ASSESSING ALTERNATIVE MEASURES OF TREE CANOPY COVER: PHOTO-INTERPRETED NAIP AND GROUND-BASED ESTIMATES

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ABSTRACT

In preparation for the development of the National Land Cover Database (NLCD) 2011 tree canopy cover layer, a pilot project for research and method development was completed in 2010 by the USDA Forest Service Forest Inventory and Analysis (FIA) program and Remote Sensing Applications Center (RSAC).This paper explores one of several topics investigated during the NLCD pilot. We compared estimates of tree canopy cover derived by photo-interpretation (PI) of 1-m resolution NAIP imagery to modeled estimates based on field-measured tree data collected on FIA plots in five study areas in Georgia, Michigan, Kansas, Utah, and Oregon, and to direct measurements of canopy cover by line intercept on FIA plots in Utah only. Photo-interpreted NAIP overestimated tree canopy cover (+10 to +20 percent canopy cover) at forested FIA plot locations compared with ground-based estimates derived from stem-mapped tree data or line intercept field measurements. Oblique viewing angles at sample locations away from the image nadir, and excessive shadowing in some NAIP images, could be the primary reasons for overestimation of canopy cover by PI. We also examined canopy cover estimates derived from NAIP imagery using an automated algorithm implemented in image processing software, as an alternative to manual PI by humans. This initial test showed that automated PI of NAIP images by image analysis could be a feasible approach for generating canopy cover data at reduced time and cost, but the current rule set exacerbated the problem of overestimation.

INTRODUCTION

The National Land Cover Database (NLCD) comprises a suite of 30-m resolution map layers depicting land cover characteristics for the United States, developed by the Multi-Resolution Land Characteristics Consortium (www.mrlc.gov). The NLCD 2001 product suite included a percent tree canopy cover layer based on circa 2001 LANDSAT imagery. A decadal update to the NLCD 2001 products is scheduled to begin production in fall 2011. In preparation for the development of an NLCD 2011 tree canopy cover layer, a pilot project focused on research and method development was completed in 2010 by the USDA Forest Service Forest Inventory and Analysis (FIA) program and the USDA Forest Service Remote Sensing Applications Center (RSAC).

Mapping tree canopy cover at continental scales involves developing empirical models to relate percent canopy cover from a set of reference locations to predictor variables derived primarily from satellite imagery. Reference data on tree canopy cover can be obtained by different methods including direct field measurements on FIA plots where available (e.g., Interior West FIA line intercept, USDA Forest Service 2007), estimates derived from models based on tree-level data (e.g., stem-mapping, Toney and others 2009), and estimates derived by sampling high-resolution imagery using either human- or computer-based interpretation methods. In addition to differences in cost and processing time, each method of canopy cover observation entails different sources of error and bias relative to other methods. As a result, frequency distributions of tree canopy cover observations across the landscape may differ appreciably among different methods. The distribution of tree canopy cover in the reference data should largely determine the distribution of predicted canopy cover depicted in final map products, assuming reasonably good models.

This paper explores one of several topics investigated during the NLCD pilot. Our objective was to describe characteristics of and relationships between alternative measurements of tree canopy cover for reference locations, specifically, to compare estimates of canopy cover derived by photo-interpretation (PI) of 1-m resolution aerial imagery with estimates derived from field-measured tree data collected on FIA plots. We also examined canopy cover estimates derived from aerial imagery using an automated algorithm implemented in image processing software, as an alternative to manual PI by humans.

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METHODS

COMPARISON OF PHOTO-INTERPRETATION WITH GROUND-BASED CANOPY COVER ESTIMATES

For the PI canopy cover estimates, a grid of PI locations was established across five study areas located in Georgia, Michigan, Kansas, Utah, and Oregon as part of the pilot effort (figure 1). The PI grid was designed as an intensified FIA grid so that a subset of the PI locations was coincident with the FIA sample locations within each pilot area. The aerial imagery used was natural color, 1-m resolution and obtained from the National Agricultural Imagery Program (NAIP) (USDA Farm Service Agency 2009). The PI method used 90 m x 90 m dot grids on 2009 NAIP imagery at each sample location, with 105 regularly spaced points in each grid classified by human interpreters as either tree canopy or not tree canopy. Shadowed areas were left to the interpreter's judgment, and all 105 points in each grid were used for the canopy cover estimate. Percent canopy cover for the dot grid was calculated as the number of points classified as tree canopy divided by 105. In each pilot area, we included only the subset of PI locations that were coincident with entirely forested FIA plots (all conditions on the plot classified as forest), since FIA plots (or portions of plots) classified as nonforest lack any ground measurements from which a canopy cover estimate could be derived. We also included only the FIA plots that had been sampled within two years of the NAIP images (plots measured in 2007, 2008, and 2009 if available) so that the plot measurements would be reasonably concurrent with the NAIP imagery.

