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OFFICE OF
PREVENTION, PESTICIDES
AND
TOXIC SUBSTANCES

Memorandum

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SUBJECT: Benefits Assessment for Endosulfan Use on Broccoli: Impacts from Changes in the Re-Entry Interval

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SUMMARY

Endosulfan has been identified as posing health risks for workers engaged in post-application activities such as thinning and hand harvesting. The proposed re-entry interval (REI) following an application of endosulfan as an emulsifiable concentrate (EC) would be extended from the current one (1) day to nine (9) days and be extended to fourteen (14) days for the wettable powder (WP) formulation. For less intensive activities like irrigating or scouting, the REI would be extended to seven (7) days for EC and twelve (12) days for WP. This assumes an application rate of 2 lbs active ingredient (a.i.) per acre, the maximum allowed under the current label.

Growers mainly use the EC formulation, but at an average application rate of around 1 lb a.i./acre. Endosulfan is used to control pests during the initial, stand-establishment period when growers engage in critical activities including hand weeding and thinning. To adequately control weeds, growers need to enter fields at a maximum of five-day intervals. BEAD believes that extending the REI beyond a maximum of five days would induce growers to switch to an alternative pesticide such as imidacloprid. Imidacloprid is much more expensive, with additional costs of $18 to $36 per acre in California and $50 more in Arizona. Higher costs lead to lower net revenues with declines ranging from 3.8 to 18.6% for affected acres. It should be noted, however, that imidacloprid is widely used on broccoli and that there may be benefits to its use, such as longer control or control over more pests, that are not considered in this analysis.

Use of endosulfan on broccoli appears to be declining and is currently used on about 2% of the acreage. Industry losses are therefore expected to be small, ranging from $168,600 to $213,600 annually. Gross value of production is around $552 million, so these losses represent less than 0.05% of gross revenues.

LIMITATIONS AND SCOPE OF ANALYSIS

The scope of this analysis includes an examination of potential per-acre and industry-level impacts associated with changing formulations and extending the re-entry intervals (REIs) for selected activities that follow application of endosulfan in broccoli. This mitigation scenario reflects the health risks to farm workers as identified by the Health Effects Division of the Office of Pesticide Programs. This analysis does not attempt to address impacts associated with mitigation efforts targeted at mixers, loaders, or applicators of endosulfan, nor potential mitigation for various environmental risks (i.e., risk mitigation for risks to terrestrial plants and organisms or water contamination). Nor does it address the impacts of a reduction in the allowable application rate.

There are limitations to this assessment. The impacts estimated by this analysis only represent potential short-term – 1 to 2 years – impacts on the broccoli production system and grower returns. National impacts are calculated by simply scaling up the estimated per-acre impacts. We ignore potential changes in price that may result from production changes and we assume that grower impacts will not result in a shift from broccoli to other crops.

Assumptions about yield and quality losses associated with the various scenarios are based on the best professional judgement of BEAD analysts when estimates were not available from other sources. Assumptions are based on a review of available USDA crop profiles, state crop production guides, discussions with university extension and research entomologists knowledgeable in broccoli production, and other sources listed. Broccoli production is a very complex system that can be influenced by a variety of parameters (e. g., weather). BEAD's ability to quantitatively capture the wide array of events that could unfold given each hypothetical scenario listed above is very limited.

BROCCOLI PRODUCTION

Total U.S. broccoli production was 2.1 billion pounds in 2001, and was valued at $504.2 million. California and Arizona comprise the major production region (Table 1). Texas, Oregon, Michigan and Minnesota produce minor quantities. Over 90% of production goes to the fresh market and accounts for over 95% of value. However, over the past three years, fresh market utilization has declined slightly.

Table 1. Broccoli: 1999-2001 Average Area, Production, and Value of Production.

