# Use of Reflectance Sensors to Monitor Plant Nitrogen Status in Horticultural Plants

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Nitrogen is an essential element for plant growth and development. It is a major component of chlorophyll in plant leaves. Chlorophyll levels affect leaf area, leaf weight, plant size, and transpiration rate. Too little nitrogen can cause nitrogen deficiency symptoms affecting plant quality, productivity, and salability. Too much nitrogen is not good either, as nitrogen toxicity can occur in overfertilized plants, leading to stunted growth and a poor quality plant. Overfertilizing can be a source of unnecessary extra costs as well as an environmental hazard in the case of nutrient runoff. Four approaches to detect plant nitrogen levels in plants include visual diagnosis, soil-testing, foliar analysis, and use of spectral nondestructive sensors. Reflective sensors represent a new approach showing great potential to provide quick and easy, nondestructive estimates of plant nitrogen status. This fact sheet is designed to discuss some different spectral sensors available in the market, including an overview on operating and usage in a greenhouse.

## Principle

Several sensors have been designed that measure either the reflectance or the absorbance of green color present in the leaves. The greenness of the leaves represents the amount of chlorophyll found in the chloroplasts, which can be used as an indirect indicator for the photosynthetic processes of the plant to determine plant health and vigor. Growers can use this to monitor plant nitrogen levels using sensor readings to determine whether plants need nitrogen fertilization.

Figure 1 shows the spectral absorbance of chlorophyll in living leaves. Chlorophyll has absorbance peaks in two distinct regions: the blue region (400nm to 500nm) and the red region (600nm to 700nm), with no transmission in the near infra-red (NIR) region. Taking advantage of this fact, scientists designed sensors that emit light in the red region and the NIR region. By comparing the reflectance or the absorbance of these transmittances at the two wavelengths, a value is generated that represents green vegetation of the sample. Normalized difference vegetation index (NDVI) is an example of a vegetation index value that is calculated using equation 1. It was proven to correlate with the photosynthetic efficiency, leaf area index, and plants biomass. Those parameters were used to predict productivity and increase plant quality or yield in a number of agronomic crops.

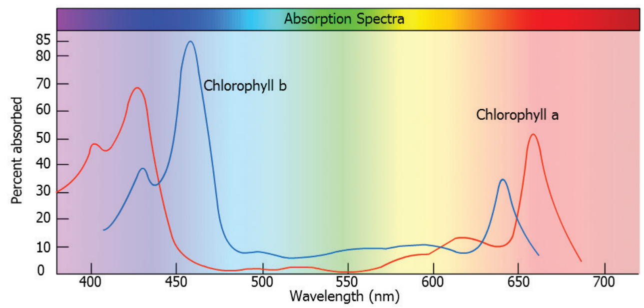


**Figure 1. Spectral absorbance of chlorophyll in living leaves.**

$$\text{NDVI} = \frac{(\text{R} - \text{NIR})}{(\text{R} + \text{NIR})} \quad (1)$$

## Select Sensors on the Market

### GreenSeeker™

A GreenSeeker™ handheld prototype was developed at Oklahoma State University in 2010, and commercially released in 2012 by Trimble Company (Westminster, USA). The GreenSeeker™ handheld sensor is a lightweight, easy-to-use mobile sensor that calculates NDVI and displays it on an LCD screen (Figure 2). The device is nondestructive, affordable, has a long-lasting rechargeable battery, a comfortable hand grip and trigger, and an easy to read display screen. For more features see Table 1.

Readings taken by the GreenSeeker™ correlate strongly with the chlorophyll content of the plant and can be used to make an estimate of plant nutrient status and fertilization needs. The GreenSeeker™ sensor is considered a pioneer in spectral sensors because it is the only sensor to use the reflectance quality of the canopy. This allows the user to take readings for the plant as whole and not just a single leaf.

