Geoderma 232–234 (2014) 381–393

Contents lists available at ScienceDirect

Geoderma

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

Determination of site-specific management zones using soil physico-chemical properties and crop yields in coastal reclaimed farmland

Rong-Jiang Yao [a,b], Jing-Song Yang [a,b,*], Tong-Juan Zhang [b], Peng Gao [c], Xiang-Ping Wang [a], Li-Zhou Hong [d], Mao-Weng Wang [d]

[a] State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences (CAS), Nanjing 210008, China
[b] Dongtai Institute of Tidal Flat Research, Nanjing Branch of the Chinese Academy of Sciences, Dongtai 224200, China
[c] Department of Geography, University of South Carolina, 709 Bull Street, Columbia, SC 29208, USA
[d] Institute of Agricultural Sciences of the Coastal District in Jiangsu Province, Yancheng, 224002, China

ARTICLE INFO

Article history:
Received 29 May 2013
Received in revised form 21 April 2014
Accepted 4 June 2014
Available online 14 June 2014

Keywords:
Management zone
Fuzzy k-means clustering
Spatial variability
Coastal
Reclaimed farmland

ABSTRACT

Delineating site-specific management zones is increasingly attracting attentions due to the need in understanding the intrinsic relationship between spatially varied productivity and soil characteristics, and growing public concern about the productivity of soils and maximum efficiency of crop inputs. Our primary objectives were to characterize the spatial variability of soil attributes associated with crop productivity, to delineate and to evaluate the appropriateness of the resultant site-specific management zones. A total of 15 soil attributes representing soil chemical and physical properties (0–10 cm) and crop above-ground biomass on 85 sampling locations was chosen in a typical coastal newly-reclaimed farmland of north Jiangsu Province, China. Site-specific management zones were identified based upon the spatial variability of soil attributes and crop above-ground biomass, and the appropriateness of management zones was evaluated in comparison with that of the rotation systems presently used. Results indicated that separating the study area into two site-specific management zones was a good compromise between sensitivity and visually variability patterns of soil and crop. The two management zones exhibited significant difference in SOC, SOCD, TN, AN, AK, EC_e, pH, ρ_b, Clay, K_s and crop yield. The obtained management zones had higher appropriateness over the rotation systems presently practiced although the spatial pattern of management zones showed similarity to that of rotation systems. Such results allowed us to conclude that the resultant management zones were mainly dominated by cultural practices used in different rotation systems as the management zones were developed using our preliminary knowledge of cropping rotation systems in this area. Utilizing site-specific management zones would help manage the within-field variability of yield-limiting soil chemical and physical properties.

1. Introduction

With the advent of precision farming, the need for understanding the relationship among spatial variability of soil properties, field management practices, and crop yields is getting increasingly important because of growing concern about the higher productivity of soils and more efficient application of agricultural inputs. Precision farming or site-specific management aims at managing soil spatial variability by applying inputs according to site-specific requirements of a specific soil and crop (Fraisse et al., 1999). The key concept of site-specific management is to identify and manage spatially coherent regions within the geographic area defined by field boundaries. These regions or management zones should represent a homogenous combination of potential yield-limiting factors. Determination of sub-field areas is difficult due to the spatial variability and complex combination of factors that may affect crop yield (Fridgen et al., 2000; Schepers et al., 2004). In some cases, improperly defining management zones may be no better than uniform management of the field.

Site-specific management zones have many other applications in addition to representing areas of equal productivity potential. Khosla and Alley (1999) used homogenous management zones as an alternative to optimize grid soil sampling and Fleming et al. (2000) developed nutrient maps for variable rate fertilizer application based upon management zones. Spatially coherent areas within fields may also be useful in delineating spatial variability of soil properties (Mzuku et al., 2005), identifying soil classification (Chen et al., 2005), and relating yield to

* Corresponding author at: State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences (CAS), Nanjing 210008, China.

http://dx.doi.org/10.1016/j.geoderma.2014.06.006

soil and topographic parameters for crop-modeling evaluation (Fraisse et al., 2001).

There are numerous approaches for delineating within-field management zones, but most approaches rely on spatial information sources that are stable or predictable over time and are related to crop yield (Doerge, 1999). Topography factors (slope, gradient and elevation, etc.), aerial photographs (soil brightness, remote sensing images, etc.), soil attributes (nutrients, electrical conductivity, organic matter and texture, etc.), and yield maps have been used as logical basis to define homogenous zones in agricultural fields (Franzen et al., 2002; Li et al., 2007; Schepers et al., 2004). Topographic attributes and landscape position data were the most widely used factors in mapping within-field areas of high and low productivity (Jaynes et al., 1994; Sudduth et al., 1997). In these studies, footslope positions generally out-yielded side-slope positions due to higher water availability unless waterlogging resulted from poor drainage. Aerial photographs have also been suggested as approaches to delineate management zones (Schepers et al., 2000). Aerial images revealing soil brightness, which is expressed as digital numbers for red, green, and blue spectral bands of the images, can be acquired at high frequency and has been used with success in determining management zones (Schepers et al., 2004). Boydell and McBratney (1999) found that imagery of a growing crop and yield data collected in the same year were highly correlated and could be used as an accurate representation of crop production potential for that specific year. Remote sensing technology is especially appealing in identifying management zones because it is noninvasive and low in cost (Mulla and Schepers, 1997). Evidence from numerous literatures for suggesting practical use of remote sensing technology to delineate management zones is increasing (Vanderstraete et al., 2005; Varvel et al., 1999).

