Biosystems Engineering (2006) **95** (3), 359–370
doi:10.1016/j.biosystemseng.2006.07.007
PA—Precision Agriculture

Neural Network Optimisation of Remotely Sensed Maize Leaf Nitrogen with a Genetic Algorithm and Linear Programming using Five Performance Parameters

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(Received 6 October 2005; accepted in revised form 17 July 2006; published online 18 September 2006)

An algorithm was developed to select an optimum model among several neural network (NN) models using the Manhattan and Euclidean metric measures. The algorithm was implemented to find an optimum NN prediction model based on simultaneous comparison of five performance parameters. Weighted coefficients were given to each performance parameter based on their significance for specific condition. The associated weighted coefficients were optimised using two optimisation techniques: (i) genetic algorithm; and (ii) linear programming. The algorithm performed satisfactorily in determining acceptable models and selecting an optimum NN model. The radial basis function NN model based on green vegetation index texture yielded an average prediction accuracy of 92·1% for predicting leaf nitrogen content under field conditions.

1. Introduction

Leaf nitrogen is a critical component for the growth and development of crops. Assessment of leaf nitrogen may be useful to accurately determine the variation of crop nitrogen status. Leaf nitrogen affects crop growth and crop yield. Previous studies have examined the relationships between leaf nitrogen, crop growth, and yield (Beatty *et al.*, 2000; Cihacek & Kerby, 1991; Flowers *et al.*, 2000; Hong *et al.*, 1997; Reeves *et al.*, 1993). The laboratory-based conventional technique for determining leaf nitrogen is time consuming, expensive, and labour intensive. Field techniques, such as the use of hand-held chlorophyll meters are tedious (Reeves *et al.*, 1993; Scharf & Lory, 2000). Thus, there is a need for developing an alternative technique to determine leaf nitrogen in the field.

There are many approaches to the assessment of leaf nitrogen under field conditions in the literature. Leaf nitrogen was determined by quantifying nitrate concentration in the laboratory (Filella *et al.*, 1995; Greenwood *et al.*, 1991). Leaf nitrogen was also related to crop growing stage (Huggins & Pan, 1993; Zhuang & Bemard, 1990) and was reported to vary with ambient air temperature (Cihacek & Kerby, 1991; Sauchelli, 1964). Research was also conducted to establish a relation between chlorophyll and leaf nitrogen (Hong *et al.*, 1997). The correlation between the chlorophyll and nitrogen content of rice leaves ranged between 0·90 and 0·94 (Hong *et al.*, 1997). Leaf nitrogen was also determined using leaf canopy reflectance (Flowers *et al.*, 2000; Reeves *et al.*, 1993; Scharf & Lory, 2000; Viets & Hageman, 1971). The coefficient of determination between plant nitrogen spectral index and nitrogen uptake at different spectral bands (*i.e.* red at 761 nm and near infrared (NIR) at 780 nm) was found to be 0·67 (Stone *et al.*, 1996). Stone *et al.* (1996) found a correlation coefficient of 0·87 at 550 nm, which was higher than those at 430 and 680 nm wavelengths. Leaf chlorophyll and nitrogen of maize was determined using airborne hyper-spectral and infrared remote sensing (Beatty *et al.*, 2000). Beatty *et al.* (2000) found a more prominent variation of spectral response in the green and NIR bands. Leaf nitrogen of maize crop was also determined using aerial images (Blackmer & White, 1998). A correlation coefficient of 0·74 was found between spectral reflectance (green at 550 nm and red at 710 nm) and leaf nitrogen. In a similar study, aerial images were used to compare the variability of leaf nitrogen deficiencies (Blackmer *et al.*, 1996). The red band image was reported to provide a higher correlation with nitrogen deficiencies. Variation of reflectance, transmittance, and absorption spectra of normal and nitrogen deficient maize leaves was separated by Al-Abbas *et al.* (1974).

