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Application of local binary patterns in digital images to estimate botanical composition in mixed alfalfa–grass fields

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ABSTRACT

Botanical composition in mixed stands of alfalfa and grass is a critical parameter in equations estimating harvest fiber concentration for dairy rations. Composition is difficult to estimate by visual observation. Digital image analysis in mixed stands could reduce botanical composition uncertainty and improve spring harvest management decisions. Mixed stands were sampled ($n = 168$) in farmers' fields in Tompkins County, New York in May 2011. A digital image was taken of standing samples at 5-Megapixels resolution using a Canon PowerShot A3100IS, and alfalfa and grass height relationships were recorded. After clipping representative samples at 10-cm above ground level, samples were manually separated into alfalfa (*Medicago sativa* L.) and timothy grass (*Phleum pratense* L.), and dried to calculate fractions on a dry matter basis. Uniform rotation invariant local binary patterns (LBP) were extracted from whole images and 64×64 pixel tiles, and were used to develop regression equations estimating grass fraction. Tiles were manually classified as alfalfa (0), grass (1) or unclassifiable. An iterative process selected most accurate local binary pattern operator settings. Grass fraction was estimated in three regression model development approaches: (1) using average tile LBP histogram bins from whole images and botanical height relationships, (2) developing a binary tile classification model from tile LBP histogram bins, and using tile model-predicted grass probability averaged for tiles in whole images (grass coverage estimate) and botanical height relationships as inputs in whole image models, and (3) using LBP histogram bins extracted directly from whole images (1024 by 1024 pixel square) and height relationships. Predictive accuracy in whole image models using tile LBP histogram averages was highest for models generated from LBP tile histogram bin means (R^2_{pred} up to 0.847), followed closely by combined tile models and whole image models (R^2_{pred} up to 0.807), with pairwise correlations between tile model-generated grass coverage estimates and sample grass fraction up to 0.895. Local binary patterns are effective in differentiating alfalfa and grass under field conditions, because the method is robust to changes in color and illumination. Furthermore, key LBP histogram bins (e.g., symmetric edges) strongly differentiate alfalfa and grass in tiles. The LBP method is promising based on this study, but further evaluation under diverse field conditions, including different cameras and grass species, is necessary to assess usefulness.

1. Introduction

Timing of spring forage harvests in the northeast U.S. is critical to ensure high quality forage for dairy cattle production throughout the growing season. Spring forage harvest timing can be predicted based on neutral detergent fiber (NDF) concentration (Parsons et al., 2006b), and target NDF depends on the class of livestock being fed when forages are the principal source of fiber in rations. Target NDF at harvest for dairy cattle is approximately 50% of dry matter for pure grass stands for silage and 40% of dry matter for alfalfa (Cherney et al., 2006). Other forage quality parameters, such as protein and fiber digestibility, are important for ration balancing, but they are not as useful for harvest date targets.

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Forage sampling of farmers' fields in New York has produced simple equations for the prediction of nutritive value and harvest timing for pure stands of alfalfa (*Medicago sativa* L.), grass (e.g., *Phleum pratense* L., *Phalaris arundinacea* L., *Dactylis glomerata* L., and *Festuca arundinacea* Schreb.), and mixed stands of alfalfa and grass (Parsons et al., 2006a, 2009, 2012). Forage stands can also be tested for dry matter loss and changes in NDF at variable stubble height, another important management factor (Parsons et al., 2009, 2012). These equations have proven useful over a range of conditions and years.

Alfalfa is sown with a perennial grass companion on over 80% of the alfalfa acreage in New York (Cherney et al., 2006), and accurate mixed stand equations are important for effective harvest management. Required inputs for mixed stand equations include alfalfa maximum height, stand composition (grass fraction in the stand), and targeted harvest NDF concentration (Parsons et al., 2006a). Botanical or stand composition is a critical parameter in the equation, and is difficult to accurately predict by visual observation (McRoberts et al., 2012a). Difficulty in estimating stand composition was reported by extension educators at the Cornell Field Crop Extension Educators' Retreat in April 2011 as the principle problem limiting the utility of mixed stand equations for farmers in the northeast U.S. Overestimating grass by just 20% can result in late harvests by five or more days, potentially leading to NDF at harvest >5% past target levels. Underestimating grass fraction results in early harvests, lower spring forage yields and higher unit cost per ton of forage dry matter produced. Thus, misestimating composition represents critical potential nutritive and economic losses for dairy farms. Reducing uncertainty in the stand composition estimate could improve the quality and timing of spring forage harvests.

