CALIFORNIA LEAFY GREENS RESEARCH PROGRAM

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WEED MANAGEMENT SYSTEMS FOR LEAFY GREENS

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ABSTRACT

The Californian lettuce industry has been largely dependent on either manual labor for hoeing or on one herbicide – pronamide (Kerb) to control weeds. The loss of the Kerb registration for leaf lettuce in August 2009 has seriously reduced the lettuce herbicide options. While some new weed control equipment from Europe has been developed, these systems cannot reliably distinguish between leafy green vegetables and weeds, but rely on a number assumptions (such as the crop plant always being larger than the weed) that may not be reliable in commercial fields, causing the performance to degrade when these assumptions are invalid. As an alternative, we have developed a new concept for an automatic weed control machine based upon taking a systems approach to the problem and using a novel method for distinguishing leafy green vegetable plants from weeds called crop signaling. Our 2015 results show that the crop signaling approach gives nearly 100% recognition rates in automated machine recognition of Iceberg and Romaine lettuce in the presence of weeds.

OBJECTIVES

The long-term goal of this project is to provide leafy vegetable growers with tools and information that leads to cost-effective and labor-efficient weed management systems that will be sustainable in the long-term. Our team at UC Davis, in cooperation with Aginnovation/ Centor Group of Walnut Grove, CA, has developed several novel technologies for creating a unique crop marking system. This new technology temporarily marks the crop for automated machine recognition and differentiation from weeds and does not involve use of biotechnology or transgenes. In this project we will develop and test a machine vision system to identify lettuce plants vs. weeds in real-time from a mobile platform based upon this novel technology.

PROCEDURES

Three trials were performed outdoors in lettuce fields in Salinas in 2015. Trial #1 was initiated on May 13, 2015 and completed on June 5. This time period matches the growth stage when juvenile lettuce plants are most vulnerable to resource competition from weeds in commercial fields. In this trial, three dual pigment crop signaling materials and one single pigment crop signaling material were evaluated. Each material was applied directly to the foliage of Romaine lettuce transplants using a specially designed speckle pattern just prior to transplanting. Digital color photographs of each plant were taken every three days, on average, to evaluate material performance. Crop signal levels were compared to a reference standard to evaluate the in-field stability of the material and its performance under direct sunlight. The performance trend over time was evaluated and used to compare the in-field performance of the different materials.

The 2nd trial was on June 24, and completed on July 30 in Salinas in 2015. In this trial, the crop signaling material was applied to a plant label rather than the plant itself. The plant label is co-located with the crop plant to provide the crop signal, but without direct application of the crop signaling material to the crop itself. Five different label materials were evaluated, each coated with one of three dual pigment crop-signaling materials. The physical robustness of the plant label materials were over a period of 4 weeks and 3 months of direct contact between the label material and moist soil. Materials that showed good mechanical strength after a period of 4 weeks were transplanted into beds in a lettuce field. Digital color photographs of each plant were taken every week, on average, to evaluate material performance. Signal levels were compared to a reference standard to evaluate the in-field stability of the material and its performance under direct sunlight. The performance trend over time was evaluated and used to compare the in-field performance of the different materials.

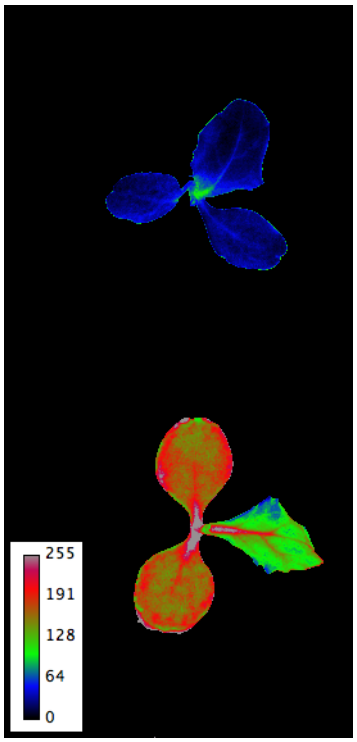
After the field data from the first two trials was evaluated, one of the best crop signaling materials from trial #1 was selected for further study. In this third trial, the foliage of 600 Romaine lettuce seedlings were treated with the orange dual pigment crop signaling material and the seedlings planted in a lettuce field in Salinas in August 2015. Five weeks after transplanting, the field was imaged using the mobile UC Davis crop signal detection system. Computer vision analysis of the digital images collected by this system was performed to evaluate the material's potential for use as a crop indicator for automatic weed control.