Ground-based estimates of tree canopy cover for the forested FIA plots were obtained by stem-mapping individual trees within each plot, and predicting the dimensions of each tree crown from stem diameter using published equations. Details of the stem-map model were described by Toney and others (2009). Canopy cover from the stem-map model is defined as an estimate of the vertically projected canopy cover of live FIA tally trees on the plot that are 1-inch diameter and larger. The stem-mapping approach uses the spatial data on individual trees that are available for FIA plots, unlike the canopy cover estimate in the Forest Vegetation Simulator (Crookston and Stage 1999) which assumes that trees are distributed randomly within the stand for the purpose of overlap adjustment. The stem-map model was developed and validated with line-intercept field measurements of canopy cover (USDA Forest Service 2007) on approximately 12,000 plots from the Interior West FIA unit (Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico). Model predictions were compared to field measurements of canopy cover on 1,454 plots that were not used in model development. The mean absolute difference between field-measured and model-predicted values was ± 7.9 percent canopy cover, with mean bias of -0.7 percent canopy cover. The relationship between field-measured and predicted values was linear with approximately constant variance and a correlation coefficient r = 0.875.

Since field-measured canopy cover was available from Interior West FIA but not from the other regional FIA units, we also compared PI canopy cover with line intercept canopy cover in the Utah pilot area. Line intercept canopy cover in Utah was measured with four 25-foot transects in each of four subplots per FIA plot, arranged in cardinal directions beginning 1 foot from the subplot centers. The length of crown interception of live tally trees was recorded along each transect. Canopy cover was calculated by FIA condition class within the plots, by dividing the total live crown interception length by the total length of transect within each condition (400 feet total transect length in plots where all conditions are forested). For plots in which more than one forest condition was delineated by field crews, plot-level canopy cover was calculated as a weighted average of condition-level canopy cover, weighted by the proportion of the total plot area that each condition occupied. Measurement precision of the line-intercept canopy cover was assessed by FIA using blind check plots during 2000-2003 (Pollard and others 2006). A target tolerance of ± 10 percent canopy cover was specified for the measurement. Blind check data showed that measurements were within tolerance 88 percent of the time, and were within 2x tolerance 99.1 percent of the time (n = 101 plots).

PI canopy cover was compared with ground-based canopy cover (i.e., stem-map modeled canopy cover, along with line intercept field measurements in Utah only) by qualitative analysis of scatterplots. The mean absolute difference was calculated as

$$mean\_absolute\_difference = \left(\sum \left|PI_i - G_i\right|\right) \div n$$

where n is the number of plots, PIi is the PI canopy cover for plot i, and G_i is the ground-based canopy cover for plot i. Bias was assessed with the mean difference:

$$mean\_difference = \sum (PI_i - G_i) \div n$$

AUTOMATION BY OBJECT-BASED IMAGE ANALYSIS

An object-base image analysis (OBIA) approach was used to estimate tree canopy cover at 488 PI locations in the Georgia pilot area, as an initial test of the feasibility of automating the PI work flow. The OBIA method involves two steps: image segmentation and classification. Image segmentation divides an image into "spatially continuous, disjoint, and homogeneous regions" (de Jong and van deMeer, 2004), which are referred to as image objects. In

OBIA approaches, classification occurs on the image objects as opposed to individual pixels.The classification process involved separating image objects into “tree canopy” and “not tree canopy” categories. As a final step, percent canopy cover was derived by calculating the area occupied by image objects belonging to the “tree canopy” category and dividing by the total area of each image chip (i.e., the area sampled by the 90-m x 90-m dot grids).

Images were processed with eCognition Developer (v. 8.0.1), and both image segmentation and classification steps were included in a single rule set. A multi-resolution segmentation algorithm was used to segment each image (scale parameter: 30; shape criterion: 0.1), and utilized red, green, blue, near-infrared, and NDVI input bands. In the classification phase, NDVI was used to discriminate between vegetated and non-vegetated parts of each image chip. In order to separate tree cover from other vegetation, a series of expressions that used spectral and texture information were combined to identify tree-cover image objects.

