Citrus Orchard Floor Management 2001-2003: Comparison of a Disk, "Perfecta" Cultivator, and Weed Sensing Sprayer.[1]

Ryan J. Rector[2], William B. McCloskey[2], Glenn C. Wright[3], and Chris Sumner[4]
[2]Department of Plant Sciences, University of Arizona, Tucson, Arizona
[3]Department of Plant Sciences, Yuma Mesa Agricultural Center, University of Arizona, Yuma, Arizona
[4] Yuma County Pest Abatement District, Yuma, Arizona

Abstract

An optical weed sensing sprayer (WeedSeeker) was evaluated for making postemergence glyphosate herbicide applications in a Yuma, AZ lemon orchard. In addition, mechanical (disk and Perfecta cultivator) and chemical weed control strategies were compared. Results were fairly similar; however, the use of the WeedSeeker units combined with a preemergence herbicide (H1) increased weed control three fold compared to disking (D) and perfecta (P1). Additionally, when the WeedSeeker units were used in conjunction with preemergence herbicides, spray volume was reduced by 66% compared to a conventional sprayer and by 57% when used for postemergence applications only. There was a relationship between weed ground cover and the area sprayed by the WeedSeeker units indicating that maximum postemergence herbicide savings will occur at low weed densities or less than 10% groundcover. The use of a sprayer with an improved suspension system allowed for faster spraying speeds than were possible with the tractor mounted sprayer. Weed control was similar for the conventional and the WeedSeeker sprayer. However, yields were variable for both years. Future investigations will include efforts to develop crop budgets based on experimental operations.

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Introduction

Weeds are a significant impediment to the efficient production of Arizona tree, nut and vine crops. Whether orchards are flood, furrow, micro-sprinkler, or drip irrigated, water is a limiting resource in Arizona crop production systems. Several studies in citrus have shown weeds reduce tree crop yields by using irrigation water and other resources (Wright et al., 2003). Both preemergence (McCloskey and Maurer, 1997) and postemergence herbicides can be used to maintain a clean orchard floor. Common strategies include: (1) the exclusive use of postemergence herbicides, (2) a combination of preemergence herbicides to reduce weed emergence and postemergence herbicidesto control weeds that escape the preemergence herbicide, (3) the exclusive use of mechanical tillage or (4) some combination of herbicides and mechanical tillage. Preemergence herbicides must be incorporated and are usually broadcast on the entire orchard floor since growers do not know where weeds will emerge. Growers with drip irrigated or micro-sprinkler irrigated orchards have a difficult time adequately incorporating preemergence herbicides and are often reduced to trying to predict when significant rainfall will occur. Mechanical incorporation with a disk or Perfecta field cultivator can prune feeder roots near the surface of the soil, especially in flood-irrigated orchards, while water incorporation is feasible only in flood irrigated orchards. The degree of root injury increases when mechanical weed control equipment is used to control weeds growing close to the tree. Careless operation of equipment can also result in tree damage (i.e., broken branches and injured trunks) that can provide an entry point for plant pathogens (Matheron et al., 1998). In addition to damaging roots and trees, mechanical weed control strategies such as disking and use of the Perfecta field cultivator, incorporate and bury weed seeds in the soil inducing seed dormancy and bring buried seed to the soil surface breaking their dormancy and priming them for germination (Ross and Lembi, 1999). In addition, mechanical weed control, particularly disking, buries weed biomass into the soil and creates breeding habitat for the Liohippelates eye gnat, *Liohippelates collus*, which is quite annoying to homeowners and workers in citrus orchards (Metcalf and Metcalf, 1993). As a result of these considerations, postemergence herbicides, especially glyphosate (e.g., Roundup), have become popular tools for weed control in Arizona tree crops. Although some Roundup foliar injury can result from incidental contact with bearing citrus trees, this injury does not cause yield losses or result in permanent injury to mature trees (McCloskey and Wright, 1998).

The advantages associated with the use of postemergence herbicides without tillage include not disturbing the soil profile and stimulating weed emergence, having the ability to select an herbicide based on the type of weeds in the orchard, and being able to spray herbicide only where weeds are present. Currently, tree crop growers in Arizona choose between broadcast applications of postemergence herbicides to the entire orchard floor or spot spraying weeds. Broadcast applications waste chemical by spraying bare ground and require more mixing and loading operations, especially when weeds are small and percent ground cover is low. Spot spraying is slow and incurs high labor costs. An ideal solution to this dilemma would be to use a sprayer that could optically distinguish between weeds and bare ground and only spray when and where weeds are present. One such sprayer, the NTech WeedSeeker sprayer that utilizes infrared light to detect chlorophyll, was found to reduce herbicide use up to 60% at 20% weed ground cover and up to 86% at 5% weed ground cover (Hanks and Beck, 1998).

While many different orchard floor management strategies are used, there is no consensus as to which regime results in the greatest yield and tree growth and the most cost effective weed control. Arizona tree crop producers need more information regarding the use of the Perfecta cultivator and currently do not use weed-sensing sprayers. Thus, the objectives of this project are; 1) to evaluate the effect of the Perfecta cultivator on tree yields and eye gnat populations, 2) to evaluate the potential for reduced herbicide use in Arizona tree crops with the NTech Weed Seeker sprayer; 3) evaluate the utility of the WeedSeeker sprayer used in conjunction with preemergence herbicides or the Perfecta, and 4) collect tree yields and field operational data in order to develop crop budgets and determine the economics of using the Perfecta cultivator and the WeedSeeker sprayer technology.

