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An Innovative Approach to Aphid Mitigation

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Abstract: *Aphid infestations pose a serious threat to the health of many different crops. Presently, controlling aphid populations in crops requires regular spraying with pesticides that in- crease upkeep costs and can have negative environmental impacts if used too liberally. This paper aims to explore an alternative approach to pest control and develops a method for controlling pests using lasers as an alternative to harmful chemicals. Such a system would have no negative environmental impacts and could continue to function without needing to be refilled as long as a steady power supply is available. We hypothesized that A specific exposure duration would be sufficient to kill aphids without harming the host plant. To test this we exposed individual aphids to a 500mw laser for varying durations and recorded mortality rates. A second group of aphids were placed into the same testing apparatus but the laser was not powered on. Our results show that a three second laser pulse is enough to create a significant increase in the mortality rate of the exposed group. Previous studies suggest that this type of laser will not have a negative effect on plant growth, but more research is necessary into the long-term effect that this exposure could have on different species of plants over the course of their lifespan. In the future we will also explore different wavelengths of laser to maximize the aphids absorption of energy while minimizing the absorptivity of the host plant. Our results demonstrate that this approach shows promise as an alternative to conventional pesticides for pest control.*

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I. Introduction

The world population projection for 2050 is over 9 billion people. To feed the world in 2050 our current food production rates will have to double. This increase in food production will be further constrained due to decreasing urbanized arable land, and decreasing rural labor force. On a converging track sustainability is another constraint that is becoming more imperative. Water quality and quantity, soil health, and chemical runoff are restrictions that will dictate factors in food production of 2050.

Corn and sorghum are two important warm season grain crops in the U.S. that totaled over 97 million acres in 2015 [8]. Each year losses from arthropod pests attacking these crops are estimated at around $470 billion [2]. Presently, these pests are managed by using conventional methods like crop rotation, insecticides, and by plant incorporated protec- tants (PIP's) like Bt (Bacillus thurengiensis) in corn. For years, Bt has been an excellent management tool for corn farmers; however, field-evolved resistance to some Bt toxins has developed in several of these key pests and as a result, farmers are using more insecticides, sometimes even in conjunction with Bt to gain control of these pests. Historically, one of the most reliable forms of non-chemical control, rotation with a non-host crop, has failed in portions of the Corn Belt with the western corn rootworm (WCR) now laying eggs in soybeans instead of corn [10]. Both the WCR and some ear-feeding caterpillars have shown resistance to pyrethroids, a widely used insecticide (Pereira et al., 2015). In sorghum, a new pest called the sugarcane aphid has rapidly spread across the central and southern portions of the U.S. since it was first discovered infesting Texas sorghum crops in 2013. Farmers in the sorghum areas of the US as far north as Kansas have lost up to 100 % of their crop due to the aphids' ability to produce mass quantities of their excretion called honey dew which can create severe harvest problems. There is no Bt for sorghum available and only two insecticides are labeled for control of this important new pest. Because the conventional control strategies are failing in some key corn producing areas in the U.S., there is a clear and present need for innovative pest management tools for safe, sustain- able crop production. Over-spray is another proliferating issue that has repercussions on food production, water quality, soil health, and urban interaction. To garner more yields, producers are increasing chemical means to deal with weed and pest species. The quantity of chemical product used is not precisely controlled and meant to adequately cover the crop, which produces unused chemical runoff and added producer cost. The crop could be manually sprayed to precisely control the weeds and pests without over-spraying but would mean an impractical amount of labor and time. Another drawback of chemical use is the affect on beneficial insect species. Insects, such as lady bugs (Coccinellidae) are a natural way of mitigating pests, such as aphids. Automation is at the stage technologically where it can be applied to identify non-wanted plants and/or pests and eradicate them through a variety of means such as spot spraying or laser eradication. This along with advances in robotic vehicles and the new GPS high accuracy satellite being deployed [1] makes automation a very viable next phase of precision pest management in that now we can send a machine to do precise tedious work. Overuse of pesticides can have several negative environmental impacts, while lasers produce no environmentally harmful chemicals. Pesticides also need to be purchased regularly, adding to upkeep costs for farmers. By contrast, a laser pest control system would never need to be refilled and could continue operating indefinitely provided a steady supply of electricity is available. Some work has been done on insect reflectance [9] and laser efficacy [3, 5, 11]. In the case for laser eradication there are two strategies. One strategy is to hit each pest with a point laser. This strategy would be best suited for larger pests and would require a identifying algorithm and target mapping software. The option is to use a plane laser and scour the entire plant with a laser of the right wavelength and intensity as the robotic vehicle goes by. The trick is to not damage the plant. This experiment aims to examine the effectiveness of scourer lasers as a method to control aphid populations. The goal of this research is to find values of laser intensity and exposure duration that will exterminate aphids but leave most crops undamaged. The results of this experiment will factor into the design of a new pest control system for cropland, which uses lasers instead of insecticides. This type of system would have several advantages over a conventional pest control system.