RESULTS AND DISCUSSION

COMPARISON OF PHOTO-INTERPRETATION WITH GROUND-BASED CANOPY COVER ESTIMATES

Differences in size and shape of the sampled areas were responsible for some of the variability in the relationship between PI canopy cover derived from the 90-m dot grids, and canopy cover estimates derived from tree measurements on the four 24-feet radius subplots comprising each FIA plot location (figure 2). However, there was a consistent pattern of higher canopy cover estimates by PI compared with ground-based estimates. At forested FIA plot locations in the Georgia pilot area, PI canopy cover was higher than stem-map canopy cover by an average of 19, with a mean absolute difference of ±21 percent canopy cover (figure 3a). Eighty-five percent of the PI estimates at forested plots in Georgia were in the highest cover class of 90 to 100 percent, with a median value of 98 percent. Stem-mapped canopy cover in Georgia was more evenly distributed between 50 and 100 percent with a median value of 80 percent. The pattern was similar in the Michigan pilot area where 83 percent of the PI estimates at forested plot locations were in the highest cover class with a median value of 100 percent, while the stem-mapped cover was more evenly distributed between 50 and 100 percent with a median value of 75. The mean difference was 24 percent canopy cover (figure 3b). At forested plot locations in the Kansas pilot area, PI canopy cover was higher than stem-map canopy cover by an average of 20, with a mean absolute difference of ±25 percent canopy cover (figure 3c). Variability and mean differences were lower in the western pilot areas. At forested plot locations in the Utah pilot area, PI canopy cover was higher than stem-map canopy cover by an average of 13, with a mean absolute difference of ±18 percent canopy cover (figure 3d). As expected, a similar relationship was seen between PI canopy cover and field-measured line intercept canopy cover on the Utah plots. PI canopy cover was higher than line intercept canopy cover by an average of 12, with a mean absolute difference of ±17 percent canopy cover (figure 3e). At forested plot locations in the Oregon pilot area, PI canopy cover was higher than stem-map canopy cover by an average of 13, with a mean absolute difference of ±16 percent canopy cover (figure 3f).

A tendency for overestimation of tree canopy cover derived from NAIP imagery was expected due to off-nadir view angles and excessive shadowing in some images (Guess 2010), but the magnitude of differences relative to ground-based estimates has not been previously quantified. The viewing angle between camera and ground is variable within a NAIP image depending on distance from the flight line. Portions of an image near the flight line provide vertical viewing (near nadir), but with increasing distance from the flight line view angles become oblique (off-nadir). Trees viewed at oblique angles appear to occupy a greater area than their canopies actually cover with a vertical projection, and openings can be obscured (Guess 2010). Tree canopy measurements are expected to be most accurate near the image nadir (Korpela 2004). Shadowing can also be heavy in NAIP images due to sun angle and terrain. Excessive shadowing may lead to overestimation of canopy cover since shadows can make the canopy appear denser that it actually is, and shadows may cause additional difficulty in discerning non-tree background vegetation from tree canopy. View angles vary from location to location within images, and shadowing varies from image to image, so these sources of bias could be highly variable in magnitude. The current NAIP products do not include flight line data, so analysis of, and possible adjustment for these sources of bias do not appear feasible at present.

It is possible that the stem-map model underestimates canopy cover in some eastern forest types. The stem-map model has two components. A geometric component involves overlaying the crowns of stem-mapped trees ≥ 5 inches diameter on the subplot boundaries to calculate vertically projected canopy cover accounting for overlap. Crown dimensions are predicted from stem diameters using equations from Bechtold (2003, 2004), Bragg (2001), Gill and others (2000), and others. Trees ≥ 1 inch diameter but < 5 inches diameter are denoted as saplings in FIA protocols and are only measured in one 6.8-feet radius microplot within each FIA subplot. Since saplings cannot be stem-mapped across the entire plot, the contribution of saplings to total canopy cover is estimated with a regression equation that includes predictor variables characterizing stand structure and the spatial pattern of overstory trees. This empirical component of the stem-map model was developed using field data from the Interior West FIA unit, and has not been validated in eastern forest types. To the extent that eastern forest types tend to differ structurally from interior west types, especially if they tend to be more multi-layered, the stem-map model could underestimate the total canopy cover of trees ≥ 1 inch diameter on the plot. If this is true, then the magnitude of overestimation from photo-interpreted NAIP is probably overstated for the Georgia, Michigan, and Kansas pilot areas (+19 to +24 percent canopy cover on average). It is possible that the actual overestimation for these pilot areas is more similar to that reported for the western pilot areas (+12 to +13 percent canopy cover on average) where the stem-map model has known reliability.

