coupled with water management required for rice production controlled johnsongrass and prevented rice yield reductions.
Reprint Address: FRANS, RE, UNIV ARKANSAS,DEPT AGRON,FAYETTEVILLE,AR 72701.

Record 35 of 48
Author(s): CAMACHO, RF; MOSHIER, LJ
Title: ABSORPTION, TRANSLOCATION, AND ACTIVITY OF CGA-136872, DPX-V9360, AND GLYPHOSATE IN RHIZOME JOHNSONGRASS (SORGHUM-HALEPENSE)
Source: WEED SCIENCE, 39 (3): 354-357 JUL-SEP 1991
Abstract: Rhizome johnsongrass grown in the greenhouse and treated with glyphosate at 1680 g ai ha-1 at an early (3- to 4-leaf) or late (6- to 8-leaf) growth stage displayed injury within a week. Plants treated with CGA-136872 or DPX-V9360 at 40 g ai ha-1 at both growth stages displayed injury 1 to 2 weeks later. CGA-136872 did not prevent regrowth at either growth stage. No regrowth occurred from DPX-V9360 or glyphosate-treated plants. Foliar absorption by greenhouse-grown plants within 24 h of application was greater with C-14-glyphosate than with C-14-DPX-V9360 or C-14-CGA-136872. More C-14-DPX-V9360 was absorbed than C-14-CGA-136872. Growth stage influenced glyphosate absorption (more by younger plants) but not CGA-136872 or DPX-V9360 absorption. Translocation of the C-14-CGA-136872 and C-14-DPX-V9360 out of the treated leaf was less than 20% of the absorbed label and was less than glyphosate translocation. Growth stage of rhizome johnsongrass at the time of treatment had no effect on the distribution of radiolabeled herbicides within 24 h.
Reprint Address: CAMACHO, RF, KANSAS STATE UNIV,DEPT AGRON,MANHATTAN,KS 66502.

Record 36 of 48
Author(s): KENT, LM; WILLS, GD; SHAW, DR
Title: INFLUENCE OF AMMONIUM-SULFATE, IMAZAPYR, TEMPERATURE, AND RELATIVE-HUMIDITY ON THE ABSORPTION AND TRANSLOCATION OF IMAZETHAPYR

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Source: WEED SCIENCE, 39 (3): 412-416 JUL-SEP 1991
Abstract: The effects of 1.24 kg ha-1 ammonium sulfate, 5 g ae ha-1 of the isopropylamine salt of imazapyr, and air temperatures of 18, 27, or 35 C at 40 or 100% relative humidity (RH) on the absorption and translocation of the ammonium salt of C-14-imazethapyr applied postemergence to pitted morningglory were evaluated. Absorption of C-14-imazethapyr was greater at 100 than at 40% RH (88 vs. 47%). At 40% RH, absorption was increased to 79% by the addition of ammonium sulfate. At 100% RH absorption was similar with all treatments. Translocation of C-14-imazethapyr applied alone was greater at 100 than at 40% RH (34 vs. 17%). Addition of ammonium sulfate increased translocation at 40% RH but not at 100%. Addition of imazapyr did not affect C-14 translocation. Distribution of C-14 throughout the plant was more acropetal than basipetal with the greatest distribution at 35 C.
Addresses: MISSISSIPPI STATE UNIV,DEPT PLANT PATHOL WEED SCI,MISSISSIPPI STATE,MS 39762
Reprint Address: KENT, LM, DELTA BRANCH EXPT STN,STONEVILLE,MS 38776.

Record 37 of 48
Author(s): SALISBURY, CD; CHANDLER, JM; MERKLE, MG
Title: AMMONIUM-SULFATE ENHANCEMENT OF GLYPHOSATE AND SC-0224 CONTROL OF JOHNSONGRASS (SORGHUM-HALEPENSE)
Source: WEED TECHNOLOGY, 5 (1): 18-21 JAN-MAR 1991
Abstract: Ammonium sulfate enhanced the initial control of johnsongrass by glyphosate and SC-0224 applied in the fall or summer. Glyphosate at 0.42 kg ha-1 in combination with ammonium sulfate at 3.33 kg ha-1 provided levels of fall johnsongrass control and spring regrowth control comparable to glyphosate at 0.84 kg ha-1. Spring applications to mixed populations of seedling and rhizome johnsongrass showed that ammonium sulfate added to glyphosate or SC-0224 afforded little enhancement of herbicide efficacy. Glyphosate or SC-0024 at 0.42 kg ha-1 applied in combination with logarithmically decreasing rates of ammonium sulfate demonstrated reduced weed control with ammonium sulfate rates above 9.7 kg ha-1.
Reprint Address: SALISBURY, CD, TEXAS A&M UNIV SYST,DEPT SOIL & CROP SCI,COLLEGE STN,TX 77843.

Record 38 of 48
Author(s): FLINT, JL; BARRETT, M
Title: ANTAGONISM OF GLYPHOSATE TOXICITY TO JOHNSONGRASS (SORGHUM-HALEPENSE) BY 2,4-D AND DICAMBA
Source: WEED SCIENCE, 37 (5): 700-705 SEP 1989
Reprint Address: FLINT, JL, UNIV KENTUCKY,DEPT AGRON,LEXINGTON,KY 40545.

