Computers and Electronics in Agriculture 109 (2014) 172–178

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Delineation of management zones using an active canopy sensor for a tobacco field

Dong Chang, Jun Zhang, Li Zhu, Shao-Hua Ge, Peng-Yan Li, Guo-Shun Liu *

Tobacco Cultivation Key Laboratory in Tobacco Industry, College of Tobacco Science, Henan Agricultural University, Zhengzhou, Henan 450002, PR China

ARTICLE INFO

Article history:
Received 28 May 2014
Received in revised form 22 September 2014
Accepted 27 September 2014

Keywords:
Management zones
Spatial variability
Soil properties
NDVI
Tobacco field

ABSTRACT

Recent precision agriculture research has focused on the utilization of management zones (MZs) as a method for variable-rate fertilizer applications. This study tries to make use of an active canopy sensor to define MZs in contrast with the ones using soil properties. To achieve this objective, a 20-m grid-sampling scheme was imposed on the field with 101 points, and we collected soil samples from the top 20 cm at each point before tobacco planting in April 2013. The normalized difference vegetative index (NDVI) data at five growth stages of the tobacco growth cycle were measured by using a GreenSeeker handheld crop sensor at the location of each sample point. Yield mapping was carried out at harvest. Through stepwise multiple analysis, we identified the key yield-limiting factors of soil properties and stages of NDVI measured respectively. For soil property data, OM, AP and Fe were used for yield-based MZs while for canopy parameters, NDVI during knee-high and flowering were utilized. Fuzzy c-means clustering algorithm was performed in order to determine the optimal number of the clusters. Results showed that the optimal number of MZs with regard to the two methods were both five and variance analysis indicated the heterogeneity of soil properties and yield among them. Consequently, it is feasible to use an active canopy sensor to delineate management zones for tobacco-planting fields.

1. Introduction

Flue-cured tobacco (*Nicotiana tabacum*) is an economic crop of paramount importance in China. At present, Chinese tobacco production often ignores the spatial variability of soil and crop, and by implementing uniform fertilizer management, an overwhelmingly majority of farmers prefer to use one soil management set of practices for the entire field, which often results in over-application of inputs in areas with high nutrient levels and underutilization in areas with low nutrient levels (Ferguson et al., 2002). Such inappropriate management increases field management costs, decreases yields and quality of tobacco leaves, contributes to surface and groundwater pollution as well as wastes energy. Management zones are subfield regions representing homogenous attributions in landscape and soil condition. Defining management zones attempts to manage the soil, pests and crops based upon spatial variation within a field, whereas conventional farming treats a field uniformly, ignoring the naturally inherent variability of soil and crop conditions within fields. The application of precision agriculture (PA) or site-specific management (SSM) in tobacco-planting fields is a cost-effective approach to address these problems and to achieve sustainable agriculture. In China, management zones (MZs) for flue-cured tobacco was first carried out in 2009 and the results showed soil nutrients within management zones were similar and it provided a basis of information for SSM in the tobacco field (Wang et al., 2009). Jiang et al. (2011) selected four quality-limiting factors (AK, OM, AP and CEC) for tobacco by stepwise multiple regression analysis and delineated management zones by these factors.

Data collection in the field is the first step in precision agriculture application. There are several types of data for defining management zones: topography (e.g. elevation, slope), soil nutrients, texture, salinity and crop information. Among all of them, soil nutrients (Fu et al., 2010; Jiang et al., 2011; Ortega and Santibáñez, 2007; Wang et al., 2009), and soil electrical conductivity (ECa) (Johnson et al., 2003; Kitchen et al., 2005; Li et al., 2007a; Moral et al., 2010), assisted by topographic factors (Fraisse et al., 2001; Kweon, 2012), have been extensively employed to characterize MZ. Crop information, including yield and quality have also been suggested as bases for defining zones (Aggelopooulou et al., 2013; Brock et al., 2005; Jaynes et al., 2005; Tagarakis et al., 2012). However, the traditional soil sampling and measurement are generally time-consuming and labour-intensive (Morari et al., 2009). As a consequence, the cost of obtaining enough data for

* Corresponding author. Tel.: +86 037163558128.
E-mail address: liugsh1851@163.com (G.-S. Liu).

http://dx.doi.org/10.1016/j.compag.2014.09.019
0168-1699/

delineating MZ often limits its application in precision agriculture. Vegetation index is used as a means to assess plant performance. The normalized difference vegetative index (NDVI), is highly relevant to plant physiological parameters, leaf area index and canopy properties such as crop yield and biomass (Peñuelas et al., 1994). The NDVI has been considered as a measurement of amalgamated plant growth reflecting various plant growth factors (Govaerts et al., 2007). For tobacco, the leaf is harvest object, and greater leaf area and plant biomass levels result in higher NDVI values, so canopy properties can be a good indicator for tobacco yield and quality.

Many researchers have exploited remote sensing sources to construct MZ, including multispectral satellite or aerial images (Kyaw et al., 2008; Li et al., 2007b; Pedroso et al., 2010). The image must first be geometrically and atmospherically corrected and the procedures are complex and time-consuming (Tremblay et al., 2008). Likewise, there are some constraints when using remote sensing sources associated with weather conditions, timing of image acquisition and elaboration (Stamatiadis et al., 2010), although these methods have significant advantages such as easy and rapid covering of large areas. The GreenSeeker handheld crop sensor (Trimble Ltd., USA) is a commercial device which employs active radiation from red (650 nm) and near infrared (NIR) (770 nm) LED to obtain NDVI value [$NDVI = (R_{NIR} - R_{RED})/(R_{NIR} + R_{RED})$]. It has showed significant merits for SSM such as overcoming the weather factor, elimination of soil reflectance interference and implementing real-time measurement (Yang et al., 2011).