Materials and Methods

The experiment was started on May 6, 2001 in a flood-irrigated, Limoneira 8A Lisbon on *Citrus macrophylla* rootstock , lemon grove planted in spring 1998. Location of the grove was on the Yuma Mesa (soil series: Superstition Sand) and the grove was managed by Glen Curtis, Inc. Experimental design was randomized complete block with six blocks. Each plot (i.e., experimental unit) consisted of a row of 10 trees and the tree middles on either side of the tree row. Adjacent plots were separated from each other by a row of trees that provided a buffer between plots. The experimental treatments were:

1. (D) Disk only: the treated orchard floor was disked in two directions (east-west and north-south) with a standard orchard disk. Weeds at the base of the trees were spot sprayed with herbicides.

2. (P1) Perfecta field cultivator: the treated orchard floor was cultivated in two directions with a "Perfecta" cultivator, depending on weed growth. Weeds at the base of the trees were spot sprayed with herbicides on an as needed basis.

3. (P2) Perfecta field cultivator plus broadcast herbicide (Surflan + Solicam applied in the fall): the treated orchard floor was cultivated in both directions with a "Perfecta" cultivator (at the same time as treatment P1), depending on weed growth. Pre- and post-emergence herbicides were used to control weeds as needed. Postemergence herbicides were applied with the WeedSeeker sprayer. Weeds at the base of the trees were spot sprayed with herbicides on an as needed basis. Comparison of this treatment with treatment 2 (P1) was designed to evaluate the possible effects of root damage caused by the "Perfecta" cultivator. The WeedSeeker was used to spot spray weeds in the uncultivated strip.

4. (H1) WeedSeeker postemergence herbicide: the NTech WeedSeeker sprayer was used to spray glyphosate (various formulations of Roundup) on the orchard floor as needed.

5. (H2) Broadcast preemergence plus WeedSeeker postemergence herbicide: Surflan and Solicam were applied in the fall followed by applications of glyphosate (Roundup Ultramax) applied with the NTech WeedSeeker sprayer on an as needed basis.

6. (H3) Broadcast Postemergence herbicide: glyphosate (Roundup Ultramax) was sprayed on an as needed basis using a conventional orchard sprayer.

For each treatment, records of material, equipment, and labor costs were maintained for economic analysis. Emergence cages were used to monitor eye gnat emergence from the soil in treatments D, P1, P2, H1 and H2. Weeds at the base of the trees not controlled by mechanical cultivation were spot sprayed with herbicides in D, P1, and P2. Weed populations were monitored regularly. The growth of mature trees was determined by collecting fruit yield and packout data.

An Olympus Camedia C3030 digital camera mounted 2 m above the ground on a pole was used to take 4 images per plot (32.69 ft^2/image) in treatments sprayed with the WeedSeeker sprayer in 2001 and 2002. A software package, SigmaScan from SPSS Science Software, was used to digitally analyze the ratio of green picture pixels to non-green pixels and calculate percent ground cover. In 2003, a Minolta 7Hi digital camera, instead of the Olympus camera, was used to take three images per plot. The new camera was mounted on a pole at a height of 2.43 m. This height, coupled with the extended viewing capability, increased the image area to 72.4 ft^2 thus decreasing the number of images needed per plot. Despite the increased area per image taken by the camera, new problems were created. Due to the height of the pole, ambient light interfered more with the image quality compared to the original setup with the lower pole. This occurred for the pictures on February 19, 2003 and resulted in the images not being usable for analysis of percent groundcover. However, the use of polarizing and green color enhancing filters mitigated the problems.

Results and Discussion

In April and May of 2001, a sprayer with a 16 gallon tank, diaphragm pump, and a side and rear boom was constructed and mounted on a 50 hp tractor (John Deere 2240). NTech WeedSeeker spray units were mounted on the side and rear booms and cables were routed to a control computer mounted near the driver's seat. The side boom contained spray units mounted at angles (from the end of the boom to the tractor) of 45, 30, 15, 0 and 0 degrees from vertical. This allowed the spray swath to extend about 2 feet beyond the end of the boom. The outside three spray units were protected from tree branches by a shield. The rear boom contained eight WeedSeeker spray units so that the total spray swath was about 13 feet wide.

The orchard floor developed high weed densities in the spring of 2001 for a variety of reasons including our inability to obtain sufficient quantities of Surflan due to manufacturing and supply problems. Thus, the orchard was mowed on May 1 to reduce weed height and the orchard was irrigated. At this time, the experiment was reconfigured and converted from three to six blocks by reducing plot size, and the treatments were re-randomized Several problems during spraying on June 6 and 8 precluded comparing spray volumes in treatments sprayed with the conventional sprayer versus those sprayed with the WeedSeeker spray units. However, observation of the spray patterns and the red LED lights on each WeedSeeker unit indicated that the units were spraying intermittently and applying less spray volume compared to the conventional sprayer. After experimenting with different WeedSeeker sensitivity settings, it was determined that setting the soil background needed to be performed in the field with the boom under the tree canopy and that the ideal sensitivity setting for the units was 4 on a scale of 1 to 10 with 1 being the most sensitive. Without doing this, the boom intermittently sprayed shadows and darker soil under the tree canopy. Additionally, several problems were identified with the NTech WeedSeeker sprayer during the June spray operations. The diaphragm pump could not produce sufficient pressure or spray volume, the small spray tank required frequent mixing and loading operations, the 0 to 10 GPM (gallons per minute) flowmeter used was not sensitive enough to measure the small flow rates that were observed, the lack of a suspension system limited tractor speed, and the tractor with the rear mounted sprayer was too long making it difficult to maneuver in the orchard. Thus, a second spray system was constructed using a 65 gallon cone tank, an electric roller pump (10 GPM) and equipped with a 0.3 to 3 gpm flowmeter (Great Plains Industries) in August 2001. This spray system, the NTech computer controller and the previously constructed NTech WeedSeeker spray booms were mounted on a 4 wheel drive Kawasaki Mule equipped with a radar ground speed detector.