**Table 1. Optical sensors feature comparison.**

| *Features* | *Greenseeker ™* | *SPAD-502* | *atLEAF+* |
|---|---|---|---|
| Measures | NDVI | Chlorophyll content | Chlorophyll content |
| Measurement system\ wavelength | Reflectance of red (660nm) and NIR (770nm) | Absorbance of red (650nm) and NIR (940nm) | Absorbance of red (660nm) and NIR (940nm) |
| Measured sample | Plant canopy | Plant leaf | Plant leaf |
| Measurement area | 50 cm | 2x3 mm | 9x9 mm |
| Size | 254x89x64 mm | 164x78x49 mm | 164x 78x49 mm |
| Weight | 270 g | 225 g (batteries not included) | 225 g (batteries not included) |
| Price | $495 | $2,200 | $245 |
| Power source | Rechargeable port | 2 AA alkaline batteries | 2 AA alkaline batteries |
| Unit range | 0.0 - 1.0 NDVI | -9.9 to 199.9 SPAD unit | 0 to 99.9 atLEAF unit |
| Time to measure | Less than a sec | Less than 2 sec | Less than a sec |
| Memory capacity | 1 reading | 30 readings | 5,000 readings with names |
| Data transfer | NA | NA | USB with software for Windows |
| Controls | NA | Recall data, delete data, calculate the average of the readings and clear data history | Recall data, delete recent data, clear all data and transfer the data to a PC |
| Error detector | Screen display | Buzzer and screen display | Screen display |
| Other | Auto power off | User calibration function, water resistant | Comes with a software, auto power off |
| Advantages | Senses whole plant, inexpensive, calculates an average | Easy to handle, calculates an average | Measures thick leaves, data transfer to PC, inexpensive |
| Disadvantage | No data memory, no data transfer to P.C., disturbance from background around the pot | Expensive, does not represent whole plant, low memory, no data transfer to P.C. | Not easy to handle, does not represent whole plant, average is calculated after data downloaded. |

Measurements are taken by holding the device at approximately 24 inches above the canopy, and pressing the trigger at the bottom of the device. Normalized difference vegetation index values will appear on the screen instantly. It has two electroluminescent diodes (LEDs), which emit a high intensity light at 660 nm in red and at 770 nm in NIR wavebands. The reflectance of those two wavebands is received by a high-quality active lighting optical sensor. An NDVI value appears on the screen, with values in the range of 0 (no green) and 1 (green), depending on greenness of the leaves. The GreenSeeker™ handheld sensor has been proven to correlate with nitrogen content of plants in field crops and several greenhouse plants. The sensor is capable of generating an average reading for a scanned area by keeping the trigger engaged. This is rather important in field crops and grasses. Trimble offers a fertilizer estimation chart for field crops on their website. Sensor readings are not affected by light intensity, so it can be used in any weather conditions.

For greenhouse growers, this device has some drawbacks; it can only sense the canopy accurately in the vegetative phase, as colors (derived from flowers or coloring bracts) disrupt the readings because of the color reflectance. Another problem would be the background noise that the sensor detects due to its wide field of view. Background noise comes from media


**Figure 2. GreenSeeker™ handheld sensor.**


**Figure 3. SPAD-502 meter.**

in the pot, slow release fertilizer granules, neighboring pots and plants, and water on the floor. This makes the sensing procedure rather restricted; growers cannot use the device after watering, or when pots are spaced close to each other. In fact, growers will probably need to take the pots off the bench and place the pot on the floor to get the 24 inches required height for holding the device. The device is height- and angle-sensitive, and has to be used at a consistent height and at the right perpendicular angle to get comparative readings. Background noise interference makes readings taken in the early stages of establishment uncorrelated to plant nitrogen content. This can affect the success of recovering deficient plants, since fertilizer correction should be done as early as possible. During plant establishment, using multiple pots grouped together is advised to reduce background noise. When comparing readings for different pots, growers need to record the value quickly because it will disappear from the screen after ten seconds, and there is no option for recalling the data or downloading them on a PC. Lastly, even though this sensor showed great results in field crops, it is inconvenient to use for trees, shrubs and vines, and needs some modifications for greenhouses handling.

## SPAD-502

The Soil-Plant Analysis Development (SPAD) meter is a lightweight, portable pocket size device providing an estimation of the amount of chlorophyll present in a plant leaf.

The main features are that it takes nondestructive readings, is highly accurate, quick and easy-to-use, water resistant, has an easy-to-read LCD screen, has a reading checker that detects errors in positioning the leaf, and has a memory space for 30 readings. For this last feature, the developers also included four buttons that enable the user to: recall data, delete data, calculate the average of the readings, and clear data history. For more features refer to Table 1.

Chlorophyll content of a leaf can be estimated by inserting a leaf between the clamps of the SPAD aperture. When the clamps are closed, two LEDs diodes send beams of light at two wavelength regions, red at 650 nm and near NIR at 940 nm. A silicon photodiode measures the absorbance of the leaf. A numerical value is calculated from the optical density difference at the two transmittances, and the value is displayed on the screen within two seconds. Growers can use these readings to make a real-time decision on the need for additional fertilization. Just like GreenSeeker™, SPAD is suitable for use in all weather conditions, but unlike GreenSeeker™, SPAD can be used on larger trees, shrubs, and vines.