The Aphid laser project is part of a larger vision funded by the Kansas Corn Commis- sion. The project is called CareTaker and was a four year program to develop a pest image algorithm and use it on a small autonomous vehicle that would roam corn fields getting imagery from underneath the canopy and identifying and dealing with processing spotted pests.

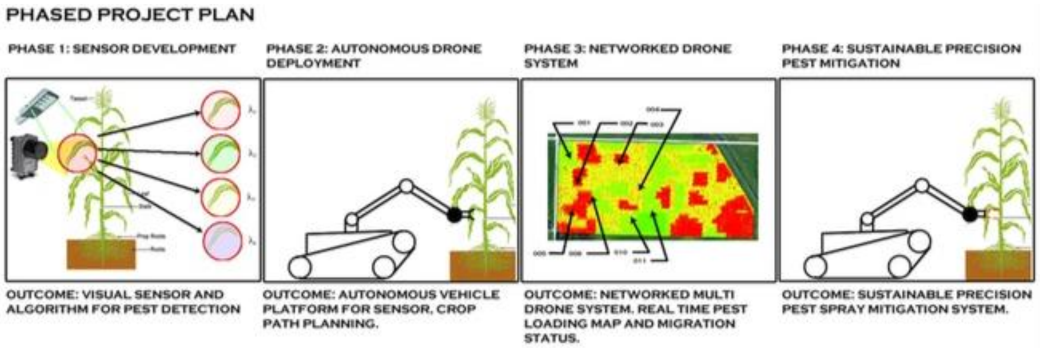

Figure 1: CareTaker project

The destructive impact of a laser on small insects is well established. A series of similar experiments have been performed using fruit flies and have shown success. One study reported a death rate above 99 percent for fruit fly larva exposed to a 60 mW laser for 1282 seconds [4]. A similar study tested two different laser wavelengths of 532 nm and 1064 nm. This study concluded that 532 nm was the more efficient wavelength, requiring an energy density of around 6 KJ/m2 [7]. These results are encouraging, but do not confirm the effectiveness of lasers in exterminating aphids. They also fail to consider the possible harm that could come to the aphids' host plant from laser radiation. There is a separate body of research examining the impact of lasers on plant growth. Results generally seem to indicate that sensitivity to lasers varies for different species of plant. Most of these studies use lasers with power ratings of 5 W or higher, which is much larger than the lasers we used in this experiment. As an example, one study at Aalborg University in Denmark used a variety of lasers including a 5 W 532 nm laser to treat the apical meristems of three different weed species with the goal of preventing plant growth [6]. They used curve-fitting techniques to construct a dose response model for the impact of their laser on the growth of the plant. They found that the most sensitive of all plants tested required 1.4 J of laser energy directly applied to the apical meristem for 90% effectiveness. Another study using rice plants focused on the leaves instead of the apical meristem, and found that with a 532 nm laser the threshold for influencing the plant was four treatments between 56.6 GW/m2 and 144 GW/m2 [7]. Both of these values are much larger than the power density seen in this experiment. These results are encouraging because they suggest that a smaller 500 mW laser (such as used in the current study) would have little impact on the growth of most plants.