U.S./State	Harvested Acreage (Acres)	Production (1000 lbs)	Percent of U.S. Production	Yields (ton/acre)	Value of Production ($1000)	Price ($/ton)
United States[1]	144,400	2,100	–	7.3	552,040	525.84
California	130,700	1,829	87.1	7.0	481,551	526.48
Arizona	13,400	268	12.8	10.0	69,843	528.68
Texas	300	2	0.1	3.9	647	554.29

[1] Only three states reported.
Source: USDA/NASS Vegetable Summary 2002.

U.S. broccoli exports in 2000 were over 180,000 metric tons (MT), about 17% of total U.S. production (USDA/ERS, 2001). Japan was the largest consumer with 85,000 MT, followed by Canada with 73,000. Exports of broccoli were valued at over $126 million.

USAGE OF ENDOSULFAN ON BROCCOLI

Over the period 1990 to 1999, approximately 16,000 lbs. of endosulfan was applied annually to about 15,000 acres, representing between 10 and 13 percent of harvested acreage (BEAD, 2000). The trend in recent years has been a decline in both percent of the crop treated and the pounds of active ingredient applied. USDA (2001) reports only minimal usage in 2000, suggesting only two percent of the crop was treated with a total of 2,400 lbs active ingredient (a.i.). While California is the primary producer of broccoli, the state uses a relatively small amount of endosulfan, less than 1,300 lbs a.i. in 2000 and down from over 4,500 in 1998 (Cal EPA). Arizona uses about 1,000 lbs annually, treating over 12% of the area in broccoli (USDA). Texas usage was not reported in 2000, but had, in 1998, been at about the percentage as Arizona, suggesting only about 40 acres treated and just over 30 lbs a.i. used.

Average rates of application for California and Arizona are less than 1 lb a.i./acre, about half the current maximum rate allowable.

Table 2. Endosulfan usage on broccoli, 2000.

State/Region	Harvested Acreage	% Crop Treated	Acres Treated	lbs a.i. Applied	Rate (lbs/acre/year)
United States	144,300	2.0	2,890	2,400	0.8
California	133,000	1.1	1,450	1,280	0.9
Arizona	11,300	12.7	1,440	1,120	0.8

Source: USDA/NASS, 2001; California EPA, 2000.

USE OF ENDOSULFAN ON BROCCOLI

Endosulfan has been important for stand establishment. The preferred formulation is the emulsifiable concentrate (EC). It is applied as a foliar application to young broccoli plants to control whiteflies, thrips, aphids and flea beetles (see Appendix). Use of endosulfan has been declining as many growers have begun using imidacloprid at plant.

In Arizona, broccoli is planted continuously beginning in late August and ending in mid-December. Most broccoli is directly seeded but a small proportion of broccoli is transplanted. Sprinkler irrigation is sometimes used to establish transplants or promote seed germination. Irrigation is then usually switched to furrow. Hand hoeing weeds and thinning seedlings is performed during stand establishment. Harvesting is by hand and begins in mid-November and ends by the beginning of April.

In California, broccoli is both direct seeded and transplanted, but the majority is direct seeded. The coastal areas transplant approximately one third of their broccoli acreage, whereas this proportion drops to approximately 10% in the Desert. Both direct seeded and transplanted broccoli are established by sprinkler irrigation. Once established, broccoli may either be furrow, sprinkler or drip irrigated. California has placed many restrictions on use of endosulfan around water; therefore, usage of endosulfan has sharply declined.

The target margin of exposure (MOE) for hand-harvest and thinning is 9 days for the EC formulation and 14 days for the WP formulation. Low exposure activities, irrigating and scouting, reach their target MOE at day 7 for the EC formulation and 12 for the WP formulation. Since most applications are of the EC formulation, this analysis will focus on those re-entry intervals (REI).