Electromagnetic induction (EM) measuring apparent soil electrical conductivity in a fairly quick manner has been suggested as a noninvasive approach to define the field boundaries of management zone. Electromagnetic induction has been used widely to effectively map spatial variability in soil properties such as salinity, water content and clay content from field to catchment scales (Triantafilis and Lesch, 2005; Yao and Yang, 2010). Recently, electromagnetic induction has gained popularity in precision agriculture, such as improvement of digital soil mapping (Zhu et al., 2010), identification of manure accumulation area and soil constraints to the crop yields (Dang et al., 2011; Woodbury et al., 2009), and assessment of potential nutrient build-up (Cordeiro et al., 2011). Another promising noninvasive approach to define management zone involves the use of ground penetrating radar (GPR) to measure soil dielectric properties using high frequency electromagnetic waves. Recently, surface GPR approaches have been used to estimate and map soil water content (Huisman et al., 2003; Lunt et al., 2005), subsurface flow pathways (Gish et al., 2002), and soil depth (Sucre et al., 2010) in a noninvasive manner and with high spatial resolution. Electromagnetic induction and ground penetrating radar have evolved from tools for measuring soil properties to a means of mapping spatial variability of soil physical and chemical properties for applications in precision agriculture.

Spatial variability in soil chemical and physical properties and yield maps has also been used to define homogenous management zones. Chung et al. (2001) found that grain yield, electrical conductivity, soil base cations and SiO_2 exhibited large-scale variability within a relatively small area. Soil compaction, total porosity and bulk density have also documented as varying significantly within single fields, which have influence on the spatial distribution of crop productivity potential (Wells et al., 2000). Worthy to mention is that electrical conductivity (EC) also plays an important role in delineating management zones. Johnson et al. (2003) found that management zones based on EC mapping provided a useful framework for soil sampling and could potentially be applied to assess temporal impacts of management on soil conditions. Using soil brightness, elevation and EC, Schepers et al. (2004) assessed the appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. Franzen and Kitchen (1999) utilized a variety of data resources such as topography, satellite imagery, soil EC, crop yield maps and intensive soil survey data to construct management zones for N fertilizer management. Li et al. (2007) used soil EC, fertility, cotton yields and normalized difference vegetation index (NDVI) to identify management zones of low, medium and high yield in coastal farming region. When developing management zones of crop productivity, practical application of yield mapping, however, has been plagued by spatial and temporal variation in measured yield (Sadler et al., 1995). Therefore, most efforts in yield map interpolation have focused on identifying generalized zones of low, medium and high yield (Stafford et al., 1998).

A coastal farming area reclaimed from tidal flats in north Jiangsu Province, eastern China was selected for this study. The experimental site characterized by low soil quality and crop productivity was typical of coastal newly-reclaimed salt-affected soils in China, and two crop rotation and management systems (rice/rape rotation and cotton/barley rotation), representing the major crop rotation patterns in north Jiangsu Province, were practiced in the experimental site. By means of fuzzy k-means (FKM) clustering algorithm, a pool of 15 soil attributes consisting of 9 soil chemical properties and 6 soil physical properties were selected to identify management zones of crop productivity. Recognizing the importance of soil spatial variability in determining management zones, the presented research was conducted with the following objectives: (*i*) to characterize the spatial variability of soil chemical and physical attributes associated with crop productivity, (*ii*) to identify the management zones using fuzzy k-means clustering analysis based on the spatial variability of the selected soil chemical and physical attributes, and (*iii*) to evaluate the appropriateness of the resultant site-specific management zones in comparison with the present rotation systems.

2. Materials and methods

2.1. Experimental site description

The experiment site was situated in Jinhai Farm as located southeast of Dafeng City (32°59′–33°01′N, 120°49′–120°51′E), north Jiangsu Province, China (Fig. 1). This farm was approximately 5 km to the coastline of China Yellow Sea and the topography was flat with an average elevation of 1.5 m across the farm. Formed from the Yangtze River alluvial sediments and marine sediments, the predominant soil is silt loam, classified as a loamy, mixed, hyperthermic, Aquic Halaquepts according to soil taxonomy (Soil Survey Staff, 2010). This farm is in subtropical zone and strongly affected by the southeast monsoon from Spring to Autumn and northwest monsoon in Winter. Mean air temperature is 15.5 °C and mean annual precipitation is 1035.1 mm (from 2001 to 2011) with approximately 67% of annual rainfall occurring June through September. Cold, dry season is from October to March and the hot, wet season is from April to September. Salinization and low fertility are known as the most significant limitations to soil productivity in this farm and large areas of salt-affected land was observed due to high surface soil salinity as well as very saline shallow water table. This farm covers a variety of soil salinity conditions and it is typical for large areas of coastal salt-affected farmlands in north Jiangsu Province.

2.2. Land use and management history

The experimental site consisting of 26 stripping fields was reclaimed from tidal flats in 1999 and had no documented history of cultivation until 2001. Two crop rotation systems including rice/rape rotation and cotton/barley rotation, representing the most commonly used rotation systems in extensively farmed coastal areas were practiced in the experimental site. Using conventional soil fertility and pest management practices, the eastern portion of the site (eastern 12 stripping fields) has been in a rice (*Oryza sativa* L.)/rape (*Brassica campestris* L.) rotation (rice in summer and rape in winter) since its reclamation. The western portion of the site (western 14 stripping fields) has been consecutively