OBJECT-BASED IMAGE ANALYSIS

The OBIA method consistently overestimated tree canopy cover relative to human photo interpretation using a dot grid (figure 4). OBIA canopy cover was higher than PI canopy cover by an average of 11 (mean difference ranging from 0 to 94). During the segmentation process, continuous image objects that included shadowed areas between or adjacent to individual tree crowns were created. As a result, it was expected the OBIA would tend to estimate a higher percentage of canopy cover than a human interpreter in areas with less dense canopies, which could be exacerbated in images with excessive shadowing due to low sun angles. Other issues such as variations in color and brightness among images and the limited contextual information due to the small image extents led to some difficulty in discriminating trees from other vegetation in some images (figure 5). Some of these problems could be overcome with additional development work on the OBIA approach. Once a rule set is developed, the approach requires little manual intervention and processing time is fast. In contrast to the stem mapping approach, the OBIA method does not rely on the availability of in situ tree data, and unlike human photo interpretation it is fully repeatable.

CONCLUSIONS

The use of photo-interpreted NAIP as reference data for continental mapping of tree canopy cover has important operational advantages. The generation of PI data does not require in situ tree measurements. In contrast, most FIA sample locations classified as nonforest by definition are not field-visited, even though many of these nonforest locations can have significant tree cover (e.g., urban and residential areas). Likewise, PI data can be collected relatively efficiently from an intensified grid, so that (at least low levels of) intensification are probably feasible within time and cost constraints, resulting in larger sample sizes and increased map accuracy. PI data from NAIP generally can be produced so that it is concurrent with the satellite imagery being classified. In contrast, the FIA grid is sampled on a 5-year (eastern U.S.) or 10-year (western U.S.) inventory cycle. Plot measurements that are disjoint in time from image acquisition dates may no longer reflect ground conditions accurately for the time period of interest. The spatial registration of reference locations with pixels in the satellite imagery also should be as accurate as possible to support the development of predictive models. The horizontal accuracy of NAIP is currently specified as “inspected locations match photo-identifiable ground control points with an accuracy of within 6 meters at a 95 percent confidence level” (USDA Farm Service Agency 2009). The 90-m x 90-m dot grids used for PI in the NLCD pilot were positioned coincident with 3x3 pixel blocks on the 30-m LANDSAT imagery to be classified. Error rates for FIA plot coordinates have not been described systematically and could exceed NAIP specifications, and FIA plot footprints cannot be “snapped” to specific pixel configurations.

Photo-interpreted NAIP appears to overestimate tree canopy cover at forested FIA plot locations compared with ground-based estimates derived from stem-mapped tree data or line intercept field measurements. The magnitude of overestimation is likely in the range of 10 to 20 percent canopy cover on average, but with moderate to high variability that may be related to characteristics of the NAIP imagery. Oblique viewing angles at sample locations away from the image nadir, and excessive shadowing in some NAIP images, could be the primary reasons for overestimation of canopy cover. Map products developed from PI reference data derived from NAIP may depict canopy cover in forested areas that is too high on average, and the variability of mapped canopy cover in some forested areas could be artificially low if nearly all PI samples are in the highest cover class (90 to 100 percent canopy cover). Future research should consider the possibility of obtaining flight line information for NAIP images to test the feasibility of adjustments to PI canopy cover for view angle and sun elevation.

An initial test showed that automated PI of NAIP images by object-based image analysis could be a feasible approach for generating canopy cover data at reduced time and cost. An algorithm-based method also has the advantage of being fully repeatable. However, the rule set used in the present study exacerbated the problem of overestimation, resulting in percent canopy cover values higher by 11 on average compared with human PI of NAIP. Additional development work on the OBIA approach, ideally in conjunction with research on the effects of view angle and sun angle mentioned above, is warranted considering the potential for large gains in efficiency.