The potential of determining plant chlorophyll at different spectral bands of visible or NIR spectrum has previously been examined (Huggins & Pan, 1993; Zhuang & Bemard, 1990; Sauchelli, 1964; Stone *et al.*, 1996; Blackmer & White, 1998; Blackmer *et al.*, 1996). A strong relationship was also reported between plant chlorophyll and leaf nitrogen (Huggins & Pan, 1993; Stone *et al.*, 1996). Nitrogen, when consumed by plants in the form of nitrate, converted to ammonia and subsequently to glutamine (Black, 1999). The glutamine is a key enzyme for the development of protein in the leaves (Black, 1999) and, thus, for the quantification of chlorophyll in plants. In addition, prior studies reveal that the chlorophyll affects the spectral properties of the light reflected from leaves (Beatty *et al.*, 2000; Flowers *et al.*, 2000). Therefore, spectral properties of plants in the form of images may contain information to predict leaf nitrogen. Hence, it was hypothesised that image information in the form of statistical and textural features can be used to predict leaf nitrogen in field conditions.

The application of artificial intelligence techniques, such as neural networks (NN) is appropriate to develop prediction models, such as prediction of leaf nitrogen in field conditions (Sérélé *et al.*, 2000; O'Neal *et al.*, 2002; Tumbo *et al.*, 2002; Yang *et al.*, 1996; Pachepsky *et al.*, 1996; Drummond *et al.*, 2002). The use of this technique enables more complex data to be analysed, compared to other methods (*e.g.* statistical techniques), particularly when the feature space is complex and all data do not follow the same distribution pattern (Benediktsson *et al.*, 1990; Schalkoff, 1992; Atkinson & Tatnall, 1997). Moreover, the NN technique incorporates a priori knowledge and realistic physical constraints into the analysis (Brown & Harris, 1994; Foody, 1995). Previous studies described the use of various NN architectures, such as multilayer perception (Thai & Shewfelt, 1991; Foody, 1995; Tumbo *et al.*, 2002; Pachepsky *et al.*, 1996) and radial basis function (Huang, 1999; Chen *et al.*, 1991; Behloul *et al.*, 2002). The selection of specific NN architecture depends on the nature of the problem and data type.

This study focuses on the development of various NN models using two NN architectures; a multi-layer perceptron and a radial basis function. Moreover, the performance of NN models was evaluated based on simultaneous comparison of multiple parameters. In addition, an algorithm was developed to select acceptable models out of several NN models based on user-defined threshold criteria and then to determine an optimal NN model. Weighted coefficients were given to each performance parameter based on their significance. The optimal values of each weighted coefficient were determined using two optimisation techniques: (i) genetic algorithm; and (ii) linear programming.

2. Image processing and feature extraction

2.1. *Image acquisition and determination of plant nitrogen*

A portion of the best management practice research site at Oakes, North Dakota, USA, was selected as the field of investigation. The geographical coordinates of the site are 46·051974 °N, 98·111879 °W and 46·048341 °N, 98·101856 °W. There are 68 sub-plots within the research site and the area of each sub-plot is 171·13 m^2. The maize crop was planted in the summer of 2001.

Aerial images of the maize crop were acquired at noon on a cloud-free sunny day during the 3rd week of July, 2001, using a Cessna aircraft flying at an approximate height of 1000 m. The images were acquired both in visible and NIR bands of electromagnetic spectrum using a 35 mm camera loaded with 100 Ektachrome slide film. The slides were scanned with a Nikon Scanner at 2800 dot per inch resolution and the digital images were saved in tagged image file format (TIFF). The spatial resolution of the acquired images was 1-m in visible and NIR bands.

Several leaves were randomly collected from 10 maize plants in each sub-plot to determine leaf nitrogen. The leaves were collected on the same day as the image acquisition. The nitrogen content of the leaves was determined using the Kjeldahl nitrogen digestion procedure (Black, 1999). The leaf nitrogen content was expressed as a percentage of total dry weight.

2.2. *Feature extraction*

The TIFF images were imported into Idrisi using the import module of Idrisi software (Idrisi32.11, 2000) in a Microsoft Windows platform. The visible and NIR band images were geo-referenced using world geodetic system 1984. Each visible image was split into red, green, and blue bands. Only the red and green band images in the visible band and the NIR image in the NIR band were used for further image processing and feature extraction. In addition, two additional images