HERBICIDE DRIFT AND THE USE OF SENTINEL PLANTS TO ASSESS EXPOSURE OF NONTARGET CROPS[1]

by
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In regions of highly diversified agriculture, herbicides used in one field may not be compatible with crops growing in nearby fields. Injury to nontarget crops may occur from point sources like direct drift of sprays during application or from secondary drift as a result of vapor movement. In the former case, drift of a well-defined mass of aerosols occurs during the actual spray operation. Depending on whether spraying is done by tractor or aircraft, deposition of most aerosols occurs within 500 meters of the spray [1-3]. With direct spray drift, the pattern of injury or symptomology seen in affected fields shows a gradient of decreasing injury as the field is traversed [4]. Thus, the edge of the field closest to the sprayed field shows the most severe injury.

In the case of secondary drift, movement of pesticide vapor occurs after deposition of spray aerosols and thus can occur over longer periods of time and perhaps greater distances than point source drift. An atmospheric inversion could enhance the long-distance movement of pesticide residues, whether from direct or secondary drift, away from the targeted field. The contamination of nontarget crops by unregistered pesticides as a result of vapor drift has been documented [5].

Monitoring of air and precipitation has shown that airborne pesticide residues occur widely over agricultural regions in an analogous manner to nonpoint source contamination of aquatic systems [6-8]. Airborne pesticide residues may translocate and deposit on a regional scale or be carried thousands of miles from the source. For example, triazine and acetanilide herbicides found in rain on the east coast and in the midwest are believed to arise during regional use of sprays on corn in the early spring [8,9]. On the other hand, toxaphene, a mixture of highly chlorinated compounds, was concluded to have contaminated Lake Michigan as a result of long-distance transport from sprayed fields in the southern U.S. [10].

The occurrence of herbicides in precipitation over large regions suggests that nontarget plants may be exposed to residues. The biological significance of the low levels of herbicides found in precipitation has not been studied. Most detections have been below 1 ppb, but levels as high as 40 ppb have been found in some midwestern samples [8]. Ultimately, the effect on a nontarget plant will depend on species susceptibility.

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For example, grapes are particularly sensitive to 2,4-D [11], and conflicts between grape and wheat growers (who use phenoxyacetate herbicides) in eastern Washington (WA) were mostly resolved by the implementation of state regulations that mandated the use of low volatility phenoxyacetate formulations. Despite these changes, random symptomology of 2,4-D exposure occurs on isolated grape leaves in many vineyards of south central WA (Felsot unpublished). Residues of 2,4-D have been detected in the air over south central WA, and attempts have been made to correlate drift and general transport with weather patterns and formulations [12,13].

Over the last decade, the newer acetolactate synthase inhibitors, which include the imidazolinone and sulfonylurea (SU) classes of herbicides, have become major pesticides used in wheat and soybeans; SUs have recently been introduced into the corn market [14]. Although these compounds are used at rates of grams per hectare, their toxicity equivalence is greater than or at least equal to the more conventional triazine and acetanilide compounds. These compounds have not been monitored in rainfall nor in the atmosphere, but biomonitoring in WA has suggested that atmospheric deposition of trace levels can cause observable morphological changes on leaves [15,16]. Coincident with the increasing use of acetolactate synthase inhibitors in the Corn Belt, are increasing complaints of nontarget plant damage from herbicide drift [17]; however, a cause and effect relationship has not been established.

During the late 1980's in the Pacific Northwest, growers of minor crops like cherry, prune, alfalfa, and asparagus complained of significantly diminished yields that they attributed to herbicide drift, specifically drift of the SU herbicides [18]. The affected growers mainly resided in the Badger Canyon, which lies west-southwest of the TriCities area (Richland, Kennewick, Pasco) in south central Washington. To the south, the Badger Canyon is bordered by the Horse Heaven Hills formation which is a region that includes approximately 250,000 acres of dryland wheat production. A report on meteorological conditions in this whole region suggested prevailing wind patterns could carry herbicide residues from dryland wheat-producing acres on the Horse Heaven Hills into the canyon [19]. A symptom most often reported over the entire region is a diffuse chlorotic spot that can cause leaf puckering when present near the edge of the leaf. The spots are commonly observed in the early spring.