The appropriate plots were disked (D) and cultivated with the Perfecta (P1 and P2) on July 17 and 18, 2001 (Table 1a). Several problems were noted at this time. The Perfecta treatments (P1 and P2), particularly P1, still contained substantial living bermudagrass and the soil surface was very non-uniform. In addition, in the other Perfecta and herbicide treatments, there was a large amount of standing, dead weed biomass that would interfere with the application of preemergence herbicides onto the soil surface. Thus, all treatments were disked on July 25, 2001. This resulted in a soil surface free of weed biomass and made the treatments the same with respect to weed competition with the trees. Treatments P2, H1, H2, and H3 were sprayed with Roundup Ultramax on August 22, 2001 and treatments P2 and H2 were sprayed with Solicam and Surflan on August 27, 2001 (Table 1b). Weed growth in the orchard during September and early October prompted Roundup Ultramax applications on October 15, 2001.

The appropriate treatments were disked or cultivated with the Perfecta cultivator on December 4 and 5, 2001 and the herbicide treatments were sprayed on December 6, 2001 (Table 1a and b). The postemergence herbicide treatments were again applied on March 4, 2002 after disking and Perfecta cultivating operations on January 28, 2002 (Table 1a and b). Following cultivation with the Perfecta, disking, and herbicide applications on May 23, May 24 and June 4, respectively, eye gnat emergence from the treatments was monitored using cages placed on the soil surface between June 12 and June 19, 2002. The total numbers of gnats emerging from the disk, Perfecta and herbicide treatments were 614, 12, and 1, respectively, suggesting that the Perfecta cultivator may not provide suitable breeding habitat for *Liohippelates collus*. In July and August of 2002, a new conventional sprayer was built to replace the existing sprayer. A sprayer with dual 65 gallon cone tanks, two diaphragm pumps, and folding wings (20 ft swath width) was mounted on a 34 hp Model L2850 Kubota tractor. The new tractor and sprayer were smaller than the existing sprayer thus improving maneuverability in the orchard. From this point forward, all conventional applications were made with this sprayer with the beginning postemergence application on August 13, 2002 (Table 1b).

On October 24, 2002, treatments H2 and P2 were sprayed with a tank mix of preemergence herbicides, Surflan and Solicam, using the conventional sprayer (Table 1b). An additional postemergence application was performed on November 21, 2002. The combination of the preemergence herbicide applied on October 24th and the postemergent application on November 21, 2002 suppressed weed growth enough that the first postemergence application in 2003 was not performed until February 19, 2003 and the second application was not needed until May 20th (Table 1b). A disking and Perfecta cultivation on June 18, 2003 preceded the July 2, 2003 postemergence application with the final application occurring on August 4, 2003 (Table 1b).

There were differences in spray volume and area treated for all spray dates. On October 15, 2001, treatment H3 was a conventional broadcast postemergence Roundup Ultramax application that sprayed the entire ground surface of each plot, about 0.37 A, using 5.84 gal/plot (Table 2). Roundup Ultramax was applied in treatment H1 using the WeedSeeker spray units which sprayed 0.206 A/plot using 4.17 gal/plot (Table 2). Treatment H2, preemergence herbicides followed by postemergence Roundup Ultramax applied with the WeedSeeker units, had a much smaller percent weed groundcover than H1 and H3 and, not surprisingly, had the smallest area sprayed and spray volume, 0.095 A/plot and 1.92 gal/plot, respectively (Table 2). The Perfecta cultivator treatment P2 was similar to H2, in percent groundcover, spray volume, and area sprayed, because at the time of the October 15th herbicide applications there were no differences in field operations between these treatments since the disking on July 25, 2001. Similar to the October 15, 2001 data, the area sprayed on December 6, 2001 in H2 was smaller than in H1 reflecting the residual weed control provided by the preemergence herbicides in treatment H2 (Table 2). Interestingly, cultivating with the Perfecta just prior to spraying did not reduce the area sprayed as much as on October 15th. We speculate that perhaps this occurred because the rough soil surface texture and dying biomass still present on the soil surface triggered the Weedseeker spray units to spray. Also, on this spray date there was a poor correlation between the weed groundcover calculated from the digital pictures and weed detection and spraying by the WeedSeeker units for unknown reasons.

On the March 4, 2002 application, the area sprayed in treatments H1 and H2 were similar suggesting that the Surflan at 6.0 lb ai/A plus Solicam at 2.5 lb ai/A were no longer providing residual weed control 6.5 months after their application (Table 3). Better year long preemergence herbicide weed control could be obtained by making semiannual residual herbicide applications compared to one annual application. The Perfecta cultivation on January 28, 2002, about a month before spraying, was much more effective in reducing the sprayed area in treatment P2 compared to December 6, 2001 perhaps because irrigation had smoothed the soil surface and uprooted weeds died before spraying. On March 4th, there was a good correlation between weed groundcover calculated from the digital photographs similar to the data collected on October 15, 2001. The weed groundcover data was highly variable on December 6th and to a lesser extent on other dates suggesting that the area of ground photographed in each plot was too small. The spray data from the July 16, 2002 application again indicated that the preemergence herbicides were no longer providing residual weed control in agreement with the March 4, 2002 data (Table 3). There were few differences between treatments on July 16th perhaps due to the cultural and herbicide spray operations that took place between March 4th and July 16, 2002 and the lack of residual preemergence herbicide effects (Table 1 and 3). The area sprayed, spray volume, and weed groundcover in treatments H1 and H2 on August 13 were very similar (Table 4). Two possible reasons for this include the fact that the preemergence herbicide applied to H2 was no longer active and that the orchard floor was mowed a day before the treatments due to excessive growth. However, even with the mowing on August 12th, the spray volume in H1 and H2 were 56 and 60% lower, respectively, compared to H3 (Table 4). The first postemergence herbicide application made after the preemergence herbicides were applied on October 24th was on November 21, 2002. On this date, differences were observed between treatments with P2 and H2 showing the lowest spray volume and area sprayed (Table 4). However, H1 did not have a much higher spray volume or area sprayed compared to H2 which may indicate that the preemergence herbicide was not fully active at this time due to an insufficient number of irrigations needed to move the herbicide into the soil profile.

