

Potential for Boom-Mounted Remote Sensing Applications in Seedling Quality Monitoring

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Abstract: Remotely sensed aerial and satellite sensor imagery is widely used for classification of vegetation structure and health on industrial and public lands. More intensively than at any other time in the life of a planted tree, its health and status will be maintained and monitored while under culture in a bareroot or container nursery. As a case in point, inventories to track seedling root-collar diameter, height, bud development, and merchantability at the University of Idaho Center for Forest Nursery and Seedling Research greenhouses are conducted and discussed bi-weekly. Plant moisture and nutrient status, and the presence of pests and pathogens, are monitored continuously. Many nurseries are equipped with overhead irrigation boom systems designed to deliver fertigation uniformly. Because of their slow speed and complete coverage, these systems provide an opportunistic location on which to mount lightweight, portable sensors for remote seedling quality assessment. We conducted measurements with an ASD Field SpecPro™ radiometer (Analytical Spectral Devices, Boulder, CO) in a laboratory setting to evaluate whether spectral indices used to predict biomass and nitrogen status from tractors in dryland wheat crops might also be capable of detecting differences in nitrogen effects on Scots pine (*Pinus sylvestris*). We regressed the Green Normalized Difference Vegetation Index (GNDVI) on seedling stem mass and the Canopy Chlorophyll Content Index (CCCI) on foliage chlorophyll content. GNDVI explained 77% of the variation in shoot biomass and had an average prediction error (RMSE) of 19% of the mean. CCCI predicted 61% of the variation in foliar chlorophyll content, with an average prediction error of 16%.

Keywords: seedling monitoring, container nursery

Introduction

Remote sensing technology provides a variety of measurement and monitoring tools to forest scientists and land managers. Aerial photography and satellite sensor imagery have long been used to classify vegetation types on large industrial and public lands. Recent advances in sensors, analytical methods used for spectral analysis, the ability of computers to process large amounts of geographic data, and the ready availability of public data sources over the Internet have resulted in the growth of remote sensing into an integral component of natural resource inventory and forest health monitoring (Wulder 1998). Airplane-based and satellite sensor images are commonly used to assess stand structural variables, extent of pest and

pathogen outbreaks, forest successional stage, biomass and Leaf Area Index, and Net Primary Productivity (Tucker and Sellers 1986). In agriculture, hand-held spectral radiometers are also being used to automate quality monitoring in precision crop management. For example, Eitel and others (2008) monitored nitrogen status in dryland wheat crops using a portable multi-spectral radiometer.

The health and status of a bareroot or container seedling will be maintained and monitored more intensively in the nursery than at any other time in its life. While managed forests are rarely inventoried more than once in a 5-year period, nursery inventories to track seedling root-collar diameter, height development, and merchantability are conducted with greater frequency. As a typical example, inventories in the University of Idaho Center for Forest Nursery and Seedling Research (CFNSR; Moscow) greenhouses are conducted bi-weekly; irrigation levels, macro- and micronutrient status, and the possible presence of harmful pests and pathogens are monitored at weekly or daily intervals; and relative root and shoot biomass, bud development, tissue cold hardiness, and root growth potential are of interest throughout the growing season.

Many forestry and conservation nurseries are equipped with automated overhead irrigation boom systems. Overhead irrigation was designed to deliver fertigation to seedlings at a consistent rate and thereby minimize variability in growth characteristics within the crop (Landis and others 1989). The overhead boom is characterized by slow speed, self-propulsion, complete crop coverage, and appropriate height to allow proper water dispersal from the spray nozzles. While these characteristics exist for the purpose of delivering nutrients and moisture to seedlings, they may also make the overhead irrigation boom an opportunistic location on which to mount small, lightweight, portable sensors. In this study, we sought to evaluate whether spectral indices being used to predict biomass and nitrogen status in dryland wheat were also capable of detecting differences in nitrogen effects on Scots pine (*Pinus sylvestris*) seedlings. We regressed the Green Normalized Difference Vegetation Index (GNDVI) on seedling stem mass and the Canopy Chlorophyll Content Index (CCCI) on foliage chlorophyll content. CCCI is a metric that may be useful for detecting plant foliar chlorophyll while simultaneously accounting for differences in plant biomass. Lastly, we also described other boom-mounted remote sensing studies being conducted at the CFNSR.

Methods

Informal and formal research at the University of Idaho CFNSR is evaluating several possible boom-mounted remote sensing applications. During fall 2007, a passive multi-band spectroradiometer (MSR), the CropScan™ (CropScan Incorporated, Rochester, MN) was used to take readings of blue spruce (*Picea pungens*) and ponderosa pine (*Pinus ponderosa*) crops. The CropScan™ is a passive sensor that utilizes incident ambient sunlight to measure the reflectance of particular spectral bands off of crops. While calibration procedures exist, the reliance of this MSR on incoming light provides a challenge for container seedling quality monitoring in a greenhouse environment because greenhouses are

designed to scatter light (Landis and others 1992) throughout the bays from a variety of directions. The large amount of diffuse light inside a greenhouse adds difficulty to sampling with a passive sensor.

