GREENHOUSE AND INDOOR PRODUCTION OF HORTICULTURAL CROPS

Plant Monitoring Using Smartphones in Protected Horticulture

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Protected horticulture involves growing vegetables, ornamentals, fruits and flowers in high tunnels, greenhouses and indoor farms by controlling the growth environment. Monitoring plants and environment is important in protected horticulture due to its intense nature of farming, including high plant density and resource use. Without monitoring, productivity per square foot can decrease, and probable monetary losses can increase from poor plant growth, delayed finishing time, wasted resources and decreased plant quality.

Issues with Plant Monitoring

Monitoring in protected horticulture includes assessing both growth environment and plants. Growers are generally familiar with environmental monitoring using sensors; for example,

for temperature, light and fertilizer concentration. Methods for plant monitoring include visual (for size and color), manual (for height and germination counts) and laboratory (for nutritional disorders).

Visual or manual methods can be inaccurate, and lab methods may not be feasible for large protected horticulture systems. The accuracy of visual assessments depends on a grower's experience, which varies from person to person. Moreover, visual assessments of color are possible only after damage occurs, such as from nutritional disorders. Manual measurements are laborious and may not be precise for such measures as germination counts and plant height. Monitoring can be even more challenging in large-scale operations when thousands of plants are at stake.

Solution to the Problem

Conventional outdoor agriculture may offer a solution to the problem of plant monitoring in protected horticulture systems. With thousands of production acres, plant monitoring is extremely challenging in outdoor farming operations. Among the plant monitoring technologies used in outdoor agriculture, crop imaging using satellites and drones is promising. Using this technology, farmers can assess crop establishment, nutritional status, pest and disease status, and growth and yield. Unfortunately, such technologies are rarely used in protected horticulture, in part because simple and affordable equipment is scarce. Available equipment is high cost, complicated and not suited to confined structures.

Plant Monitoring with Smartphones

At Purdue University, we are developing smart sensing techniques for protected horticulture systems. The techniques use a smartphone to collect plant images and automatically help monitor several plant traits (see details below). Growers capture plant images using the smartphone camera and send images to an online web server. The images are processed by the server and results returned to the smartphone within a few minutes (Figure 1).

The method is highly reliable and easy to use. In large-scale operations, workers can collect images of plants from different locations using their smartphones, thereby increasing monitoring capabilities. For most of the plant measurements, growers need only a smartphone to capture plant images. However, some additional deep measurements (e.g., tissue nitrogen concentration) require special images that can't be captured by a smartphone alone. For these measurements, growers also need a low-cost (<$200) "smart accessory unit." The smartphone is remotely connected to the accessory unit for control.

Using a smartphone to monitor plants has many advantages. The method is highly affordable, flexible, non-destructive and simple. This technique can significantly increase technology adoption in protected horticulture.
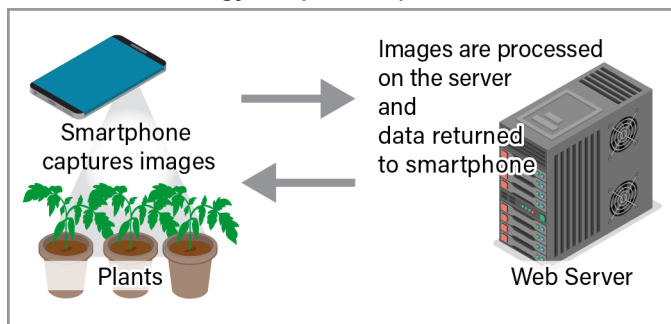

Figure 1. Logic used for monitoring plants with a smartphone.

Four Examples of Plant Measurements Using a Smartphone

Plant Growth

Monitoring plant growth is important for identifying production-related issues, making timely decisions about cultural practices, and ensuring that the crop is uniform and on track for the targeted harvest date. Images of plants captured by a smartphone can be used to estimate the area of green leaves. We found that, for many species, estimated green leaf area is highly correlated with shoot weight (Li et al., 2020). For leafy greens like lettuce, shoot fresh weight is the economic yield. For these species, a smartphone can be used to regularly capture plant images to nondestructively estimate shoot fresh weight.

