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Detection of soybean aphids in a greenhouse using an image processing technique

Mohammadmehdi Maharlooei [a,b], S. Sivarajan [b,*], Sreekala G. Bajwa [b], Jason P. Harmon [c], John Nowatzki [b]

[a] Dept. of Mechanical Engineering of Biosystems, Shahid Bahonor University of Kerman, Kerman, Iran
[b] Dept. of Agricultural and Biosystems Engineering, North Dakota State University, Fargo, ND, USA
[c] Dept. of Entomology, North Dakota State University, Fargo, ND, USA

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ABSTRACT

Soybean aphid (*Aphis glycines*) is one of the most important insect pests of soybeans in North America. Insecticide application is performed if the aphids count exceeds the economic threshold of 250 per plant. Precise estimates of aphid densities are needed for field conditions to maximize insecticide application efficiency. The current method of identifying and counting aphids on a plant is a labor-intensive and time consuming process. The objective of this study was to use image processing technique to detect and count different sized soybean aphids on a soybean leaf. The trials were conducted with soybean plants grown in a greenhouse. Three sets of data were collected on different dates using replicate plants from 4 soybean varieties infested with a range of aphid densities. Images of infested soybean trifoliate leaves were captured with different cameras under 2 different illumination conditions with different cameras used across the different data sets. The images captured were processed in MATLAB™ R2014a software using the Image Processing Toolbox to identify and count aphids. In order to evaluate the accuracy of the algorithm, the aphids counted with the sensing system were compared to a count generated manually by a trained expert. The algorithm counting with SONY™ camera images correlated ($r^2 = 0.96$) very well with manual counts. The misclassification percentage was low for most cameras with different resolutions under high illumination conditions. The results also showed that images captured with an inexpensive regular digital camera gave satisfactory results under high illumination conditions.

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1. Introduction and background

The soybean aphid, *Aphis glycines*, is a serious and damaging insect pest in soybean production systems in Northern America (Ragsdale et al., 2011). The soybean aphid was identified in the eastern part of North Dakota in 2001, one year after it was originally spotted in Wisconsin. Since then, soybean aphids have been detected in many North Dakota fields, and fields with significant infestations are often treated with insecticide to limit yield losses (Glogoza, 2004). High infestations enhance yield loss by up to 40%, and can adversely affect seed size, seed coat quality, pod number, plant growth and height (Ragsdale et al., 2007; Rhainds et al., 2008). Photosynthetic rate can be reduced by as much as 50% in highly infested plants due to soybean aphid feeding (Macedo et al., 2003). Soybean aphids have the ability to reproduce rapidly when conditions are suitable. A single soybean aphid can multiply to 4000 on a plant and reduce seed yield by 38% (Beckendorf et al., 2008). The potential yield loss can be up to 75% for aphid infestations starting at a late vegetative growth stage and up to 48% if the infestation starts at the early reproductive (R2) stage (Catangui et al., 2009). Moreover, a two-year study by Beckendorf et al. (2008) concluded that seed yield, yield components and seed oil concentrations were inversely proportional to the number of aphids and the maximum cumulative aphid days per plant. The economic impact due to yield loss and the additional cost of insecticide usage to treat soybean aphids has been estimated to be around 2–5 billion dollars annually in the United States (Kim et al., 2008; Song and Swinton, 2009).

The connection between yield loss and the size of an aphid population is important for the integrated pest management of aphids (Kieckhefer et al., 1995). One of the most important practices is to avoid applying insecticides until the aphid infestation reaches a certain threshold (Hodgson et al., 2012). This helps diminish the costs and potential adverse effects of unnecessary applications. Soybean producers in North America are commonly advised to avoid insecticides until an action threshold of 250 aphids per plants, which will keep the aphids from reaching the point where

* Corresponding author.
E-mail address: Saravanan.sivarajan@ndsu.edu (S. Sivarajan).

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they will cause economic injury to the soybeans (estimated to be 674 aphids per plant) (Ragsdale et al., 2007; Hodgson et al., 2012). Such insecticide applications based on threshold pest population size have the potential to prevent yield loss and unnecessary insecticide application (Johnson et al., 2009).

Soybean densities vary greatly within and between years, so it is critical to scout and count soybean aphids in each field to get accurate population estimates. For example, soybean aphid infestation levels were very high in north central regions of US in 2003 and 2005, with more than 1000 aphids per plant (O'Neal, 2005). Therefore, intensive scouting and sampling are usually recommended to maximize the efficiency of current management options. Pan trapping is one method that can be used for counting soybean aphids as the log-transformed pan count is strongly correlated to whole plant counts (Hodgson et al., 2005). Speed scouting is another method for counting soybean aphids as the treatment decisions based on speed scouting and those based on whole plant counts were almost the same about 79% of the time (Hodgson et al., 2007). Both of these sampling methods depend on multiple samples over time to assess population growth rates accurately. Both of these methods are also labor-intensive and time consuming, especially when monitoring large commercial fields over time.