Treatment H3 had significantly higher spray volume and area sprayed compared to all other treatments on the February 19th, 2003 spray application (Table 5). However, weed groundcover data could not be used to detect differences between treatments due to camera error. On this date, no filters were used on the camera to take images in the plots. The resulting images were washed out from ambient light and thus unusable for calculating percent groundcover. However, from this date forth, a polarizing filter was used to decrease the interaction of ambient light with the plot images. On February 19th, treatment H1 did not have significantly higher spray volume compared to P2 and H2. The authors suspect that the cool temperatures in December and January suppressed weed growth across all plots in the orchard regardless whether or not they received preemergence herbicide. However, differences were seen in weed groundcover, spray volume, and area sprayed between treatments on the May 20th application with treatment H2 having the lowest spray volume (2.39 gal/plot) (Table 5). The differences seen at this application were produced by the effect of the preemergence herbicide applied the previous fall. A possible reason for the increased spray volume in P2 (3.65 gal/plot), even though it received a preemergence application, is due to a Perfecta cultivation on March 24, 2003 which moved the remaining herbicide below the germination line for weeds or, more likely, disrupted the integrity of the herbicide layer. This soil disturbance, coupled with increased soil temperature and release of weed seed from dormancy, produced a higher weed density compared to treatments that were not tilled. Cultivation on June 18th preceded the herbicide application on July 2nd. On this date, P2 had significantly lower values for weed groundcover, spray volume and area sprayed compared to the other treatments due to the short time length between the last cultivation and spraying (Table 6). However, this result was not seen in the next application on August 4, 2003. On this date, P2 had significantly higher weed groundcover with 3.81% compared to 1.63% and 1.94% for H1 and H2.

Several weed control ratings were taken throughout the experiment. A weed control assessment on July 10, 2001 showed that the chemical control treatments, H1 and H2, had superior weed control compared to the mechanical weed control treatments including even P2 which was sprayed at the same time as H1 and H2 (Table 7). Weed control in H3 was not as good as in H1 and H2 probably because there was a longer time interval between herbicide application and the weed control evaluation. Weed control ratings on October 31, 2001, about two weeks after the postemergence herbicide applications, showed that weed control resulting from spraying Roundup Ultramax was similar for the conventional and WeedSeeker sprayers (Table 7). However, all herbicide treatments had significantly higher weed control compared to the mechanical tillage treatments. Comparatively, weed control ratings on July 2nd and July 29, 2003 showed similar results between H1, H2, and H3 (Table 8). However, H1, H2, and H3 weed control was much higher compared to both the disk and perfecta treatments due to the mechanical treatments being performed in June compared to the chemical treatments being performed on July 2nd.

The field was strip-harvested (all fruit removed from the trees) on November 14 and 15, 2001. Fruit yields for each plot were estimated by counting the whole and fractional standard 545 kg wooden bins containing harvested fruit. A 32 kg sample was collected from each bin to determine fruit size and exterior quality. The sample fruit were passed through a trailer-mounted, completely automated photographic fruit sorter (Autoline, Inc., Reedley, CA) on November 16, 2001. The fruits that passed through the sorter were weighed and color, exterior quality (% blemish), and fruit diameter data were optically determined and recorded by a computer that is an integral part of the sorter. There were no significant yield or packout differences between any of the treatments for 2001 due in part to the young age of the trees and because treatments had not been imposed long enough prior to harvest for differences in tree growth to affect treatment yields (Table 9). The 2002 harvest occurred on December 9th. Significant differences were seen for yield with the herbicide free treatment (P1) reporting the highest yield (182.1) and H2 the lowest (159.7 lb/tree) (Table 9). The yield results for both years differ from those of Wright et al. (2003) who reported that a clean culture treatment that used preemergence (Solicam and Surflan) and postemergence (Roundup and Poast) herbicides for weed control had a greater cumulative 3 year yield (11,537 kg/30 trees) than the disk (9,964 kg/tree) or mow treatments (9,600 kg/30 trees). In addition, the clean culture treatment had a significantly greater percentage of fruit in the 115 and larger size category at the first harvest than either the disk or mow treatments thus increasing economic returns to growers. Additionally, the results from this study do not agree with those of Jordan (1981) who reported that Valencia orange tree yields under sprinkler irrigation were 66.9 kg/tree in the absence of weed competition but trees competing with annual weeds or bermudagrass yielded 28.7 and 15 kg/tree, respectively. Tree volume, trunk circumference, leaf area per tree, and length of new shoot growth were also greatest in the absence of weeds and trees competing with weeds were more water stressed than trees not competing with weeds leading to the conclusion that the weeds and trees were competing for water.

In summary, there were consistent trends in the data from different spray application dates. With the use of preemergence herbicides in conjunction with the WeedSeeker spray units (H2), the amount of herbicide and water volume was reduced by 66% compared to the conventional treatment (H3). Even using the WeedSeeker spray units to apply postemergent herbicides (H1) reduced spray volume by 57% compared to the conventional treatment. There was a relationship between weed ground cover and the area sprayed by the WeedSeeker units that indicated the maximum herbicide saving will occur at low weed densities of approximately 10% (Figure 1). The use of the Kawasaki Mule with its superior suspension system allowed for faster spraying speeds than were possible with the tractor mounted sprayer and this also reduced spray volume (H3 versus H1 and H2). Weed control was similar for the conventional and the WeedSeeker spray booms. Future investigations will include efforts to development crop budgets based on treatment experimental operations. The economic evaluation will allow assessment of the long-term benefits of purchasing the expensive WeedSeeker spray units.