Early in the season, hand hoeing weeds and thinning are critical to establish the stand of broccoli. Seedlings are very susceptible to weed pressure and to get healthy plants started, these activities need to be done at a maximum interval of five days. BEAD believes that, facing a nine-day REI with endosulfan, most growers would switch to imidacloprid at planting to provide about 60 days of protection from these pests. If aphids become a problem later in the season, a foliar application of imidacloprid, dimethoate, or disulfoton are currently available.

There is concern among entomologists that reliance on imidacloprid will result in resistance of insects to this class of insecticides. They would like to maintain a couple of chemistries with which to alternate to manage insect populations. Resistance to imidacloprid by whiteflies is currently being reported in the literature.

ECONOMIC IMPACT ASSESSMENT

Per-acre impacts

A REI longer than 5 days would induce growers to switch pesticides in order to engage in critical activities. A crop budget approach was used to determine the economic impact of a *de facto* cancellation of endosulfan on producers of broccoli. Sample production costs were obtained from the Agricultural Cooperative Extension programs of the University of California. These budgets are reflective of the likely incurred costs, but are not based on cost of production surveys. This analysis assumes that farm gate prices are not affected by any changes at the grower level and that growers do not drastically alter their production practices. We focus solely on operating costs, ignoring overhead and other opportunity costs, as these are difficult to measure. Thus net cash returns overstate actual profits to the grower.

Recent yield and price data, shown above in Table 1, were utilized to determine gross returns per acre. Yields in California have been reported as 7.0 tons/acre over the past several years while prices averaged $526.48/ton (USDA, 2001). Gross revenues are approximately $3,685.50/acre. Table 3 presents gross returns, production costs and net cash returns to broccoli production in the coastal region of California (Smith, *et al.*, 2000). Net returns are similar in the desert areas (Mayberry, 2000). These figures assume an application of endosulfan at transplant of approximately 1 lb a.i/acre that is replaced with imidacloprid, at a rate of about 0.2 lbs a.i./acre. EPA data provides average costs of $12.00/acre for endosulfan and $50.60/acre for imidacloprid, more than quadrupling the cost of pest control at transplant. Assuming no other changes in production costs, this would represent a 1.1% increase in total costs and an 18.6% decrease in net revenues, a loss of $38.60/acre. These prices reflect applications against whiteflies, thrips, aphids and flea beetles. Imidacloprid is used against other pests of broccoli as well. On average, the application rate is about half that used in the table, or 0.1 lbs a.i./acre for a cost of $29.95/acre. This lower rate would increase production costs by 0.5% and lower net revenues by $17.95 or 8.7%. BEAD characterizes these losses as minor to moderate for the grower incurring such losses.

Table 3. Gross returns, production costs and net returns to broccoli production, Monterey County, California, with at-transplant spray for pest complex.

	Base Scenario: endosulfan	Alternative: imidacloprid	% Change
production (tons/acre)	7.0	7.0	0.0
price ($/ton)	526.50	526.50	
gross revenues ($/acre)	3685.50	3685.50	0.0
insecticide costs ($/acre)			
at-transplant			
endosulfan	12.00		
imidacloprid		50.60	321.4
other	112.00	112.00	
other pre-harvest costs ($/acre)	742.00	742.00	
harvest costs ($/acre)	2611.50	2611.50	
total operating costs ($/acre)	3477.50	3516.10	1.1
net cash returns ($/acre)	208.00	169.40	- 18.6

Source: University of California Cooperative Extension, BEAD calculations.