Automated methods of counting may more efficiently produce accurate estimates of pest densities, thereby helping manage the pest. Digital image processing techniques for automated detection and counting of crop pests have been studied. Cho et al. (2007) used image processing methods to identify pest insects such as whiteflies, aphids and thrips on crops in greenhouse conditions that utilized size and color of the objects in relation to the background. An automatic and accurate method was developed by Barbedo (2013a,b) to detect and discriminate whitefly nymphs, adults, exoskeletons and lesions in soybean leaves under tested conditions. A digital image processing technique was also able to detect and count the number of brown planthoppers in rice with 70% accuracy (Nutchuda and Mahasak, 2014). Finally, Shen et al. (2007) demonstrated that aphids on soybean leaves could be identified with 98% accuracy by using computer vision technology that used a Hue, Saturation, and Intensity (HSI) color system to separate aphids from leaves.

Though image processing methods are widely used for automated counting of various objects, very few studies have been conducted for detecting and counting aphids on soybean leaves, and even fewer have tested them in different conditions such as using different plant varieties with different color tones or different illumination conditions. The objective of this research was to develop an algorithm based on image processing methods to detect and count soybean aphids on soybean leaves under different illumination conditions, using different image resolutions, and on different soybean varieties. This research provides information about the usefulness of image processing technique in estimating aphid counts on soybean leaves under lab conditions, with the future objective of extending it to field conditions.

2. Materials and methods

2.1. Experimental setup

The research was conducted to evaluate the effectiveness of the digital image technique in a greenhouse under a suite of different conditions. Specifically, we evaluated our technique for counting soybean aphids using 4 conventional soybean varieties developed for use in North Dakota (Sheyenne, Trail, Ashtabula, and Prosoy), a range of aphid infestation rates with low to high levels of infestation based on Economic Threshold, 4 different cameras, and 2 different illumination conditions (high and low). Experiments were performed with different combinations of cameras and lighting across different combination of soybean variety-aphid densities.

The soybean varieties used in this study were chosen to represent different varieties specifically grown in North Dakota. All of them are considered to be susceptible to soybean aphids. Different varieties were chosen to help evaluate potential differences in plant characteristics, such as leaf color that could influence the digital image processing method used to count aphids. The preliminary image analysis for leaf color showed no distinguishable difference between the varieties; therefore varieties were not tested as an independent factor for further statistical analysis.

Varying sized infestations of soybean aphids were created by transferring different numbers of soybean aphids to each plant. Aphid colonies used in the research were originally collected from nearby soybean fields and were maintained in greenhouse colonies using established methods (Whalen and Harmon, 2012, 2015; Ballman et al., 2012). Transfers were performed by taking infested leaves from the soybean aphid colonies and gently attaching them to leaves of uninfested plants that had been grown in the greenhouse within enclosures. Aphids could then detach from the original leaf and walk to the new leaf where they would begin feeding and reproducing.

Different densities of aphids and leaves were attached depending on whether the plant was intended to have low, medium, or high aphid density. The primary goal was to create a spread of different aphid densities across plants, so the exact number of transferred aphids was not controlled. This means that the number of aphids counted at the time of the experiment is only a rough measure of differences in aphid susceptibility among varieties. Aphids were allowed to transfer and reproduce on the new, clean plant for approximately two weeks.

The different image resolutions used in this study were chosen to represent the digital cameras and cell phone cameras commonly available on the market. The high and low illumination conditions were chosen to simulate sunny and cloudy conditions, respectively.

Three sets of data were collected for this study to experiment with different camera, resolutions and illumination conditions, all using a range of aphid densities on our soybean varieties. For the first set of data collection, the four soybean varieties were planted in the first week of May in 2014 and infested with aphids on the last week of May. The same four soybean varieties were planted and infested with aphids later in June for the second set and July for the third set of data. The summary of the data collection used in this study is shown in Table 1.

For the first set of data, leaves of infested plants were imaged using a Canon EOS Rebel T2i DSLR digital camera (Canon Inc, NY, USA). The images were captured under bright illumination condition using a high resolution setting of 18 Mega Pixel (MP). Images were taken from 36 soybean trifoliate leaves (4 varieties at 3 relative infestation rates with 3 replications). The source of illumination was a 1000 W tungsten halogen lamp. The images with other resolutions (12 and 8 MP) and low light condition were created using Microsoft PowerPoint viewer software™ (Microsoft, WA, USA) for this first set of data so as to gather initial knowledge about cameras, camera resolution and light intensity, and to help with the second and third data collection regimes.

For the second set, different cameras and camera resolutions were utilized in order to understand the influence of different sensors and optical elements. Data were collected at 3 camera resolutions: 7 MP, 5 MP and 14 MP. The 7 MP images were captured using Sony DSC-W80 digital camera (Sony Corporation, NY, USA); the 14 MP and 5 MP images were captured using Panasonic DMC-ZS20 camera (Panasonic Corporation, VA, USA.). A 1000 W tungsten halogen lamp was used as the light source with and without a filter (semi-transparent paper) to create high and low illumination conditions. The change in resolution and light