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Table 1a. 2001 – 2003 mechanical applications for the experiment in a Yuma, AZ Limoneira 8A Lisbon lemon orchard.

Year	Operation Date	Treatment	Implement
2001	May 5, June 17, July 25, December 4	D	Disk
	May 5, June 17, July 25, December 4	P1	Perfecta Cultivator
	May 5, June 17, July 25, December 4	P2	Perfecta Cultivator
2002	January 28, March 24, July 17, October 14	D	Disk
	January 28, March 24, July 17, October 14	P1	Perfecta Cultivator
	January 28, March 24, July 17, October 14	P2	Perfecta Cultivator
2003	March 24, June 18	D	Disk
	March 24, June 18	P1	Perfecta Cultivator
	March 24, June 18	P2	Perfecta Cultivator

Table 1b. 2001 – 2003 chemical applications for the experiment in a Yuma, AZ Limoneira 8A Lisbon lemon orchard.

Year	Operation Date	Herbicide	Rate	Sprayer Type	Treatment
2001	June 6	Roundup Ultramax	1.13 lb a.e./A	WeedSeeker	P2, H1, H2
	August 22	Roundup Ultramax	1.50 lb a.e./A	WeedSeeker	P2, H1, H2
		Roundup Ultramax	1.50 lb a.e./A	Conventional	H3
	August 27	Surflan + Solicam	2.5 + 2.0 lb a.i./A	Conventional	P2, H2
	October 15	Roundup Ultramax	0.92 lb a.e./A	WeedSeeker	P2, H1, H2
		Roundup Ultramax	0.92 lb a.e./A	Conventional	H3
	December 6	Roundup Ultramax	1.50 lb a.e./A	WeedSeeker	P2, H1, H2
		Roundup Ultramax	1.50 lb a.e./A	Conventional	H3
2002	March 4	Roundup Ultramax	1.12 lb a.e./A	WeedSeeker	P2, H1, H2
		Roundup Ultramax	1.12 lb a.e./A	Conventional	H3
	July 16	Roundup Ultramax	1.50 lb a.e./A	WeedSeeker	P2, H1, H2
		Roundup Ultramax	1.50 lb a.e./A	Conventional	H3
	August 13	Roundup Ultramax	1.13 lb a.e./A	WeedSeeker	P2, H1, H2
		Roundup Ultramax	1.13 lb a.e./A	Conventional	H3
	October 24	Surflan + Solicam	6.0 + 2.5 lb a.i./A	Conventional	P2, H2
	November 11	Roundup Ultramax	1.13 lb a.e./A	WeedSeeker	P2, H1, H2
		Roundup Ultramax	1.13 lb a.e./A	Conventional	H3
2003	February 19	Roundup Ultramax	1.50 lb a.e./A	WeedSeeker	P2, H1, H3
		Roundup Ultramax	1.50 lb a.e./A	Conventional	H3
	May 20	Roundup Ultramax	1.50 lb a.e./A	WeedSeeker	P2, H1, H3
		Roundup Ultramax	1.50 lb a.e./A	Conventional	H3
	July 2	Roundup Ultramax	1.50 lb a.e./A	WeedSeeker	P2, H1, H3
		Roundup Ultramax	1.50 lb a.e./A	Conventional	H3
	August 4	Roundup Ultramax	1.50 lb a.e./A	WeedSeeker	P2, H1, H3
		Roundup Ultramax	1.50 lb a.e./A	Conventional	H3

Note that unless otherwise specified, all Roundup treatments included spray grade ammonium sulfate at a rate of 8.5 lb/100 gallons of spray solution.

Table 2. Percent groundcover, spray volume per plot, and area sprayed during herbicide applications on October 15 and December 6, 2001 in a Yuma, AZ Limoneira 8A Lisbon lemon orchard. Means followed by the same letter within a column are not different at P = 0.05 according to analysis of variance and the Student-Newman-Keuls mean separation test.

Trt Name	Mechanical Treatment	Herbicide Treatment and Sprayer Type	Weed Groundcover[a]	Spray Volume[b]	Area Sprayed
			(%)	*(gal/plot)*	*(acre)*
October 15					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	0.59 ± 0.82 b	2.01 ± 0.84 c	0.099 ± 0.041 c
H1	None	POST Roundup - WeedSeeker	7.47 ± 2.83 a	4.17 ± 0.52 b	0.206 ± 0.026 b
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	1.41 ± 1.33 b	1.92 ± 0.58 c	0.095 ± 0.029 c
H3	None	POST Roundup - conventional		5.84 ± 0.15 a	0.371 ± 0.009 a
December 6					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	11.5 ± 12.6 a	4.37 ± 0.98 c	0.260 ± 0.058 c
H1	None	POST Roundup - WeedSeeker	8.1 ± 6.9 a	5.17 ± 0.65 b	0.308 ± 0.039 b
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	2.03 ± 1.18 a	3.31 ± 0.71 d	0.197 ± 0.043 d
H3	None	POST Roundup - conventional		11.23 ± 0.01 a	0.382 ± 0.00 a

[a]Digital photographs, four pictures per plot, were taken with an Olympus 3030 Camedia digital camera mounted 2 m above the soil surface with a field of view equal to 3.20 m^2 or 34.5 ft^2. Computer software, SigmaScan Pro 5.0, was used to calculate the percent green pixels in each picture which was considered equal to percent weed groundcover.
[b]The output of the sprayers if operated in a continuous spray mode was 15.57 and 20.23 GPA for the conventional and WeedSeeker spray booms, respectively. Sprayer speed was about 6 MPH. The conventional spray boom contained TeeJet DG8003VS nozzles operated at about 35 PSI. The WeedSeeker spray units were operated at a sensitivity setting of 3 and contained TeeJet brass 6503EVS nozzles also operated at approximately 35 PSI.

