The Road to Automated Weeding of Vegetable Crops. Richard Smith, Farm Advisor, University of California Cooperative Extension, Monterey County

The use of automated weeders is now a reality in the Salinas Valley. Machines being sold or rented for use include the Robovator (manufactured in Denmark) and the Steketee (manufactured in the Netherlands). These machines use cameras to detect plants, a computer to process the image and calculate which plants to keep and which to remove, and a kill mechanism. The kill mechanism used by these two machines consists of a split knife that travels in the seedline removing unwanted plants and opens around 'keeper' plants. Both machines were designed for use in transplanted crops. Given that the transplanted crop plants are initially bigger than germinating weeds, current technology relies on the difference in size between crop plants and weeds early in the crop cycle to distinguish between them. Differences in spectral reflectance of the plants is also used to help distinguish crop plants from weeds. Weed detection technology is developing rapidly and other technologies that are being developed/utilized include deep learning in which images of weeds are used to train the computer to recognize weeds and distinguish them from crop plants. This technology is being used by the Seek & Spray machine, manufactured by Blue River Technology (Mountain View, CA, now part of John Deere Corp.). Crop signaling is another technique being researched by the University of California in which various types of paints, dyes and/or labels are used to mark crop plants making them more readily detectable by automated weeders. Crop/weed recognition is a critical first step in the effective operation of the automated weeders.

The two kill mechanisms in current use have distinct advantages and disadvantages. Split blade machines leave an island of uncultivated soil around the keeper plant. Adjusting the knives to cut closer to the crop plant takes out a greater percentage of weeds, but runs the risk of causing greater damage to crop plants. In four evaluations of split knife machines, there were 5.6% fewer lettuce plants in the split knife cultivated treatments (Table 1). However, based on the skill and experience of the operator, the level of collateral damage and weed control can be managed. In these evaluations, fields cultivated with split knife autoweeders took out about 51.4% of the weeds in the seedline that is left by traditional cultivation and reduced subsequent hand weeding time by 37.1% (Table 1).

The See & Spray autoweeder uses a spray kill mechanism that uses a dot-matrix sprayer that allows for flexible spraying of the seedline around keeper plants. It works by dividing the area to be treated into a grid made up of 0.5 cm x 0.5 cm squares. The computer determines if weed or crop tissue is in each square and decides which squares to treat. This system allows for more pinpoint treatment of weeds and may someday be used to treat weeds in high-density vegetable beds such as spinach and baby lettuce. However, the spray cannot reach under the leaves of the crop plant to take out problematic weeds. It is currently being utilized in cotton where glyphosate resistant weeds are a serious threat to crop production. It is hoped that the Seek & Spray machine will be developed for use on vegetable crops, but vegetable production fields present specific challenges such as greater diversity of crop types and weed species which will require greater development time and investment.

The use of selective herbicide would greatly improve the safety of machines that use a spray kill mechanism and would allow the spray to be applied more closely to the crop plant thereby improving efficacy. It is challenging to find an appropriate selective herbicide for many vegetable crops. Raptor is registered for post emergence use on chicory and we selected it for testing on lettuce, a closely related crop, in 2017. Raptor was compared with Shark which is currently registered for directed post emergence use on lettuce, and is commonly used in lettuce thinning machines. Materials were applied at the concentration used in commercial spray applications and were applied as one droplet/leaf/plant or painted on half a leaf/plant; applications were made in this way to simulate the type of incidental contact that a lettuce plant would encounter with a spray mechanism using the grid method described above. The droplet and half-leaf applications of Raptor had slight chlorosis, while Shark, being a non-selective contact material, caused necrosis to treated tissue (Table 2). There was no statistically significant difference in yield between treatments, but a trend indicates lower yield in the Shark half-leaf treatment.

Autoweeders are being used by commercial growers in the Salinas Valley. They provide a useful measure of weed control in lettuce production. However, they do not remove all weeds and follow up hand weeding must be carried out to get weed control to acceptable levels. However, the subsequent hand weeding operations are quicker and cheaper than non-autoweeded fields. Low to moderate weed populations are necessary to help the machines work effectively; this indicates that a preemergent herbicide is still very important for autoweeders to function effectively with current technology.

Table 1. Evaluation of lettuce stand and number of weeds pre and post mechanical weeding

Evaluation timing	Lettuce plants/A	Weed plants/A		Weeding treatment	Hand weeding hrs/A	Mean Plant wt lbs
Pre weeding	37,361	13,591		With autoweeder	6.1	1.73
Post weeding	35,259	6,600		Without auto weeder	9.7	1.90

Table 2. Phytotoxicity and yield of herbicide treatments

Treatments	Phyto Sept 5	Yield T/A	Mean head lbs
Raptor Droplet	0.1	22.99	1.78
Raptor Half leaf	0.6	23.90	1.85
Shark Droplet	0.5	22.65	1.75
Shark Half leaf	0.9	21.06	1.63
Untreated	0.0	22.77	1.76
Pr>treat	0.0001	0.6220	---
$LSD_{0.05}$	0.3	ns	---