II. Methods

This experiment required equipment and procedures capable of isolating aphids, exposing them to known amounts of laser radiation, and then storing them in a safe and identifiable manner for 24 hours. Testing Apparatus We used a 3D printer to fabricate a small platform with a vertical mount for our 532 nm 500 mW diode laser.

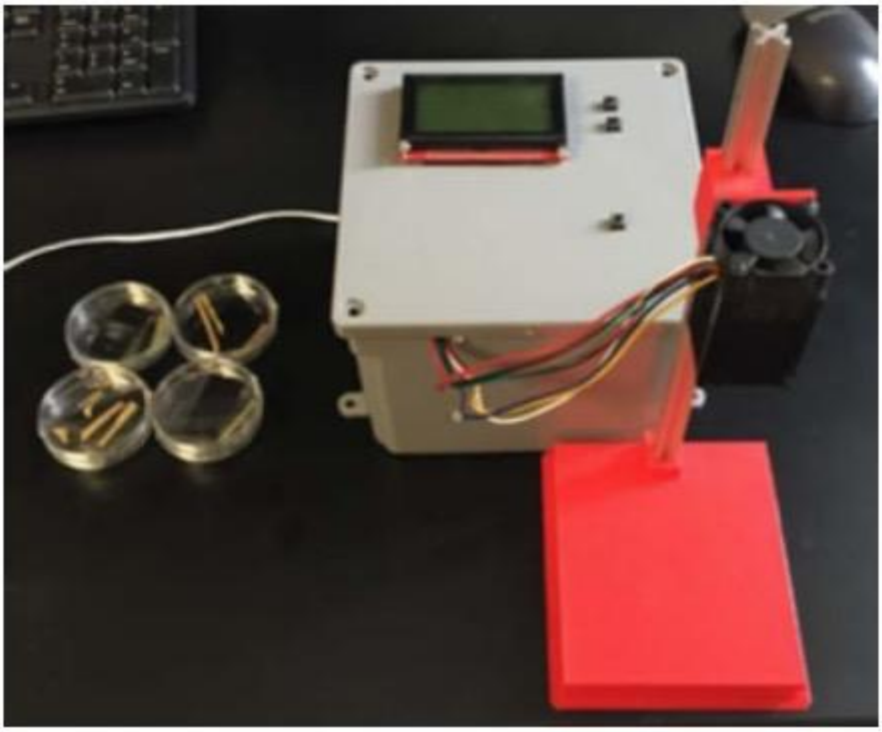

Figure 2: Testing Apparatus

We programmed a microcontroller to interface with a TTL laser driver to control the laser intensity and pulse duration. The operator uses a series of buttons and an LCD display to change these parameters and perform the test. The laser is set to run at 5% power while not delivering a pulse; this produces a dim laser dot that the operator can use to position an aphid directly in the path of the laser beam immediately prior to a test. Figure 1 is a photograph of this setup. We set the laser controller to selected pulse duration from 0.5 seconds to 3.5 seconds, in 0.5 second intervals. Including the control group, this amounts to a total of eight different exposure durations tested in this experiment.