Table 3. Percent groundcover, spray volume per plot, and area sprayed during herbicide applications on March 4 and July 16, 2002 in a Yuma, AZ Limoneira 8A Lisbon lemon orchard. Means followed by the same letter within a column are not different at P = 0.05 according to analysis of variance and the Student-Newman-Keuls mean separation test.

Trt Name	Mechanical Treatment	Herbicide Treatment and Sprayer Type	Weed Groundcover[a]	Spray Volume[b]	Area Sprayed
			(%)	*(gal/plot)*	*(acre)*
March 4					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	1.61 ± 1.59 a	1.61 ± 0.84 c	0.096 ± 0.050 c
H1	None	POST Roundup - WeedSeeker	3.58 ± 0.87 a	3.24 ± 0.71 b	0.193 ± 0.042 b
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	4.72 ± 2.35 a	3.52 ± 1.17 b	0.210 ± 0.070 b
H3	None	POST Roundup - conventional		10.75 ± 0.00 a	0.382 ± 0.00 a
July 16					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	30.3 ± 19.8 a	3.56 ± 1.06 b	0.212 ± 0.063 b
H1	None	POST Roundup - WeedSeeker	24.8 ± 20.8 a	4.27 ± 0.78 b	0.254 ± 0.046 b
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	24.0 ± 9.47 a	3.88 ± 0.55 b	0.231 ± 0.033 b
H3	None	POST Roundup - conventional		10.75 ± 0.00 a	0.382 ± 0.00 a

[a]Digital photographs, four pictures per plot, were taken with an Olympus 3030 Camedia digital camera mounted 2 m above the soil surface with a field of view equal to 3.20 m^2 or 34.5 ft^2. Computer software, SigmaScan Pro 5.0, was used to calculate the percent green pixels in each picture which was considered equal to percent weed groundcover.
[b]The output of the sprayers if operated in a continuous spray mode was 28.14 and 16.8 GPA for the conventional and WeedSeeker spray booms, respectively. Conventional and WeedSeeker sprayer speeds were about 3 and 6 MPH, respectively. The conventional spray boom contained TeeJet DG8003VS nozzles operated at about 35 PSI. The WeedSeeker spray units were operated at a sensitivity setting of 3 and contained TeeJet brass 6503EVS nozzles also operated at approximately 35 PSI.

Table 4. Percent groundcover, spray volume per plot, and area sprayed during herbicide applications on August 12 and November 21, 2002 in a Yuma, AZ Limoneira 8A Lisbon lemon orchard. Means followed by the same letter within a column are not different at P = 0.05 according to analysis of variance and the Student-Newman-Keuls mean separation test.

Trt Name	Mechanical Treatment	Herbicide Treatment and Sprayer Type	Weed Groundcover[a]	Spray Volume[b]	Area Sprayed
			(%)	*(gal/plot)*	*(acre)*
August 13					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	11.3 ± 5.32 a	4.86 ± 0.29 b	0.296 ± 0.018 b
H1	None	POST Roundup - WeedSeeker	13.0 ± 5.90 a	4.71 ± 0.79 b	0.286 ± 0.048 b
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	13.2 ± 5.9 a	4.35 ± 0.58 b	0.264 ± 0.035 b
H3	None	POST Roundup - conventional		10.75 ± 0.00 a	0.382 ± 0.00 a
November 11					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	0.21 ± 0.07 a	0.89 ± 0.36 c	0.054 ± 0.022 c
H1	None	POST Roundup - WeedSeeker	0.52 ± 0.16 a	1.64 ± 0.41 b	0.100 ± 0.025 b
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	0.43 ± 0.42 a	1.11 ± 0.34 c	0.068 ± 0.021 c
H3	None	POST Roundup - conventional		5.59 ± 0.00 a	0.384 ± 0.00 a

[a] & [b] Refer to Table 3 footnotes.

Table 5. Percent groundcover, spray volume per plot, and area sprayed during herbicide applications on February 19 and May 20, 2003 in a Yuma, AZ Limoneira 8A Lisbon lemon orchard. Means followed by the same letter within a column are not different at P = 0.05 according to analysis of variance and the Student-Newman-Keuls mean separation test.

Trt Name	Mechanical Treatment	Herbicide Treatment and Sprayer Type	Weed Groundcover[a]	Spray Volume[b]	Area Sprayed
			(%)	*(gal/plot)*	*(acre)*
February 19					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	---	3.33 ± 1.51 b	0.202 ± 0.092 b
H1	None	POST Roundup - WeedSeeker	---	3.72 ± 1.31 b	0.226 ± 0.080 b
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	---	2.81 ± 1.32 b	0.171 ± 0.080 b
H3	None	POST Roundup - conventional		5.49 ± 0.00 a	0.377 ± 0.00 a
May 20					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	5.98 ± 2.48 a	3.65 ± 0.42 b	0.222 ± 0.026 b
H1	None	POST Roundup - WeedSeeker	3.72 ± 1.51 ab	3.19 ± 1.24 bc	0.194 ± 0.075 bc
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	2.52 ± 1.75 b	2.39 ± 1.14 c	0.145 ± 0.070 c
H3	None	POST Roundup - conventional		5.59 ± 0.00 a	0.384 ± 0.00 a

[a] Digital photographs, three pictures per plot, were taken with a Minolta 7Hi digital camera mounted 2.43 m above the soil surface with a field of view equal to 6.73 m^2 or 72.4 ft^2. Computer software, SigmaScan Pro 5.0, was used to calculate the percent green pixels in each picture which was considered equal to percent weed groundcover. Percent ground cover for the February 19 spray date was not included due to overexposure to ambient light washing out the images.