Record 39 of 48
Author(s): BROWN, SM; CHANDLER, JM; MORRISON, JE
Title: GLYPHOSATE FOR JOHNSONGRASS (SORGHUM-HALEPENSE) CONTROL IN NO-TILL SORGHUM (SORGHUM-BICOLOR)
Source: WEED SCIENCE, 36 (4): 510-513 JUL 1988
Addresses: TEXAS A&M UNIV,DEPT SOIL & CROP SCI,COLLEGE STN,TX 77843; USDA ARS,TEMPLE,TX 76503

Record 40 of 48

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Author(s): KEELEY, PE; CARTER, CH; THULLEN, RJ; MILLER, JH
Title: COMPARISON OF ROPEWICK APPLICATORS FOR CONTROL OF JOHNSONGRASS (SORGHUM-HALEPENSE) IN COTTON (GOSSYPIUM-HIRSUTUM) WITH GLYPHOSATE
Source: WEED SCIENCE, 32 (4): 431-435 1984
Reprint Address: KEELEY, PE, USDA ARS,SHAFTER,CA 93263.

Record 41 of 48
Author(s): KEELEY, PE; THULLEN, RJ; CARTER, CH; MILLER, JH
Title: CONTROL OF JOHNSONGRASS (SORGHUM-HALEPENSE) IN COTTON (GOSSYPIUM-HIRSUTUM) WITH GLYPHOSATE
Source: WEED SCIENCE, 32 (3): 306-309 1984
Reprint Address: KEELEY, PE, USDA ARS,SHAFTER,CA 93263.

Record 42 of 48
Author(s): JEFFERY, LS; ENGLISH, JR; CONNELL, J
Title: THE EFFECTS OF FALL APPLICATION OF GLYPHOSATE ON CORN (ZEA-MAYS), SOYBEANS (GLYCINE-MAX), AND JOHNSONGRASS (SORGHUM-HALEPENSE)
Source: WEED SCIENCE, 29 (2): 190-195 1981
Addresses: UNIV TENNESSEE,DEPT PLANT & SOIL SCI,KNOXVILLE,TN 37916

Record 43 of 48
Author(s): LOLAS, PC; COBLE, HD
Title: TRANSLOCATION OF GLYPHOSATE-C-14 IN JOHNSONGRASS (SORGHUM-HALEPENSE L PERS) AS AFFECTED BY GROWTH STAGE AND RHIZOME LENGTH
Source: WEED RESEARCH, 20 (5): 267-270 1980
Addresses: N CAROLINA STATE UNIV,DEPT CROP SCI,RALEIGH,NC 27650

Record 44 of 48
Author(s): MCWHORTER, CG; WILLIFORD, JR
Title: FACTORS AFFECTING THE TOXICITY OF GLYPHOSATE APPLIED IN THE RECIRCULATING SPRAYER TO JOHNSONGRASS (SORGHUM-HALEPENSE) AND SOYBEANS (GLYCINE-MAX)
Source: WEED SCIENCE, 28 (1): 59-63 1980
Addresses: USDA SEA,FIELD CROPS MECH RES UNIT,STONEVILLE,MS
Reprint Address: MCWHORTER, CG, USDA SEA,S WEED SCI LAB,STONEVILLE,MS 38776.

Record 45 of 48
Author(s): MCWHORTER, CG; JORDAN, TN; WILLS, GD
Title: TRANSLOCATION OF GLYPHOSATE-C-14 IN SOYBEANS (GLYCINE-MAX) AND JOHNSONGRASS (SORGHUM-HALEPENSE)
Source: WEED SCIENCE, 28 (1): 113-118 1980
Addresses: PURDUE UNIV,DEPT BOT & PLANT PATHOL,W LAFAYETTE,IN 47907; MISSISSIPPI AGR & FORESTRY EXPT STN,DELTA BRANCH,STONEVILLE,MS 38776
Reprint Address: MCWHORTER, CG, USDA SEA,S WEED SCI LAB,STONEVILLE,MS 38776.

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Record 46 of 48
Author(s): KELLS, JJ; RIECK, CE
Title: EFFECTS OF ILLUMINANCE AND TIME ON ACCUMULATION OF GLYPHOSATE IN JOHNSONGRASS (SORGHUM-HALEPENSE)
Source: WEED SCIENCE, 27 (2): 235-237 1979
Reprint Address: KELLS, JJ, UNIV KENTUCKY,DEPT AGRON,LEXINGTON,KY 40506.

Record 47 of 48
Author(s): MCWHORTER, CG; AZLIN, WR
Title: EFFECTS OF ENVIRONMENT ON TOXICITY OF GLYPHOSATE TO JOHNSONGRASS (SORGHUM-HALEPENSE) AND SOYBEANS (GLYCINE-MAX)
Source: WEED SCIENCE, 26 (6): 605-608 1978
Reprint Address: MCWHORTER, CG, USDA,SCI EDUC ADM,S WEED SCI LAB,STONEVILLE,MS 38776.