Past studies of damage induced by low levels of herbicides have focused on vegetative growth. Symptomology following exposure to phenoxyacetate herbicides has been described in nontarget plants [4,20]. Studies in WA have examined the effects of dilute herbicide sprays (0.3-0.01 of the maximum use rates) on grapes, alfalfa, roses, and sweet cherries [21-24]. Recently published studies noted effects on reproductive physiology in sweet cherry [25,26].

In nearly all studies of the possible effects of drift on nontarget plants, the manner of dosing does not truly reflect drift of discrete aerosols because the leaves are fully covered with a spray, albeit very dilute.

The types of symptomology observed following full leaf coverage with a dilute spray and impaction by a few discrete aerosols can be very different [16]. For example, a grape leaf receiving full coverage of a dilute solution of chlorsulfuron delivered with a typical spray nozzle shows general chlorosis and rugosity. A leaf receiving discrete aerosols as a result of drift from a chlorsulfuron spray shows isolated nearly round chlorotic spots.

The chorotic spot phenomenon is presently being used in a biomonitoring program that uses sentinel plants at various locations throughout south central WA to assess deposition of airborne residues of SU herbicides. First reported by Al-Khatib et al. [15], the program has since been refined to allow an examination of the temporal relationship between applications of SU herbicides and incidences of SU induced symptomology in sentinel plants. This refinement has allowed testing of the hypothesis that the widespread observations of chlorotic spots on early leafing vegetation in south central WA results largely from deposition of regionally transported SU herbicide residues rather than from specific point source spraying.

Pea, bean, and corn seedlings have been used as sentinels to detect atmospheric deposition of trace residues. Seedlings are exposed at various locations throughout south central WA and exchanged on a weekly basis with a new set of plants. Plants are returned to a lath house and observed over three weeks for development of symptoms indicative of probable exposure to four classes of herbicides--sulfonylureas, phenoxyacetates, aminophosphonic acids, and bipyridyliniums. Symptoms were verified by releasing dilute solutions of herbicide aerosols at a 10 m distance upwind of several sets of sentinel plants.

The most frequently observed symptoms on sentinel plants from around the region were chlorotic spots on the upper leaf surfaces; the symptoms were identical to those created under controlled conditions when plants were exposed to aerosols of the SU herbicide chlorsulfuron. During 1992-1994, chlorotic spots characteristic of SU exposure were observed on sentinel plants from the first or second week in April until the second or third week in May (Figures 1-3). The maximum percentage of sites with plants exhibiting symptoms (about 50%) always occurred in April. After May, no symptoms characteristic of SU exposure were observed.

The timing of SU herbicide applications in the region varied each year of the study and was influenced by prevailing weather conditions and status of the wheat crop. Although the weekly applied amounts represented all SU herbicides used, which included applications to dryland wheat, irrigated wheat, and roadsides, the majority of applications were accounted for in dryland wheat. During 1992 and 1993 applications of SU herbicides reached a high point during the same week that sentinel plants were showing comparatively few incidences of exposure (Figure 1, 2). For example, between 5-12 May 1992, over 8000 acres were sprayed, but the incidences of symptoms were less than 5% of total sentinel sites. During 1993, about 6000 acres were sprayed during the week preceding 29 April, yet the percentage of sentinel plant sites showing symptoms was only 25%, down from 50% in each of the three preceding weeks. Also, the first week sentinel plants were placed in the field during 1993, incidences of symptoms were prevalent, but barely 500 acres had been sprayed in the weeks prior to April 8.

During 1994, nearly 30,000 acres had been sprayed prior to 7 April (Figure 3). Incidences of chlorotic spots were seen at about 50% of sentinel plant sites the first two weeks of April while significant acreage was still being sprayed. Yet, during 1-7 April SU applications had declined precipitously from the week before. Incidences of symptoms declined during the last two weeks of April coincidentally with the decline in acres sprayed. However, during the week prior to 6 May, about 20% of sentinel plant sites were recorded with symptoms, yet almost no acres were being sprayed.