An example of how to use a smartphone to track the growth of leafy greens is shown in Figure 2. A group of lettuce plants was imaged on different days after transplanting seedlings. From the images, we calculated green leaf area and estimated shoot fresh weight (g) on different days using a predetermined relationship between fresh weight and leaf area. The data were plotted on a graph to compare actual (black line) with target growth rate (orange line).
In this hypothetical example, target growth is the desired fresh weight of plants on a given day based
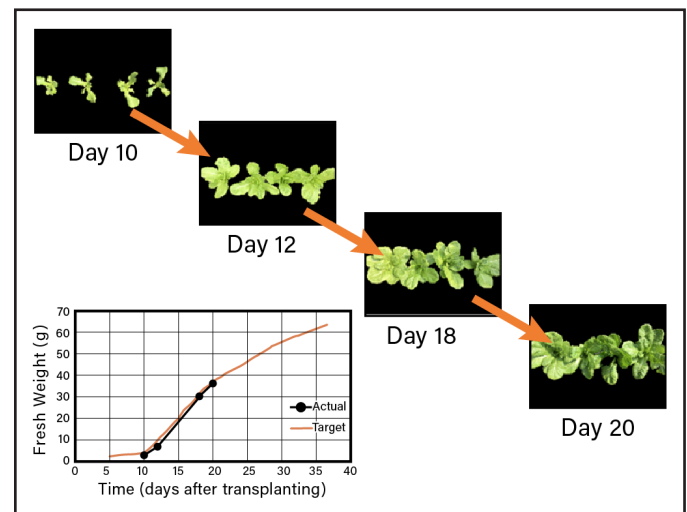

Figure 2. Monitoring lettuce plant growth with a smartphone and comparing actual with target growth.

on information collected from previous growth cycles. In Figure 2, actual plant growth rate is close to target rate, so adjusting cultural practices is not necessary. Similar information can be collected manually by harvesting and weighing plants on different days. However, manual harvests are destructive and time-consuming. A smartphone can nondestructively and automatically generate the information.

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Moreover, plant-growth measurement with a smartphone is more accurate than the destructive measurement, because the same set of plants is measured nondestructively on different days.

Timely and early adjustments to cultural practices are essential for correcting growth-related issues. Identifying small growth differences among plants using visual methods can be difficult. We found from our research that smartphone-based measurements are more effective than visual methods to identify small differences between plants (Li et al., 2019).

In Figure 3, tomato seedlings were grown under optimal and sub-optimal nitrogen treatments. About a week after transplanting, no differences were visually detected among the plants in the two treatments (see images in the top row, Figure 3). However, when images of the plants were processed, the smartphone method indicated a 14.9% increase in plant size for the optimal compared to sub-optimal treatment (see Figure 3).
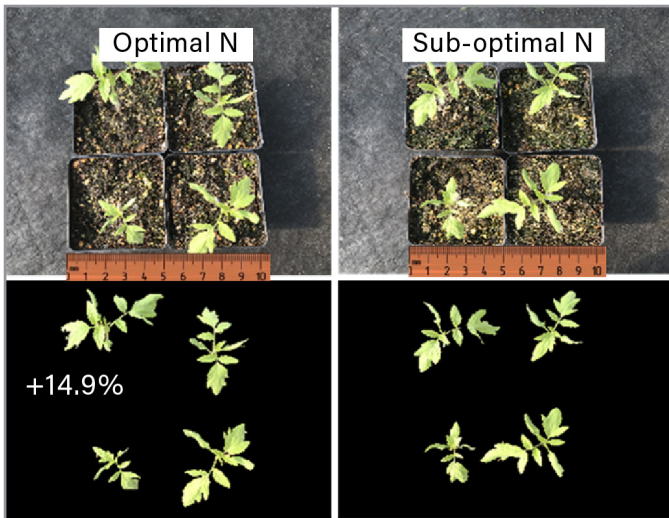

Figure 3. Monitoring small differences in tomato plant growth with a smartphone.