The SPAD meter has some negative aspects too; the main one being its high cost ( about $2,200), making it inaccessible for most small operations, growers or landscapers. It has a measuring area of 2 mm by 3 mm, which allows it to be used with smaller leaves, but at the same time, makes it difficult to use on leaves with small widths, like pine trees and some geophytes. The device does not give a whole canopy reading like the GreenSeeker™ does, so to get a plant representative reading, multiple leaves from different parts of the plant should be sensed and averaged. To be consistent when comparing pots, growers have to pay attention to what leaves they are sensing (young or old) and where to position the clamps (at the tip of the leave or at the base closer to the blade) and follow the same pattern. The SPAD meter can hardly sense leaves that are thicker than 1.5 mm (0.05 in). The SPAD meter is manufactured by Konica Minolta Sensing, Inc. (Osaka, Japan), and has been on the market since 2005.

## atLEAF+

The atLEAF+ sensor was introduced in 2013 by FT Green LLC. (Wilmington, USA). It is a nondestructive, low cost, handheld, easy-to-use portable sensor that estimates chlorophyll content of leaves. It is lightweight, simple to use, and has a high memory. For a comparison in features see Table 1.

The device works by inserting the leaf into the aperture, and clicking on the measure button, as shown in Figure 4. The device can measure leaves that are up to 0.1 in (2.5 mm) in thickness. Two LEDs emit light from the upper part of the aperture at two wavelengths, red at 660 nm and NIR at 940 nm. The atLEAF+ sensor uses a similar system as the SPAD meter. A value can be retrieved from the sensor in less than a second on the LCD screen. This device in particular has a distinct feature — it can save up to 5,000 measurements. The device can be programmed through Windows® compatible software that comes with the device, to insert up to 500


**Figure 4. atLEAF+ meter.**

species names that are up to 35 characters long. This makes it easier for growers and researchers who are investigating different species to store their data. It is also convenient that the measurements collected can be transferred to a computer using the USB mode. Users can use the keys on the device to: view stored measurements, delete recent data, clear all data, and transfer the data to a PC. The producers of this device claim that the readings of the device are as accurate as SPAD readings. On their website, there is an atLEAF+ to SPAD conversion application. Recent studies conducted at Northwest Agriculture & Forestry University in China, have shown promising results in canola, potato, corn, wheat, and barley. It is suggested as an inexpensive alternative to the SPAD meter. This sensor is suitable for use on trees, shrubs, vines, field crops, and greenhouse crops.

Some disadvantages of the atLEAF+ sensor are that it also represents a leaf value and not the plant as a whole, so multiple readings in different parts of the plants need to be averaged. Similar to the SPAD meter, for comparative purposes a consistent pattern should be followed regarding leaf position on the plant and sensing position on the leaf. The device's aperture is approximately 4 mm deep, which can cause some problems. First, readings vary with +/- 5 units, depending on whether the leaf was positioned closer to the top part of the aperture or the lower one. Second, this space allows for light to reach the sensor diode and interfere with the reading. Unlike the SPAD meter that clamps over the leaf, and has a filter to clear other wavelengths in the light spectrum, the atLEAF+ sensor has an open space and no filters, which makes readings sensitive to high light exposure. It is also hard to get an average of the readings on the spot, and like the SPAD meter, it is difficult to collect readings on leaves with small widths like conifers.

## Conclusion

Spectral sensors have great potential in monitoring nitrogen needs of plants, and improving their quality. Yet, to fully exploit this technology, the efforts of laboratories, universities, and research centers should come together in order to compile optimum values for horticultural crops. A new iPhone® mobile phone app "Plant Nitrogen Recommendation," which includes a large selection of annuals, perennials, shrubs, trees, turf, and other horticultural crops, has been developed to assist with fertilizer recommendations. With the app you can pick a plant then enter NDVI, SPAD, atLEAF+, or leaf nitrogen values and the app will determine if the plant nitrogen status is sufficient. A free iphone mobile app "Nitrogen Sensor Analysis" will determine if plant nitrogen status is sufficient at different times after planting for several greenhouse crops. The use of sensors coupled with the iPhone® mobile apps, will provide growers a tool to evaluate plant nitrogen status. This can save costs and reduce pollution in the environment. Greenhouse growers using these sensors can increase their financial return by providing a higher quality product, along with an economical fertilizer management plan.

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