For each week in April, the location of land treated with herbicides and the location of sentinel plant sites were mapped; average wind direction during the week was also plotted on the map. The distances separating the locations of exposed sentinel plants and acres sprayed were well beyond the range that drift studies have shown for deposition of drifting aerosols, especially from a ground sprayer. During some weeks, the wind should have carried herbicide spray in the opposite direction of the nearest sentinel plant sites.

According to the records from the weather stations located across the Horse Heaven Hills, precipitation did occur throughout the area during April and May. Rain intensity in the region is very light and best described as a drizzle; intense rains are very rare. Deposition of SU herbicides in rain drops is consistent with the region-wide occurrence of chlorotic spots. As noted earlier, several studies have shown the presence of herbicides in precipitation [8,9]. Another mechanism of deposition might also be through condensation, which has been reported to contain pesticide residues [27]. The morning temperatures of south central WA during April are cool enough to cause condensation.

A hypothesis of herbicide deposition in water droplets is also consistent with the pattern of putative SU exposure. SU applications are made during a definite period, generally ending by mid-May; such an application pattern would generate a defined mass of airborne herbicide residues that mostly wash out in April and May. By May the precipitation becomes very infrequent and the summers are extremely dry; indeed, the average annual precipitation in the area ranges from 15 to 25 cm. Thus, chlorotic spots may not be detected after May because the atmospheric load has dissipated and/or precipitation is too infrequent to cause widespread exposures.

Conclusions

Biomonitoring using sentinel plants has consistently shown over three growing seasons (1992-1994) in south central Washington that the majority of herbicide-induced symptoms occur in plants examined during April. The incidence of symptoms greatly diminishes throughout the rest of the growing season. The greatest number of incidences seems due to SU herbicide exposure. Ironically, however, the pattern of use of SU herbicides does not correlate with the timing of the greatest number of exposure incidences measured by biomonitoring. In other words, increased use of SU herbicides is not correlated with higher incidences of symptoms. This lack of correlation suggests that many herbicide exposures are occurring from nonpoint source atmospheric deposition rather than point source drift. If this hypothesis is correct then nontarget crops and native plants may be continually exposed to very low levels of herbicides, which are used throughout the spring, summer, and early fall.

Still uncharacterized are the level of herbicides in the air, the amounts being deposited, the source of the deposition (wet or dry), and the exact dose to a plant. If an assessment of risk of economic injury from low level herbicide exposure is to be made, then the aforementioned data need to be collected.

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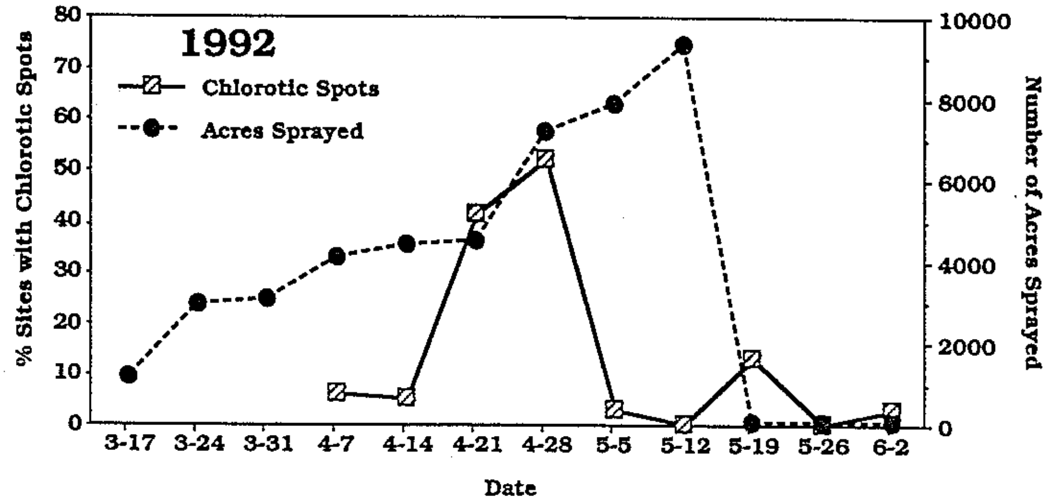

Figure 1. Relationship between weekly incidence of chlorotic spots on sentinel plants and total acres sprayed with SU herbicides during 1992.