During summer 2008, Scots pine seedlings grown by students for a University of Idaho undergraduate Forest Regeneration course were transported to the USDA Agricultural Research Service, Oregon State University laboratory (Pendleton, OR) for spectral analysis. The seedlings were grown in a 1-way factorial experiment with seven levels of fertilizer rate (2.5, 5, 7.5, 10, 12.5, 15, and 17.5 mg). The fertilizer was Osmocote® 18N:6P₂O₅:12K₂O low-start 14- to 16-month controlled release at 21 °C (70 °F) (Scotts-Sierra Horticultural Products Company, Marysville, OH). Seedlings were grown in a 50:50 mixture of vermiculite:forestry grade peat moss (v:v; Sun Gro Horticulture Distribution Incorporated, Bellevue, WA).

For each of 21 total containers, two spectral measurements were taken. The first reading targeted the individual seedling at the center position in the container, with the radiometer positioned 4.5 in (11.43 cm) above the Copperblock™ surface. The second measurement captured several seedlings, and was taken at 35.56 cm (14.0 in) above the container. Seedling root-collar diameter and stem green mass were recorded for the center seedling. Chlorophyll concentration was determined by allowing 0.2 g of foliage to soak in 80% acetone solution for 24 hours and measuring reflectance with a lab spectrometer.

Results

Effect of fertilizer treatments on shoot biomass (green weight) are shown in figure 1. Using ASD Field SpecPro™ radiometer (Analytical Spectral Devices, Boulder, CO) measurements conducted in the laboratory setting with a direct light source, it was possible to predict seedling shoot

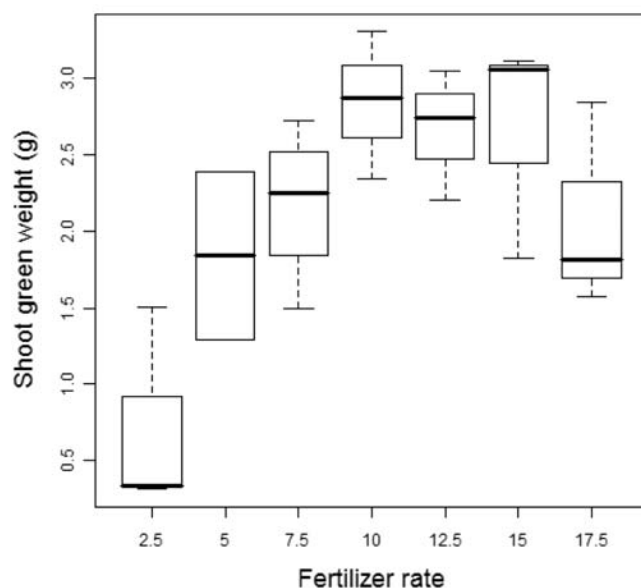


Figure 1. Relationship of fertilizer rate and shoot green weight in first year Scots pine (*Pinus sylvestris*) used in spectroradiometer study.

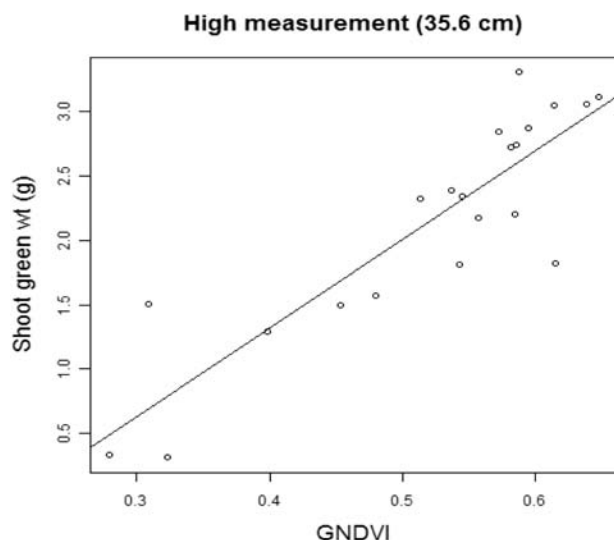


Figure 2. Relationship of GNDVI index and shoot green weight (g) (high measurement 35.6 cm [14 in]).

green weight from the spectral GNDVI index (fig. 2). The simple linear regression of shoot green mass (response) on GNDVI (predictor) had a root mean squared error (RMSE) of 0.41, indicating that the average individual prediction could be expected to vary by this amount. Expressed as a percentage of the mean, this is approximately 19% prediction error. The multiple R^2 for this model was 0.77, and residual plots satisfied linear regression model assumptions. It was also possible to predict seedling foliar chlorophyll content using from the CCCI index (fig. 3). The average prediction error (RMSE) for this model was 0.079 (16% of mean chlorophyll), and the model had a multiple R^2 of