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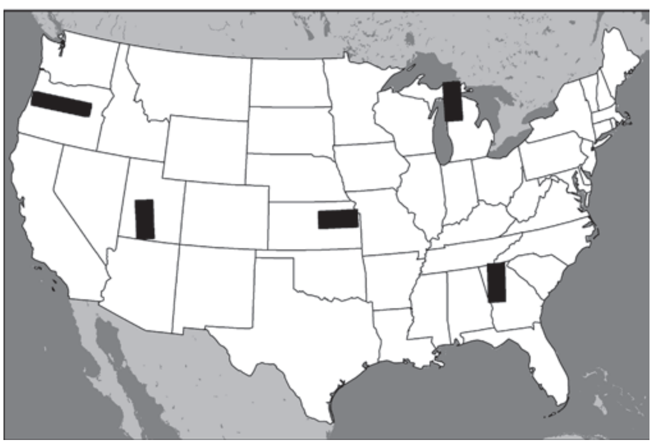

Figure 1—Locations of five pilot study areas (black shaded) in Georgia, Michigan, Kansas, Utah, and Oregon.

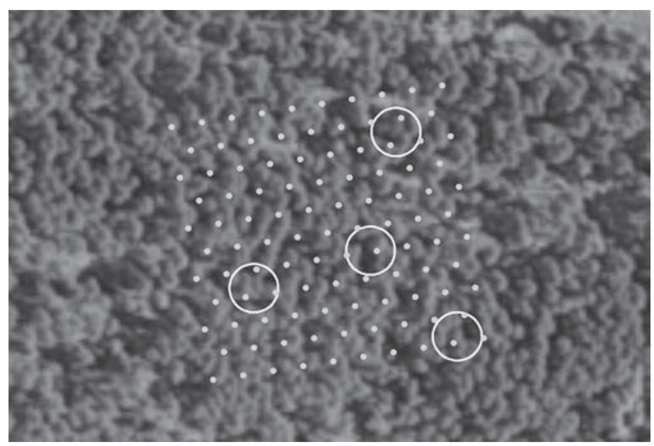

Figure 2—Example of a 90 m x 90 m grid containing 105 photo-interpretation points on NAIP imagery used to estimate tree canopy cover, along with the 24-feet radius subplots of a coincident FIA sample location.