Growers want compact growth for some ornamental plants, such as poinsettia. Plant growth regulators (PGRs) are commonly used to control plant height and width. Growers often measure plant height and width manually, to ensure that PGR treatment is applied at the right time and achieves the expected reduction in growth after treatment. Manual height and width measurements are labor intensive and may not be accurate.

In Figure 4, we used a smartphone to capture side-view images of poinsettia plants grown under normal and mild drought conditions. The images were processed to automatically derive maximum height and width of plants. The method separates plants from the background in the image, identifies the smallest

rectangle that can be drawn around the plants, and calculates width and length of the rectangle to measure plant width and height, respectively (Figure 4).
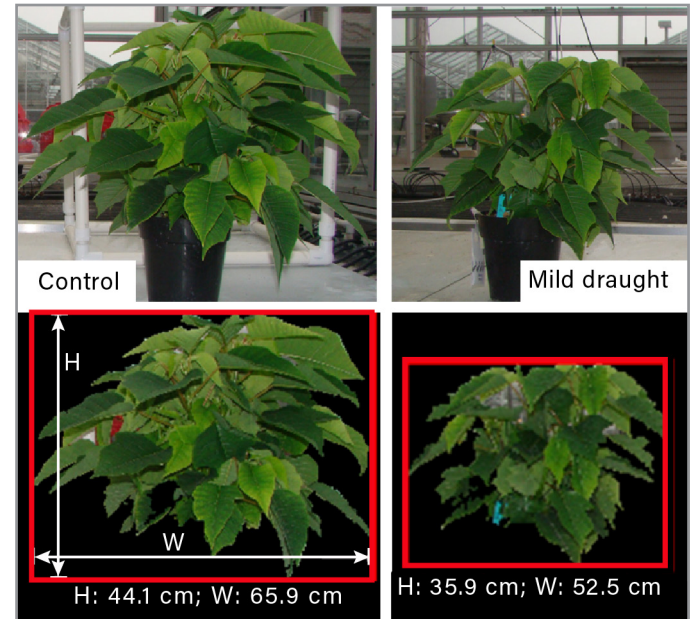

Figure 4. Monitoring height and width of poinsettia with a smartphone.

The image method allowed us to measure height and width rapidly and accurately each time an image was captured. Growers commonly maintain a record of plant height and width measurements for each season. They can use a smartphone and capture images of representative plants, compare their height and width information with the data from previous seasons, and ensure that PGR applications are imposed at the right time and finished plants are compact in appearance. Because the method is rapid, growers can randomly select two or three representative plants per 100 square feet of production area for monitoring.

Germination Percentage
Germination percentage is an important seed-quality trait for seed companies and plug (or seedling) producers. Seed lots with poor germination percentage do not meet certification standards. Customers expect 100% germination without gaps in plug trays. Plug producers must refill ungerminated cells in trays with seedlings. Thus, it is extremely important that plug producers assess germination in trays. Usually, each plug tray contains hundreds of seedlings, and thousands of plug trays are produced in a facility. Manually counting seedlings and calculating germination percentage in trays can take a lot of time.

In Figure 5, a smartphone was used to capture an image of a tray of marigold seedlings. The image was processed to separate seedlings from the background, count germinated seedlings and calculate germination percentage. The smartphone method was able to count germinated seedlings and calculate germination percentage within a few seconds. Seed companies and plug producers can use this method to calculate germination percentage in dozens of trays in a short time and benefit from increased efficiency and accuracy.

Figure 5. Monitoring marigold seedling germination in trays.

Plant Nitrogen (N) Status

Crop growth and quality are affected by plants' N status. Deficiency of N causes leaf yellowing and stunted growth. Excess nitrogen application wastes fertilizer and results in undesirable shoot growth, increased susceptibility to insects and environmental pollution from N runoff. Visual assessment of N deficiency or excess application is possible only after symptoms appear on plants. By the time symptoms are visible, it may be too late to make corrections.

Nitrogen concentration of plants is measured accurately in a laboratory. The process involves collecting leaf samples, shipping samples and analyzing them in a laboratory. The results from lab analyses are sent to growers in approximately three to 10 days and can cost up to $20 per sample. Laboratory analysis thus can be labor-intensive, time-consuming and expensive.