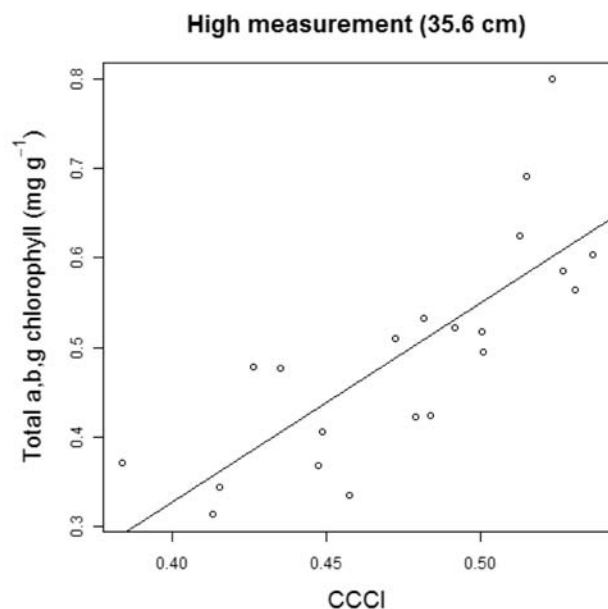


Figure 3. Relationship of total leaf chlorophyll (per gram basis) and CCCI (high measurement 35.6 cm [14 in]).

0.61. For biomass and chlorophyll prediction, the higher spectral measurement (35.56 cm [14 in], rather than 11.43 cm [4.5 in]) provided substantially better prediction than the lower measurement.

Discussion

In this study, we have briefly explored one of many possible examples of nursery seedling quality monitoring using portable remote sensing devices. An additional preliminary experiment currently being conducted at the CFNSR is evaluating the ability of a small laser (the Acuity AccuRange™ 1000 [Schmitt Measurement Systems, Incorporated, Portland, OR]) to measure seedling heights. There are many other possibilities. An advantage of boom-mounted remote sensing applications in seedling quality monitoring is that they are more likely to detect spatial patterns in nursery crops that: (1) may not be visible to growers conducting visual assessments (due to inability to view the crop from above); and (2) may not be detected in inventories based on Simple Random Sampling, 3-P Sampling, and similar probabilistic but non-spatial sampling designs. Spatial patterning in seedling quality in a nursery crop may occur for several reasons. Variation in diffuse light characteristics, differences in temperature due to the positioning of heating and cooling units, and streaking caused by poorly performing spray nozzles may all result in patterns of seedling stress or non-uniformity. A faulty spray nozzle failing to deliver fertilizer rates correctly to a 2-cell wide swath of ponderosa pine seedlings grown in Styroblock™ 160 cell/90 mL (5.5 in³) containers at the University of Idaho Pitkin Forest Nursery would equate to 1,632 seedlings.

New, portable, active spectral sensors that should be able to function robustly in high diffuse-light environments, such as nursery greenhouses, are now available. An example of such a sensor, which will be evaluated in a similar study during the summer of 2008, is the new CropCircle™ multi-band spectral radiometer. Unlike the CropScan™, the CropCircle™ emits its own light pattern that is detected upon return.

Although this technology is readily available, careful development of predictive equations relating appropriate spectral indices to seedling quality parameters of interest will be necessary to make seedling quality monitoring with boom-mounted sensors useful for commercial growers.

References

- Eitel JUH, Long DS, Gessler PE, Hunt ER Jr. 2008. Combined spectral index to improve ground-based estimates of nitrogen status in dryland wheat. *Agronomy Journal* 100:1694-1702.
- Eitel JUH, Long DS, Gessler PE, Smith AMS. 2007. Using in-situ measurements to evaluate the new RapidEye™ satellite series for prediction of wheat nitrogen status. *International Journal of Remote Sensing* 28(18):4183-4190.
- El-Shikha DM, Barnes EM, Clarke TR, Hunsaker DJ, Haberland JA, Pinter PJ Jr, Waller PM, Thompson TL. 2008. Remote sensing of cotton nitrogen status using the canopy chlorophyll content index (CCCI). *Transactions of the ASABE* 51(1):73-82.
- Landis TD, Tinus RW, McDonald SE, Barnett JP. 1989. The container tree nursery manual. Volume 4, seedling nutrition and irrigation. Washington (DC): USDA Forest Service. Agriculture Handbook 674. 119 p.

- Landis TD, Tinus RW, McDonald SE, Barnett JP. 1992. The container tree nursery manual. Volume 3, atmospheric environment. Washington (DC): USDA Forest Service. Agriculture Handbook 674. 145 p.
- Tucker CJ, Sellers PJ. 1986. Satellite remote sensing of primary production. *International Journal of Remote Sensing* 7(11):1395-1416.
- Wulder M. 1998. Optical remote-sensing techniques for the assessment of forest inventory and biophysical parameters. *Progress in Physical Geography* 22(4):449-476.