Table 4 provides data from southern Arizona (Teegerstrom and Umeda, 2001). Yields in Arizona average 10 tons/acre while prices are similar to California. Thus, gross revenues in Arizona are substantially higher, about $5,287/acre. Production costs, and particularly insecticide costs, are higher in Arizona as well. Total insecticide costs are over $900/acre. Net returns are still about twice those in California, at about $400/acre. This analysis assumes a grower makes an application of endosulfan during the stand-establishment phase and would prefer to use imidacloprid if faced with a REI of more than 5 days. EPA data does not provide costs for endosulfan on broccoli. We use data from lettuce applications to determine a cost of $8.50/acre for a rate of 0.75 lbs a.i./acre. Imidacloprid is used at a rate between 0.2 and 0.25 lbs a.i./acre for an average cost of $59.65/acre or $51.15/acre more. Overall, this represents a 1.0% increase in production costs and a 12.6% decrease in net revenues to growers who are currently using endosulfan. Similar data from central Arizona (Teegerstrom, *et al.*, 2001), where production costs are substantially lower, indicate smaller impacts (not shown). A similar price increase of imidacloprid over endosulfan would represent a 43.5% increase in insecticide costs and a 1.3% increase in total costs. However, in the base scenario for this county, net returns are almost $1,340/acre and a $50/acre decrease due to higher costs would result in a loss of net returns of 3.8%. Again, such losses by a grower would be characterized as minor to moderate.

Table 4. Gross returns, production costs and net returns to broccoli production, Yuma County, Arizona, with at-plant spray for pest complex.

	Base Scenario: endosulfan	Alternative: imidacloprid	% Change
production (tons/acre)	10.0	10.0	0.0
price ($/ton)	528.70	528.70	
gross revenues ($/acre)	5287.00	5287.00	0.0
insecticide costs ($/acre)			
at-transplant			
endosulfan	8.50		
imidacloprid		59.65	601.8
other	897.00	897.00	
other pre-harvest costs ($/acre)	936.00	936.00	
harvest costs ($/acre)	3040.00	3040.00	
total operating costs ($/acre)	4881.50	4932.65	1.0
net cash returns ($/acre)	405.50	354.35	- 12.6

Source: University of Arizona Cooperative Extension, BEAD calculations.

It should be noted that these results probably indicate an upper bound on grower impacts. Recent data indicates that use of endosulfan has decreased in favor of imidacloprid, despite the drastic difference in price. USDA/NASS (2001) estimates that 42% of the broccoli acreage in Arizona and California are currently treated with imidacloprid. This suggests that there may be some additional benefits to imidacloprid use; for example, it may provide longer control or provide control over a broader range of insects and reduce the need for later insecticide applications. This would mean that the cost increase would be somewhat less than shown here.

Industry Impacts

Endosulfan is used on about 2,900 acres of broccoli, with approximately equal acreage in Arizona and California (see Table 2, above). Two crops of broccoli are frequently grown on the same acreage each year, which may therefore require two applications of insecticide for good stand establishment. We assume this applies to about 80% of the acreage in Arizona and 50% of California acreage. Cost per acre of the change in the REI for endosulfan is about $50 in Arizona, thus the cost/acre/year is $90. In California, the cost per acre of the regulatory action ranges from $18 to $38.60, so total costs range from $27 to $57.90 per acre per year. Multiplying the cost per acre by the acres currently treated with endosulfan results in costs to Arizona of almost $130,000 out of $69.8 million in gross revenues, or 0.2%. California costs range from $39,000 to $84,000 out of $481.6 million, or less than 0.02% of the gross value. Table 5 summarizes these results.

CONCLUSION

The proposed increase in the REI for endosulfan to nine days following its application as an emulsifiable concentrate, which is the preferred formulation, would be equivalent to cancelling the use of endosulfan on broccoli. Endosulfan is used during the stand-establishment period and growers would need to enter their fields for crucial activities such as hand weeding at intervals no longer than five days. Growers would most likely switch to imidacloprid, which would provide them with equivalent control but at an increase in cost of $18 to $38 per acre per cropping period in California and an increase of more than $50 per acre per crop in Arizona. This implies losses in net revenues of 3.8 to 18.6%, which BEAD characterizes as minor to moderate. However, imidacloprid is already widely used, despite its higher cost, and there may be some benefits to its use that are not considered in this analysis.

Table 5. Summary of potential impacts to broccoli production of regulatory action on endosulfan.