Record 48 of 48
Author(s): MCWHORTER, CG
Title: WEED-CONTROL IN SOYBEANS WITH GLYPHOSATE APPLIED IN RECIRCULATING SPRAYER
Source: WEED SCIENCE, 25 (2): 135-141 1977
Addresses: USDA,ARS,SO WEED SCI LAB,STONEVILLE,MS 38776

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Appendix C

Questionnaire prepared for interviewing farmers

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Cuestionario

Datos personales e información general:

Nombre _____
Dirección _____
_____
Teléfono/Fax _____ / _____
E-mail _____
Condenadas (GPS) _____

Área con soja resistente a glifosato/bajo cero labranza _____ / _____

Área con sorgo alepo resistente a glifosato _____
En todos los campos (_____) o solo en uno (_____)?
Si en solamente uno, hay diferencias en el historial del campo?

Tipo de suelo

Secano (_____) / irrigado (_____)
Si es irrigado
Cómo?

Calidad del agua? Salinidad? Contenido de calcio y magnesio?

Filtra el agua para eliminar semillas de malezas? Sí _____, No _____

Resistencia del sorgo alepo al glifosato

Detección inicial del problema

1. Por cuánto tiempo ha usado el glifosato _____

2. Año en que se notó el problema por primera vez _____. En ese año:

a. Acerca del uso de glifosato:

Dosis. _____
(Si se usaron dosis menores a las recomendadas, describir cuándo y cómo)

Formulación (nombre de marca y de formulación) _____

Aditivos empleados? Coadyuvantes, sulfato de amonio?

Combinaciones con otros herbicidas

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b. Se presentó como plántulas no controladas? _____ Rizomas? _____

c. Estado de crecimiento del sorgo alepo más desarrollado al momento de aplicar?. Favor especificar _____

Re-aplicación en ese ciclo de cultivo? Sí _____ No _____
Indique estado de crecimiento, dosis y formulaciones, resultados?

d. El sorgo alepo resistente se presentó en manchones (_____) o al azar (_____)?

e. Muerte descendente y rebrote posterior? Sí _____, No _____

f. Algunas plantas de sorgo alepo muertas (_____) o todo el sorgo alepo vivo (_____)?

g. En una camada en particular. Especifique _____

h. Las demás gramíneas en el área afectada murieron? Si _____, No _____

i. Infestación con otras malezas mayor de la normal? Sí (cuáles) _____, No _____

j. Cerca de camino (_____), borde del campo (_____) o en el sitio donde ingresa el equipo (_____)?

k. Temperatura el momento de aplicar glifosato (_____) y durante la siguiente semana (_____)

l. Cuantos días transcurridos entre la aplicación y la primera lluvia o riego? _____

m. Monocultivo (_____) o rotación previa (_____):
Si hubo rotación, cuales cultivos/herbicidas: _____ / _____, _____ / _____, _____ / _____,

n. Realiza labores de cultivo (_____) o sólo cero labranza (_____)?

o. Se encontraba el sorgo alepo en producción de semilla al momento de cosechar el cultivo

p. Cómo/con qué controla malezas en los bordes del campo y en los bordes de camino?

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En años posteriores

q. Utiliza dosis más altas (_____) o formulaciones diferentes (_____)?

r. Si fueron eficaces, por cuanto más tiempo? _____

s. Describa la dispersión _____

t. Cómo está usted enfrentando el problema? Herbicidas, cultivos, rotaciones, labranza? Explique: _____
_____
_____

Otros aspectos

1. Difiere el sorgo de alepo normal (susceptible) en su sensibilidad al glifosato dependiendo del estado de crecimiento, época del año o regimenes de temperatura, humedad del suelo, intensidad lumínica, fertilización?
Explique en que consisten las diferencias.

2. Difiere el sorgo de alepo resistente en su sensibilidad al glifosato dependiendo del estado de crecimiento, época del año o regimenes de temperatura, humedad del suelo, intensidad lumínica, fertilización?
Explique en que consisten las diferencias.

3. Utiliza semilla de soja registrada? Sí (_____), No (_____)
Semilla de bolsa blanca? Sí (_____), No (_____)
Si usa semilla producida en la propia finca, describa el equipo de limpieza de semilla y su eficacia

4. Cosecha y acarrea con su propia maquinaria? Sí (_____), No (_____)
Limpia el equipo antes de ingresar a los campos? Sí (_____), No (_____)
Cómo? _____

5. Tiene usted alguna idea de cómo apareció la resistencia? Diseminación? Explique:
_____
_____
_____
_____

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6. Sus vecinos también tienen problemas de sorgo alepo resistente? Sí (_____), No (_____)

Detalles acerca de aquellos que lo tienen: _____
_____
_____

Detalles acerca de los que no tiene sorgo alepo resistente: _____
_____
_____

7. Indique las prácticas de su finca

_____ Monitoreo semanal de la finca por problemas de malezas
_____ Monitoreo quincenal
_____ Monitoreo eventual
_____ No realiza monitoreo alguno

8. Comentarios adicionales que desee hacer: _____
_____
_____
_____
_____

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