Manual and semi-automated approaches have been attempted to estimate botanical composition in legume–grass stands. Visual estimation methods have been used historically as the principal method. Rayburn and Green (2014) developed a visual reference guide for mixed stands of clover and grass to help calibrate the eye for human field estimation. Rayburn (2014) tested a manual point count method by iteratively superimposing a randomly placed virtual point count grid on mixed stand images, counting the number of points touching grass, legumes, forbs, bare ground, and dark shadows, and quantifying the points. Point counts were then regressed on actual botanical composition. The method was strong when using at least 100 points per image (R^2 ranging from 0.45 to 0.98). However, it is time consuming and would require manual image processing by users as well as equation calibration with different species combinations, sampling seasons, and cameras. Height relationships of species sampled were not used in their method development.

In a pot experiment, Himstedt et al. (2009) discovered high correlations between legume coverage and actual legume dry matter fraction in mixed stands ($R^2 = 0.89$ across three legume species for two sward ages; $R^2 = 0.96$ for alfalfa). Actual legume coverage was calculated by manually circling areas covered by legumes and dividing by total area. They also estimated coverage by processing grayscale images using morphological operators, including a multistep erosion process, followed by a dilation process with the same number of steps. Erosion effectively removed small objects such as grass leaves, while dilation blew the remaining objects (inner portion of alfalfa leaves) back up to their approximate original size. Grayscale thresholding was used to separate legume leaves from everything else in the image, and to estimate coverage as *legume leaves/total area*. The relationship between actual coverage and estimated coverage was strong for samples with higher percent coverage ($R^2 = 0.88$ overall, $R^2 = 0.84$ for alfalfa). However, sample size was small (64 images) and lighting and growth conditions were controlled.

Himstedt et al. (2010) furthered equation development using logit-transformed legume coverage in statistical model development, and selected a multivariate model predicting legume dry matter contribution with effects including logit-transformed legume coverage, total biomass in the sample, and their interaction. Equation testing on field samples yielded a strong relationship with legume dry matter contribution for clover–grass mixes ($R^2 = 0.98$). Practicality of such an equation for field use is questionable without further investment in technology such as field spectroscopy given the need for the total dry matter biomass variable. Single cameras were used in all tests. The technique would require further testing under variable field conditions to evaluate potential field use.

In a field study, Post et al. (2007) related plant canopy spectral reflectance (wavelengths 680 nm and 705 nm in the second derivative spectra) with alfalfa fraction in a mixed stand ($R^2 = 0.6–0.7$, $n = 95$). The approach is promising for further investigation, and potentially for post-calibration field use (Post et al., 2007). Others have implemented variations on canopy spectral reflectance to predict stand composition with promising results (Kawamura et al., 2011). However, spectral technology may not be accessible for end users.

More sophisticated image processing methods such as artificial intelligence (Aitkenhead et al., 2003) and texture classification (Sabeenian and Palanisamy, 2010) have been tested to discriminate between vegetation types (e.g., crops and weeds). Methods that permit crop–weed discrimination in real time, combined with robotic herbicide application and cultivation systems, play an important role in precision agriculture. Local binary patterns (LBP), commonly known for their use in facial recognition (Ahonen et al., 2006), provide a powerful, robust, computationally efficient method for texture classification in image analysis (Ojala et al., 2002). Under field conditions and with different image acquisition devices, illumination variability and color variability is high. The application of rotation invariant uniform LBPs to grayscale images could be useful for estimating alfalfa–grass stand composition under field conditions, because it is robust to changes in illumination and color (Ojala et al., 2002).

The study objective was to develop a practical, farmer-accessible method that can be applied to estimate stand composition (i.e., grass and alfalfa dry matter fractions in binary mixes) under variable field conditions. The dataset was tested using multiple approaches including geometric pattern matching, color separation, blob detection, and tile extraction with fast Fourier transformation (combined with naïve Bayes classifier artificial intelligence and trained and untrained support vector machines) with unsatisfactory results (McRoberts et al., 2012a). In this paper a method is developed that combines digital image analysis using local binary patterns with statistical modeling to estimate alfalfa–grass stand composition. The sampling process, local binary pattern method, and its implementation with several processing approaches to estimate stand composition are described.

2. Methods

2.1. Sampling

Mixed stands with different representative proportions of alfalfa and timothy grass (*P. pratense* L.) were identified in farmers' fields in Tompkins County, New York (42°36′N, 76°30′W) in spring 2011 ($n = 168$, including 3 pure grass and 5 pure alfalfa samples). Representative samples were selected and delineated using a round hoop (66-cm diameter), which was rested on the vegetative canopy. A digital image (JPEG format) was taken at 5-Megapixels resolution using an affordable, farmer-accessible, point-and-shoot