	Arizona	California	Total[1]
acres impacted	1,440	1,450	2,890
cost/acre/year[2]	$90.00	$27.00 - 57.90	
total cost	$129,000	$39,000 - 84,000	$168,600 - 213,600
% gross revenue	0.2	0.01 - 0.02	0.03 - 0.04

[1] Does not include potential impacts to other producing states.
[2] Assumes 80% of Arizona acreage and 50% of California acreage is double cropped.
Source: BEAD calculations.

Only about 2% of broccoli acres are currently treated with endosulfan. Thus, industry losses will total around $200,000 annually, less than 0.05% of the gross value of broccoli production.

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Appendix. Target Insects and Control

APHIDS
Green Peach Aphid (*Myzus persicae*), Potato Aphid (*Macrosiphum euphorbiae*), Turnip Aphid (*Lipaphis erysimim*), Cabbage Aphid (*Brevicoryne brassicae*)

Cabbage aphids are the most common species of aphid found on cole crops.

Aphid populations peak during the months of November and December and again during February and March. The majority of aphid damage occurs during the final heading stage of broccoli. Extreme aphid feeding can deplete a plant of enough phloem sap to reduce the plant's vigor or even kill the plant. In addition, as an aphid feeds it excretes phloem sap ("honeydew") onto the plant's surface. This provides an ideal environment for sooty mold infection, which inhibits photosynthesis. Another concern are the viruses that green peach aphids can transmit such as; alfalfa mosaic virus, lettuce mosaic virus and beet western yellows virus. Aphids are most damaging, however, as a contaminant; their presence in a broccoli head will make the head unmarketable.

Biological Control: Parasitoids and predators that attack aphids are available; however, they are usually unable to completely control aphid populations. Lady beetle larvae (syn: ant lions), lacewing larvae, syriphid fly larvae, aphid parasites are some of the insects used to control aphids. These beneficial insects, however, can also become contaminants of broccoli heads.

Chemical Control: A pre-plant application of imidacloprid is the most common method used to control aphids. This insecticide has the added benefit of long term residual control. However, this prophylactic approach to control is expensive and is applied with the assumption that the crop will receive aphid pressure. Many growers will choose to wait and apply a foliar insecticide. When foliar insecticides are used, the timing of application is critical. Endosulfan, dimethoate and imidacloprid are the most frequently used foliar-applied treatments. The initial treatment should occur once aphids begin to migrate into a crop field. To ensure that the harvested broccoli is not contaminated with aphids, it might be necessary to use repeated applications. Aphids often hide within the broccoli's flower heads making insecticide contact difficult. If aphids only occur at the field borders or in isolated areas, border or spot applications may be sufficient to control populations. Insecticide chemistries should be alternated for good resistance management.

Cultural Control: Aphids tend to build up in weeds, particularly cruciferous weeds and sowthistle (*Sonchus asper*), therefore it is important to control weeds in the field and surrounding the field. Fields should be plowed under immediately following harvest, to eliminate any crop refuse that could host aphids.

Alternative Control: Some growers use insecticidal soaps, neem oil soap, neem emulsion, pyrethrins, rotenone dust, plant growth activators, elemental sulfur, garlic spray and diatomaceous earth to control aphid populations.

<u>WHITEFLIES</u>
Sweetpotato Whitefly (*Bemisia tabaci*), Silverleaf Whitefly (*Bemisia argentifolii*)

Historically, whiteflies have not been considered a primary pest but have been a concern because of their ability to spread viral pathogens. More recently, whiteflies have become a primary pest feeding on the plant's phloem and are capable of destroying an entire crop.

Whitefly infestations are usually the heaviest during the fall. Whiteflies migrate from cotton, melon and squash fields, as well as from weed hosts. Broccoli planted downwind from these plants are particularly susceptible. Whitefly feeding removes essential salts, vitamins and amino acids required by the broccoli plant for proper growth. This feeding results in reduced plant vigor, decreased head size and delayed harvest if not controlled at an early stage. As with aphids, the phloem sap that whiteflies excrete onto the broccoli's surface creates an ideal environment for sooty mold infection. Whiteflies also contaminate the harvested broccoli head, making it unmarketable. Still a concern is the whitefly's ability to transmit viruses.