Another indirect approach is to collect leachate from the substrate and assess the concentration of fertilizer ions in the root zone. It can be laborious to collect leachate samples from plants and test using sensors in large-scale operations. This method only indicates overall fertilizer status but does not specifically indicate N status of the root zone.

Unfortunately, there are no affordable, quick and accurate methods to estimate plant N status in real-time. Being able to measure plant N concentration

on smartphones will allow growers to make timely corrections. Moreover, growers can measure plant N status regularly with minimal cost.

Because the estimation of plant N status requires special images, we developed a smartphone accessory unit to enable image collection (see Adhikari et al., 2020). The assessment requires information about the extent of red and near infrared (nir) light reflected from plants. This requires special filters and cameras, which are not available on smartphones. The accessory unit we built for smartphones contains filters, cameras and microcomputers.

When the accessory unit is powered, a grower can control it remotely by their smartphone to capture "required" plant images and save them in a folder. Red and near infrared (nir) images are collected by the accessory unit (Figure 6). The software makes a "mask" from these images and uses the mask to separate plants from the background. The assessment of plant N concentration is based on a previously determined, species-specific relationship between the laboratory-measured N concentration and image-processed value. After images are processed, plant N status information can be visualized on the smartphone (Figure 6).

The process is rapid, and results can be visualized within a few minutes. Our research indicated that plant N concentration could be estimated with approximately 75% accuracy using the smartphone method (Adhikari et al., 2020).
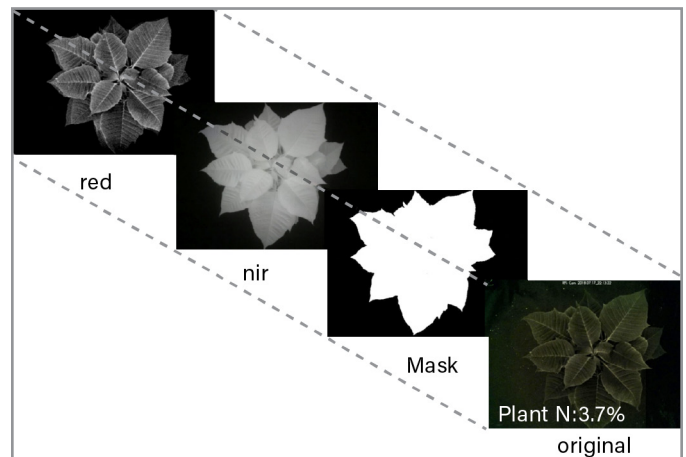

Figure 6. Monitoring plant N status with a smartphone and accessory unit with special filters for red and near infrared (nir) images.

Color Development

Quantifying color development can be quite useful in the ornamental industry. One example is quantifying development of red color of poinsettia bracts. In poinsettia, bract development is nearly complete at the time of sale. Color quantification can help track crop progression to the finishing stage. A slower rate of color development may indicate a sub-optimal growth environment. By tracking color development, growers can ensure that plants are exposed to optimal environmental conditions, and there are no disorders that delay or reduce overall bract/flower development.

The smartphone method can be used to quantify bract or flower color (only red and blue colors) in ornamental plants with green foliage. Figure 7 illustrates a smartphone method used to quantify the proportion of red area (colored bracts) compared to green area (leaves) in poinsettia. Using this method, growers can develop information on the expected color progression during the season. Then they can use such information to track bract color development during production and ensure plants are on track for finishing.

Proportion of bracts 59.4%

Figure 7. Monitoring bract color development in poinsettia with a smartphone.

Conclusions

In this article we presented examples of several plant measurements of economic value that can be made using a smartphone. We are continuously developing new techniques for plant monitoring using a smartphone, and will continue to educate growers about available technologies to monitor plants in their facilities.

Smartphone technologies can be attractive to growers because of their flexibility, precision and low cost. You need minimal training to use a smartphone for plant monitoring. Growers can capture good-quality images and submit images for processing by the web server via the internet. Make sure that only representative plants are included in the images before submitting them for processing. Because the method is rapid, Whones for plant monitoring in their facilities.

References

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