The aphids used in this experiment came from an existing colony of sugarcane aphids (Melanaphissacchari) maintained by the Kansas State University Entomology Department. The colony is tended by ants and kept on greenhouse sorghum plants. The aphids were sampled for testing by using scissors to cut a small section out of the leaf where the aphid was feeding. We then placed each aphid under the laser and performed the test while the aphid was still embedded in the leaf clipping. This procedure creates experimental conditions that closely mimic an aphid on a live plant in the field. After the exposure, we waited 24 hours before recording any data. During this time the aphids were kept in an indoor climate controlled lab and the dishes were not disturbed. We stored them in labeled petri dishes according to exposure duration. The petri dishes were labeled with the time of exposure, duration of exposure, and the total number of live aphids they originally contained. Aphids become discolored upon death, making data collection relatively simple for this experiment. After 24 hours we opened the petri dishes and looked for aphids that were still and discolored. Living aphids were also counted to ensure that all aphids were accounted for.

III. Results

As expected, our results show that increasing exposure duration increases the aphid mortality rate. The results from all tests are shown in Table 1. Figure 1 shows a graph of the mortality rates (deaths/sample population) versus exposure duration. These results clearly show that laser exposure has a significant impact on aphid populations for exposure durations of two seconds and higher. No aphids in this experiment were able to survive exposure times greater than three and a half seconds. After gathering this data, the host plant was exposed to the same set of laser pulses. This allowed for visual inspection the plant to determine whether the laser was capable of causing damage. A marker was used to define seven leaf sections on the host plant, and exposed 6 points in each section to the laser for a duration varying by section. Figure 3 shows the results of this test, with labels added to identify the exposure duration associated with each section. Visual inspection reveals that the laser begins causing spot damage to the host plant after one second exposure duration, with the visible damage worsening as exposure duration increases. We currently have no system to quantify this damage, so in this experiment only visual inspection methods were used to establish the presence and severity of harm to the host plant.

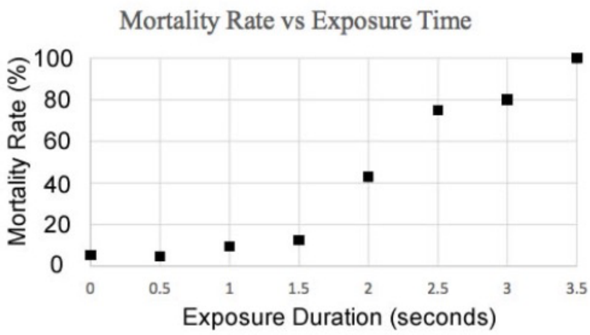

Figure 3: Mortality rate versus exposure duration

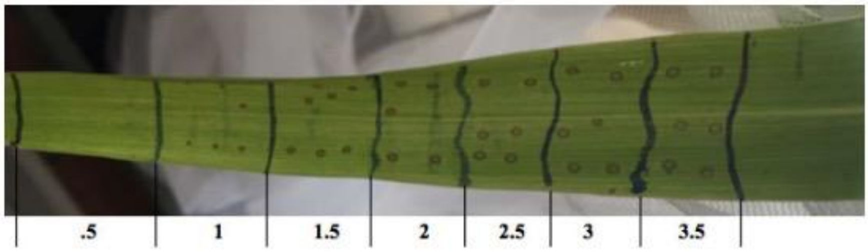

Figure 4: Host plant after laser treatment

IV. Conclusions

These results show that a 500 mW laser and exposure times of two seconds or longer are sufficient to exterminate aphids. However, additional research is needed before lasers will become practical as an alternative to chemical pesticides in agriculture. The resistance of various crops to laser exposure will need to be studied, and a safe delivery system for the laser will need to be designed. Visual inspection of the host plant during this experiment suggested that the laser was capable of causing damage to the leaves, which for the scouring laser strategy poses a problem. The amount of long-term damage caused to a plant is likely to vary drastically based on plant species and laser wavelength. Quantifying this damage for different species of plants and laser wavelengths is beyond the scope of this experiment, and requires exploration in future work. The next phase of this research will involve a search for a wavelength of light that is primarily reflected by pigments in leaves but absorbed by aphids. Using a laser of such a wavelength would minimize the risk of plant damage and potentially lead to the design of a practical laser based aphid control method.

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