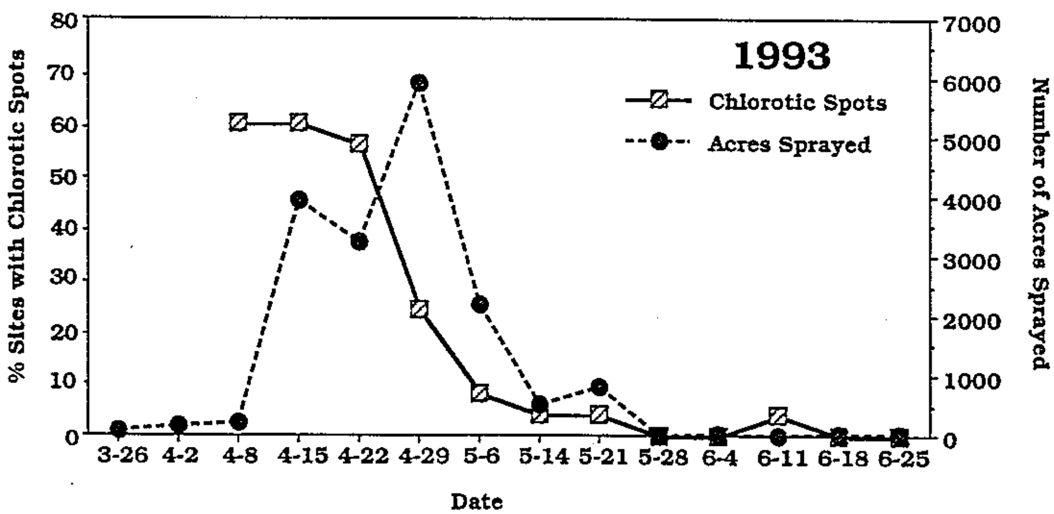

Figure 2. Relationship between weekly incidence of chlorotic spots on sentinel plants and total acres sprayed with SU herbicides during 1993.

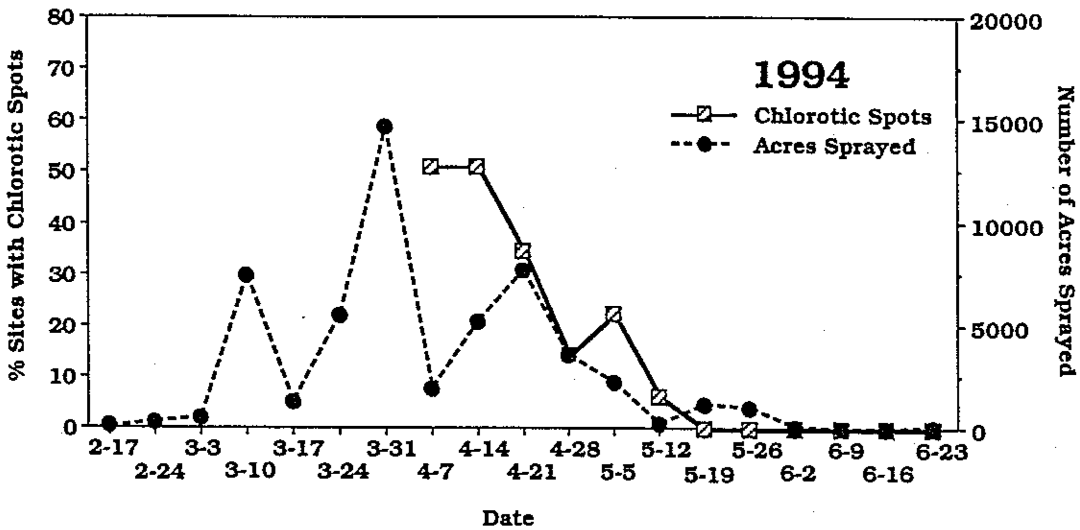

Figure 3. Relationship between weekly incidence of chlorotic spots on sentinel plants and total acres sprayed with SU herbicides during 1994.