Biological Control: Parasitoid wasps (*Eretmocerus sp.*) can be used to control whitefly populations, however they only parasitize immature whiteflies. Lacewing larvae and ladybug larvae (syn: ant lions) are also used for the control of whiteflies.

Chemical Control: If the crop is planted in August or September, when populations are at their greatest, a soil-applied prophylactic insecticide, such as imidacloprid, is often applied. If broccoli is planted after whitefly populations have declined, foliar-applied insecticides can be used as necessary. Imidacloprid, endosulfan and dimethoate are the most commonly used foliar insecticides. Tank-mixing insecticides helps control whiteflies and prevents the development of insecticide resistance. There is a strong dependence on imidacloprid to control whiteflies which may lead to increased resistance. Further, whitefly resistance to organophosphates and pyrethroids has been noted in the past, thus resistance management is important.

Cultural Control: Whitefly populations are most active in early September and tend to migrate from defoliated and harvested cotton. Delaying planting until populations have begun to decrease and temperatures are lower will help decrease whitefly infestations. However, delaying planting is not always a feasible option. Whiteflies build up in weeds, especially cheeseweed (*Malva parviflora*), thus it is important to control weeds in the field and surrounding the field. Crop debris should be plowed under immediately following harvest to prevent whitefly build up and migration to other fields.

Alternative Control: Some growers use; neem oil soap, neem emulsion, pyrethrins, insecticidal soaps, rotenone, elemental sulfur, garlic spray and diatomaceous earth to control whiteflies

<u>Flea Beetles</u>
Striped Flea Beetle (*Phyllotreta striolata*), Potato Flea Beetle (*Epitrix cucumeris*), Western Black Flea Beetle (*P. pusilla*), Western Striped Flea Beetle (*P. ramosa*)

The color of flea beetles varies between species, but all species have a hard body and large hind legs. When flea beetles are disturbed, their hind legs allow them to jump great distances.

In Arizona, flea beetles are particularly damaging to cole crops. The female flea beetle lays her eggs in the soil, on leaves, or within holes and crevices in the broccoli plant. Depending on the species, the larvae feed on the leaves or the roots of the broccoli plant. The adult beetles will also feed on the broccoli plant, chewing small holes and pits into the underside of leaves. These insects are the most damaging during stand establishment. Even a small population can stunt or kill a stand of seedlings. Mature plants, however, are more tolerant of feeding and rarely suffer severe damage. If flea beetle feeding damages the broccoli head, the plant is unmarketable.

Biological Control: There are no natural predators or parasites that can effectively control flea beetle populations.

Chemical Control: Methomyl, diazinon and pyrethroids such as lambdacyhalothrin, permethrin and cypermethrin are the most commonly utilized treatments for the control of flea beetles. Methomyl is foliar applied; diazinon and pyrethroids can be foliar applied or chemigated. Chlorpyrifos also has some activity against flea beetles. Diazinon and pyrethroids applied by chemigation have the added benefit of also targeting crickets, grasshoppers and lepidopterous larvae.

Cultural Control: It is important to control volunteer plants and weeds in and around the field that could act as a host for flea beetles. Crop rotation is important; however, flea beetles have a wide range of hosts so not all crops are suitable for rotation. Broccoli fields should be disked immediately following final harvest. It is important that Sudan grass is plowed under within a week of the final harvest, as this crop often harbors flea beetles.

Post-Harvest Control: There are no effective methods for the post-harvest control of flea beetles.

Alternative Control: Some growers use rotenone dust and pyrethrins to control flea beetles. Alternative control of these pests, however, is very difficult.