In addition to the outdoor trials in Salinas, experiments were conducted at UC Davis to evaluate the crop signaling material performance of two proprietary systemic materials (called A and B) developed by Aginnovation in Iceberg and Romaine lettuce.

RESULTS AND DISCUSSION

The outdoor performance of the dual pigment crop signaling materials when applied directly to the lettuce plant foliage, or to the plant label material was good. While some photodegradation due to sun exposure in the field was observed, the signal level of the dual pigment material remained well above the detection threshold for the entire study period. When applied directly to lettuce foliage, the pink and orange materials had superior performance to red or blue materials. For Romaine lettuce, the orange material had the brightest signal, while the pink material had slightly superior stability over time. In contrast, the signal level of the single pigment material degraded quite rapidly in the field. Additional adjustments to the formulation by the manufacturer would be required for the single pigment material before it would be suitable for the systems approach concept for automated weed control, where the photostability of the material over an 8 to 12 week period when exposed to direct sunlight is required.

(a)



(b)

Fig. 1. The photograph in 1a shows the mobile UC Davis crop signal detection system being operated in a Romaine lettuce field in Salinas in 2015. The machine colorized image in 1b shows an untreated Iceberg lettuce seedling at the top, and an Iceberg lettuce seedling treated with Aginnovation systemic crop signaling material B at the bottom.

The outdoor performance of the dual pigment crop signaling materials when applied to plant label materials was generally similar to that observed in trial #1 when the material was applied to directly to the crop foliage. Some interaction effect was observed showing that a slight variation

in material performance occurred depending upon the choice of plant label material. For example, orange materials were superior when applied to wood or paper-based products, while pink was superior when applied to cornstarch-based products. In general, paper-based plant labels degraded much more quickly than labels made from biodegradable cornstarch based polylactic acid or from biodegradable wood-based products. In this study, the paper-based materials did not have sufficient mechanical strength after 4 weeks of contact with moist soil to be suitable for use in the systems approach concept for weed control. In contrast, both cornstarch-based and wood-based products had acceptable mechanical strength after 8 weeks of contact with moist soil to be used in the systems approach concept for weed control.

The image analysis results from the mobile UC Davis crop signal detection system showed good performance in detecting the crop signaling material 5 weeks after transplanting when the material was applied to the foliage of the lettuce plants prior to transplanting. By five weeks after transplanting, the majority of the lettuce foliage present on the plant has emerged after planting. Reliable detection depended upon two factors, first the treated foliage must still be attached to the plant, and second, the treated foliage must not be hidden beneath untreated foliage. For most plants in the study, at least one leaf was reliably detected on each plant. When two or more leaves were present with the crop signaling material 5-weeks after transplanting, then both the crop detection step and the plant localization steps required for automatic weed control were satisfied. A time-series analysis of the image data from trial #1 showed that the reliability of the method increased as the time after transplanting decreased. The plant label approach was less sensitive to this effect as long as the size of the plant label was larger than the plant at the time of automatic crop detection by the crop signal detection system. When this condition was satisfied, the detection rate of the plant label approached 100%.

The crop signaling performance of two systemic materials provided by Aginnovation were evaluated in 2015. Material performance was evaluated in a number of vegetable crop species and at different crop development stages. We observed that material performance varied across vegetable crop species and growth stages. In lettuce, Aginnovation material A did not give good performance in either Iceberg or Romaine lettuce. The UC Davis crop signal detection system was able to detect the crop signal from Aginnovation material B when applied to Iceberg lettuce. An example image comparing the signal levels in an untreated Iceberg lettuce seedling (automatically colorized in blue at the top of Fig. 1b) to an Iceberg lettuce seedling treated with Aginnovation material B (automatically colorized in red and green at the bottom of Fig. 1b). Untreated weed plants would also appear blue (like the untreated Iceberg lettuce plant in Fig. 1b). As shown in this figure, the systemic behavior of the material varied with growth stage, with superior material distribution occurring at the earlier growth stage, when the cotyledons were present. As the plants get larger, the systemic material appeared mainly in the vascular tissue of the lettuce plant. Additional research is needed to improve the formulation of these systemic materials to allow good performance in both Romaine and Iceberg lettuce and to improve the performance across a wider range of plant growth stages. Material delivery via the seed pellet is an on-going area of research effort by Aginnovation.

Overall, the project demonstrated the in-field practical feasibility of using a systems approach based upon crop signaling as the basis of a smart machine for automatic weed control in leafy vegetables. Plant label-based crop signaling methods had robust in-field performance with detection rates near 100% and with no errors in accidentally misclassifying lettuce as a weed.