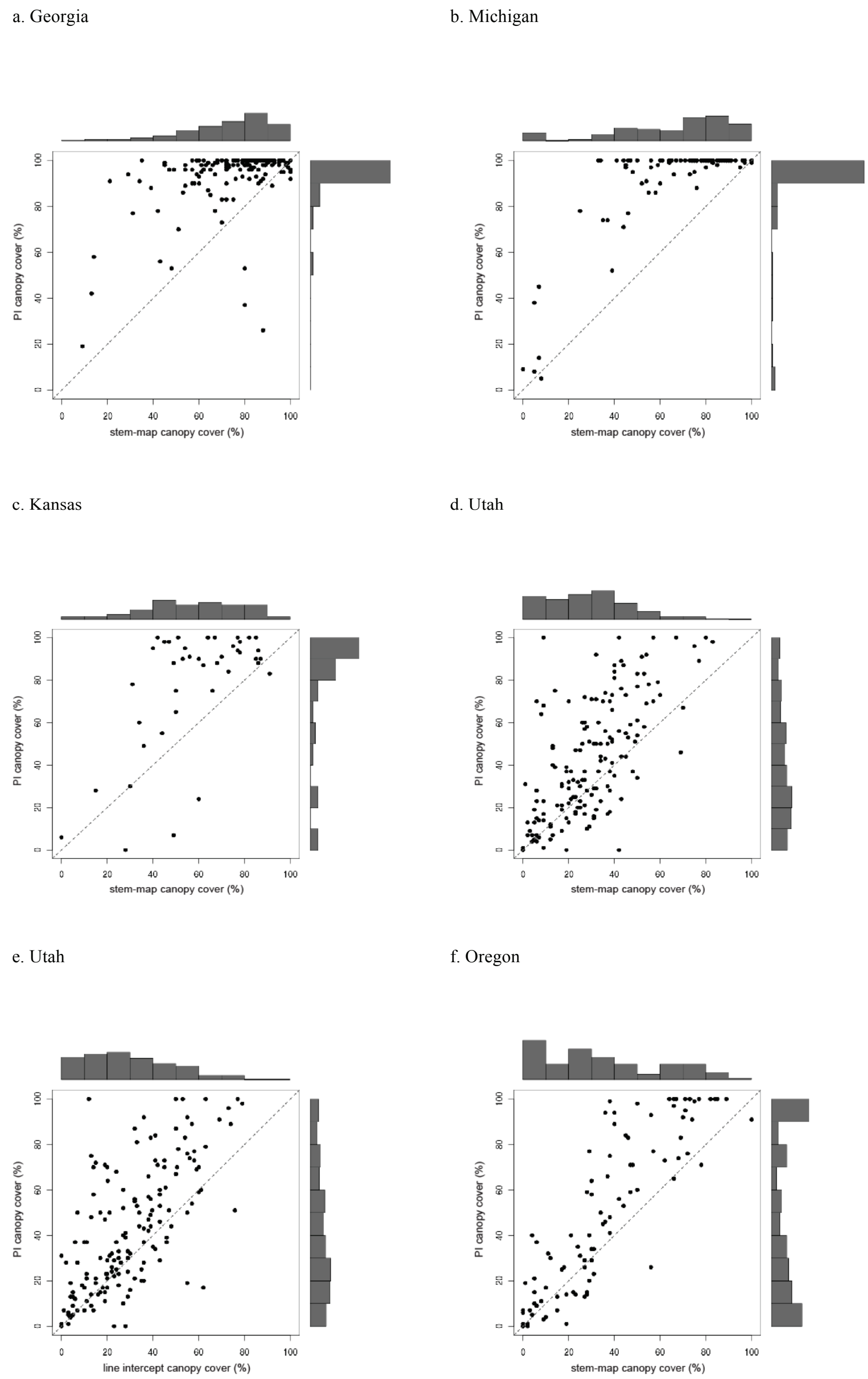

Figure 3—Comparison of tree canopy cover estimated by photo-interpretation (PI) of NAIP images with canopy cover estimated from stem-mapped tree data at forested FIA plot locations in five pilot study areas in the US, and with canopy cover measured in the field by line intercept on forested FIA plots in the Utah pilot area only. The histograms for each variable are in the margins and the dashed line is the 1:1 line. a) 144 plot locations in Georgia, b) 89 plot locations in Michigan, c) 42 plot locations in Kansas, d) 159 plot locations in Utah (stem-mapped canopy cover estimates), e) 158 plot locations in Utah (line intercept canopy cover measurements), and f) 98 plot locations in Oregon.

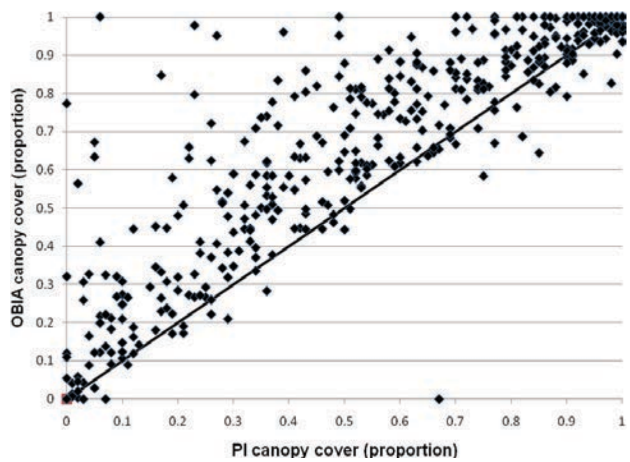

Figure 4—Comparison of tree canopy cover as estimated by human photo-interpreters (PI) interpreters using a dot grid with canopy cover estimated by an object-based image analysis (OBIA) automated mapping approach for 488 locations in Georgia, USA.

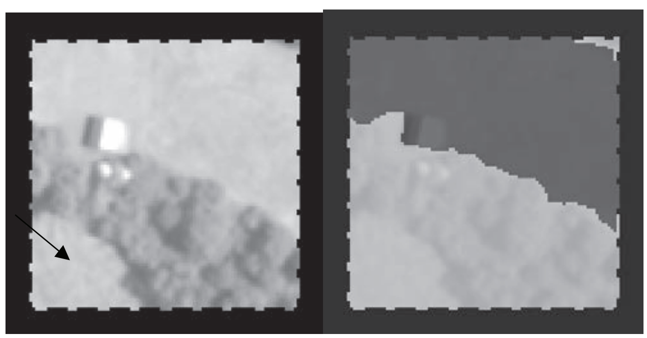

Figure 5—NAIP image chip on the left from Georgia, USA. The image on the right shows the classified image created using an object-based image analysis approach (dark gray = not tree canopy, light gray = tree canopy). The arrow indicates an area where grassy lawn was mistakenly classified as 'tree.'