[b]The output of the sprayers if operated in a continuous spray mode was 14.56 and 16.8 GPA for the conventional and WeedSeeker spray booms, respectively. Conventional and WeedSeeker sprayer speeds were about 3 and 6 MPH, respectively. The conventional spray boom contained TeeJet TT11002VS nozzles operated at about 35 PSI. The WeedSeeker spray units were operated at a sensitivity setting of 3 and contained TeeJet brass 6503EVS nozzles also operated at approximately 35 PSI. However, The WeedSeeker spray unit tips were changed to TeeJet brass 4003EVS nozzles for the May 20 spraying.

Table 6. Percent groundcover, spray volume per plot, and area sprayed during herbicide applications on July 2 and August 4, 2003 in a Yuma, AZ Limoneira 8A Lisbon lemon orchard. Means followed by the same letter within a column are not different at P = 0.05 according to analysis of variance and the Student-Newman-Keuls mean separation test.

Trt Name	Mechanical Treatment	Herbicide Treatment and Sprayer Type	Weed Groundcover[a]	Spray Volume[b]	Area Sprayed
			(%)	*(gal/plot)*	*(acre)*
July 2					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	0.38 ± 0.16 b	1.34 ± 0.35 d	0.128 ± 0.033 d
H1	None	POST Roundup - WeedSeeker	3.93 ± 2.86 a	2.86 ± 0.39 b	0.271 ±0.037 b
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	3.47 ± 1.20 a	2.45 ± 0.26 c	0.233 ± 0.024 c
H3	None	POST Roundup - conventional		5.98 ± 0.30 a	0.365 ± 0.019 a
August 4					
P2	Perfecta cultivator	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	3.81 ± 1.17 a	1.42 ± 0.38 b	0.143 ± 0.038 b
H1	None	POST Roundup - WeedSeeker	1.63 ± 0.34 b	1.31 ± 0.38 b	0.131 ± 0.038 b
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	1.94 ± 0.92 b	1.23 ± 0.42 b	0.123 ± 0.042 b
H3	None	POST Roundup - conventional		6.89 ± 0.74 a	0.419 ± 0.045 a

[a] Digital photographs, three pictures per plot, were taken with a Minolta 7Hi digital camera mounted 2.43 m above the soil surface with a field of view equal to 6.73 m^2 or 72.4 ft^2. Computer software, SigmaScan Pro 5.0, was used to calculate the percent green pixels in each picture which was considered equal to percent weed groundcover.

[b]The output of the sprayers if operated in a continuous spray mode was 16.74 and 10.53 GPA for the conventional and WeedSeeker spray booms, respectively. Conventional and WeedSeeker sprayer speeds were about 3 and 6 MPH, respectively. The conventional spray boom contained TeeJet TT11002VS nozzles operated at about 35 PSI. The WeedSeeker spray units were operated at a sensitivity setting of 3 and contained TeeJet brass 4002EVS nozzles also operated at approximately 35 PSI.

Table 7. Visual estimation of general weed control in mechanical and chemical control treatments in a Yuma, AZ Limoneira 8A Lisbon lemon orchard. Means followed by the same letter within a column are not significantly different at P = 0.05 according to analysis of variance and the Student-Newman-Keuls mean separation test.

Trt Name	Mechanical Treatment	Herbicide Treatment and Sprayer Type	General Weed Control (% weed control)	
			July 10, 2001	Oct. 31, 2001
D	Disk	None	0 ± 0 d	23.3 ± 8.8 b
P1	Perfecta cultivator	None	12.5 ± 19.4 cd	33.3 ± 20.9 b
P2	Perfecta cultivator	PREE[a] Surflan - conventional PREE Solicam - conventional POST Roundup - conventional	23.0 ± 22.8 c	84.3 ±9.5 a
H1	None	POST Roundup - WeedSeeker	71.7 ± 13.7 a	87.8 ± 3.2 a
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	69.2 ± 69.2 a	94.2 ± 2.8 a
H3	None	POST Roundup - conventional	36.7 ± 12.9 b	88.8 ± 6.4 a

[a]PREE = preemergence herbicide, POST = postemergence herbicide

Table 8. Visual estimation of general weed control in mechanical and chemical control treatments in a Yuma, AZ Limoneira 8A Lisbon lemon orchard. Means followed by the same letter within a column are not significantly different at P = 0.05 according to analysis of variance and the Student-Newman-Keuls mean separation test.

Trt Name	Mechanical Treatment	Herbicide Treatment and Sprayer Type	General Weed Control (% weed control)	
			July 2, 2003[b]	July 29, 2003[c]
D	Disk	None	70.0 ± 8.4 b	9.5 ± 2.3 c
P1	Perfecta cultivator	None	5.8 ± 5.0 c	2.8 ± 1.7 c
P3	Perfecta cultivator in strip along tree line	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	96.7 ± ∩≈∞ a	60.3 ± 28.3 b
H1	None	POST Roundup - WeedSeeker	62.5 ± ‖∑≈∞ b	88.7 ± 4.3 a
H2	None	PREE Surflan - conventional PREE Solicam - conventional POST Roundup - WeedSeeker	70.8 ± ∩←≈‖ b	88.3 ± 6.1 a
H3	None	POST Roundup - conventional	80.0 ± ∩∞≈¬ b	91.7 ± 7.3 a

[a]PREE = preemergence herbicide, POST = postemergence herbicide
[b]July 2nd weed rating was 42 DA spraying
[c]July 29th weed rating was 27 DA spraying

Table 9. Lemon yield and packout percent under disking, Perfecta cultivation, and herbicide orchard floor management regimes.