Fuzzy c-means clustering is a promising statistical approach for delineating MZ, which is widely and effectively used in a number of studies to group cells with similar attributes into classes (Schepers et al., 2004; Van Meirvenne et al., 2013; Willers et al., 2005). Molin and Castro (2008) established management zones by using fuzzy clustering technique in Brazil. Similarly, (Jaynes et al., 2003) used cluster analysis to group the yield observations collected for 224 yield plots into five temporal yield patterns.

However, none relevant studies have investigated the use of vegetation indices for management zone delineation to establish fertilizer management in tobacco-planted fields in China. Using soil nutrients to delineate MZ is generally time-consuming and labour-intensive. They restrict the application of SSM in tobacco production. Consequently, accurate and simplified procedure for the delineation of MZ, more precisely and cost-effective, management of soil fertilizer and improvement of tobacco yield and quality are increasing needed. This article aims to (1) identify the key yield-limiting factors of soil properties and stages of NDVI measured respectively in this study region; (2) characterize the spatial variability of the variables; and (3) delineate MZs using soil properties and NDVI measurements respectively by use of fuzzy clustering algorithm.

2. Materials and methods

2.1. Study area description and data collection

The study was conducted on a 4-ha tobacco field that has been planted with tobacco for the past five years. It is located in Xiangcheng County (33°51′N, 113°24′E) of Henan Province, in central China. The site features a warm-temperate continental monsoon climate, with mean annual temperature of 14.7 °C and mean annual precipitation of 728 mm. The main soil texture is brown loamy. An overview of the boundary of the study is given in Fig. 1.

Soil samples were collected before tobacco planting in April 2013. A 20 m grid-sampling scheme was imposed on the field with 101 points. At each grid point, five subsamples collected from the top layer (0–20 cm) within a five-meter area were mixed, then 101 soil samples were taken back to the laboratory, air-dried, ground to pass through a 2-mm sieve and analyzed by conventional methods. Soil pH was measured in 1:2.5 (v/v) soil/water suspension, OM was determined using potassium bichromate titrimetric method, AN was measured using alkaline hydrolysis diffusion method, AP was determined by using alkaline sodium bicarbonate as the extractant in a 20:1 ratio and AK was measured by the neutral ammonium acetate extraction method. Available Fe, Mn, Cu and Zn were extracted using 0.1 mol L^{-1} HCl and analyzed using inductively coupled plasma-atomic emission spectroscopy (Bao, 2005). The coordinate of each sample point was obtained by using a GPS unit. NDVI data was measured using a GreenSeeker handheld crop sensor at the location of each sample point. The sensor was located at 1.2 m height from the tobacco surface, to scan the whole canopy area, and NDVI values at five growth stages of the tobacco growth cycle were measured: recovery (NDVI_30, 30 days after transplanting), knee-high (NDVI_40, 40 days after transplanting), rapid growth and elongation (NDVI_50, 50 days after transplanting), flowering and topping (NDVI_60, 60 days after transplanting), and beginning of harvest (NDVI_70, 70 days after transplanting). Tobacco harvesting was performed manually in August and September 2013, and yield was measured from the corresponding soil and NDVI sample locations when leaves matured.

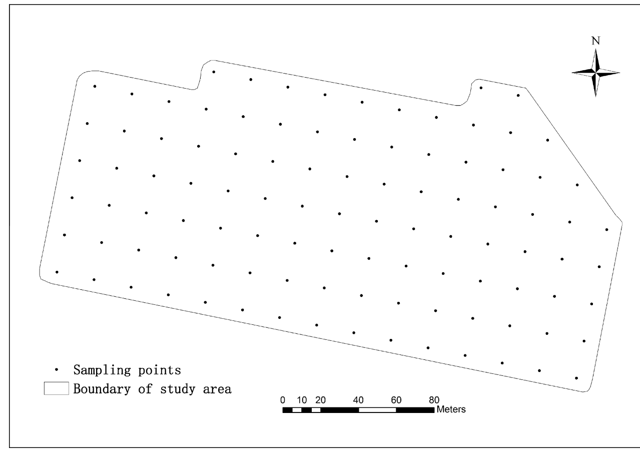

Fig. 1. Sampling points and boundary of study area.

2.2. Data analysis

Descriptive statistics including mean, standard deviation (SD), maximum, minimum, coefficient of variation (CV), and skewness were computed for each variable by SPSS statistical software (SPSS Inc., Chicago, IL, USA). Normality of all these variables were tested by using the Kolmogorov–Smirnov statistics. Stepwise multiple regression analysis as the variable selection method was used to determine the key yield-limiting factors for tobacco in this study.

Geostatistics is a kind of mathematical method, which is based on the theory of regionalized variable, and used semivariance as a fundamental tool (Matheron, 1971). It is an important tool in characterizing the spatial variability of soil properties (Mabit et al., 2008; Wang et al., 2010). Geostatistics provides a set of statistical tools for the description of spatial pattern, for quantitative modeling of spatial continuity, and for spatial prediction (Goovaerts, 1998). The aim of geostatistics is to use point information to estimate spatial variability (Liu et al., 2008). Semivariogram and kriging play a principal role in this field. The semivariance calculation and semivariogram function model fitting were performed using GS+ 7.0 (Robertso, 2000). The fitted models were then used in ordinary kriging procedure to estimate the values of variable at unsampled locations and contour maps of variables