Treatment	Yield (lb/tree)	Packout (%)						
		63[a]	75	95	115	140	165	200
2001-2002								
Disk	28.1	24.01	26.77	27.17	13.00	6.01	2.09	0.64
H1	33.6	31.07	25.37	22.67	11.99	5.43	2.17	0.90
H2	32.1	29.41	26.00	24.33	11.54	5.49	2.16	0.71
H3	37.5	34.54	25.25	22.76	9.83	4.85	2.00	0.52
P1	40.1	26.70	25.41	22.69	12.36	7.62	3.41	1.26
P2	34.1	35.56	25.64	21.64	9.79	4.72	1.82	0.59
Significance[b]	0.84	0.13	0.93	0.11	0.30	0.10	0.19	0.23
2002-2003								
Disk	167.5	-	19.0	27.5	27.7	16.4	6.7	1.5
H1	163.3	-	22.8	22.0	27.0	16.5	7.6	2.8
H2	159.7	-	23.4	26.4	26.5	14.1	6.0	2.1
H3	164.9	-	23.6	27.1	20.8	16.5	8.5	2.1
P1	182.1	-	20.7	28.0	28.2	15.5	5.8	1.0
P2	175.5	-	17.7	21.8	28.5	18.7	8.7	3.1
Significance[b]	7.78		2.37	2.56	2.63	1.40	1.13	0.75

[a] Number of fruit per box. Data missing for packout % 63 in 2002-2003 is due to fruit being larger.
[b] Significance at P = 0.05 according to the students t-test.

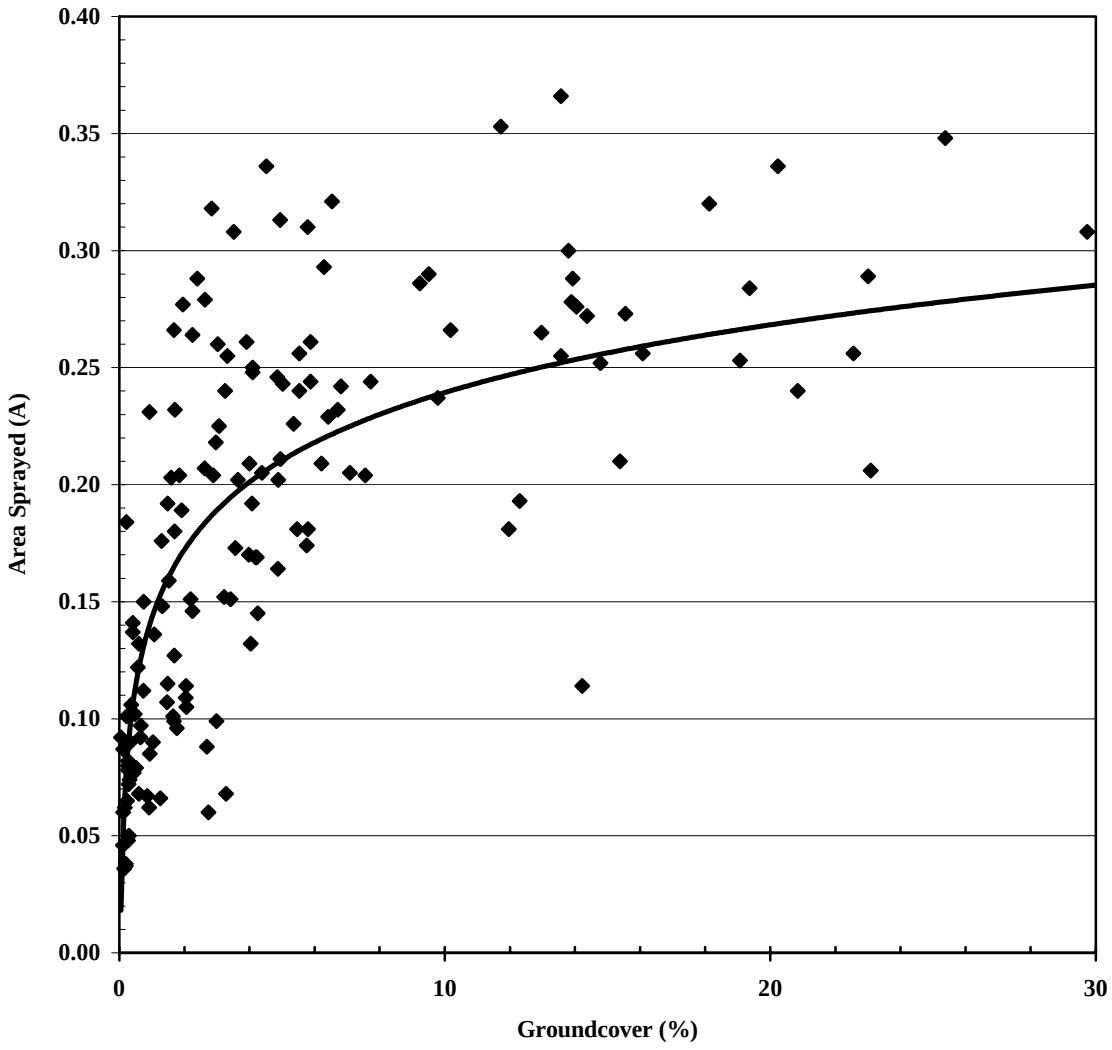

Figure 1. Area of plot sprayed as a function of percent weed groundcover calculated from digital pictures. All spray dates for H1 and H2 were used to generate graph. Maximum area of plot is about .38 acres. Fitted curve is a rectangular hyperbola.