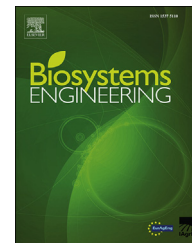




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journal homepage: [www.elsevier.com/locate/issn/15375110](http://www.elsevier.com/locate/issn/15375110)**Special Issue: Proximal Soil Sensing****Research Paper****Prediction of soil cation exchange capacity using visible and near infrared spectroscopy**Yahya Ulusoy <sup>a,\*</sup>, Yücel Tekin <sup>a,1</sup>, Zeynal Tümsavaş <sup>b</sup>, Abdul M. Mouazen <sup>c</sup><sup>a</sup> Vocational School of Technical Sciences, Uludag University, Bursa, Turkey<sup>b</sup> Agricultural Faculty, Uludag University, Bursa, Turkey<sup>c</sup> Cranfield Soil and AgriFood Institute, Cranfield University, United Kingdom

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This study was undertaken to investigate the application of visible and near infrared (vis–NIR) spectroscopy for determining soil cation exchange capacity (CEC) under laboratory and on-line field conditions. Measurements were conducted in two fields with clay texture in field 1 (F1) and clay-loam texture in field 2 (F2) both in Turkey. Partial least squares (PLS) regression analyses with full cross-validation were carried out to establish CEC models using three datasets of F1, F2 and F1 + F2. Analytically-measured, laboratory vis–NIR and on-line vis–NIR predicted maps were produced and compared statistically by kappa coefficient. Results of the CEC prediction using laboratory vis–NIR data gave good prediction results, with averaged  $r^2$  values of 0.92 and 0.72, root mean squared errors of prediction (RMSEP) of 1.89 and 1.54  $\text{cmol kg}^{-1}$  and residual prediction deviations (RPD) of 3.69 and 1.89 for F1 and F2, respectively. Less successful predictions were obtained for the on-line measurement with  $r^2$  of 0.75 and 0.7, RMSEP of 4.79 and 1.76  $\text{cmol kg}^{-1}$  and RPD of 1.45 and 1.56 for F1 and F2, respectively. Comparisons using kappa statistics test indicated a significant agreement ( $\kappa = 0.69$ ) between analytically-measured and laboratory vis–NIR predicted CEC maps of F1, while poorer agreement was found for F2 ( $\kappa = 0.43$ ). A moderate spatial similarity was also found between analytically-measured and on-line vis–NIR predicted CEC maps in F1 ( $\kappa = 0.50$ ) and F2 ( $\kappa = 0.49$ ). This study suggests that soil CEC can be satisfactorily analysed using vis–NIR spectroscopy under laboratory conditions and with somewhat less precision under on-line scanning conditions.

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## 1. Introduction

Cation exchange capacity (CEC), which refers to the soil's ability to hold positively-charged ions, is an important indicator of soil fertility. It is an important property for site-specific management of soil nutrients in precision agriculture. Generally, CEC values increase with the increase in the content of the colloidal fraction (amount and type of clay and organic matter) in the soil. The conventional analytical methods used for the determination of CEC such as the sodium saturation method (Chapman, 1965) are expensive, difficult and time consuming, because different cations must be extracted and determined. Therefore, researchers have attempted to find alternative methods that are simple, fast, and cost-effective.

Proximal soil sensing methods are promising techniques for application with decision support tools that help with soil fertility management. In a review of the application of proximal soil sensing to assess soil properties, Kuang et al. (2012) identified visible and near infrared (vis–NIR) spectroscopy as the most promising measurement technique to supply accurate and meaningful data on CEC for successful decision support on soil fertility management and vis–NIR spectroscopy has become the most attractive proximal soil sensing method for acquiring data on key soil properties including CEC. Recent studies, e.g., Mouazen, Maleki, De Baerdemaeker, and Ramon (2007), Viscarra-Rossel and Chen (2011), Tekin, Kuang, and Mouazen (2013) and Kodaira and Shibusawa (2013), have shown that vis–NIR spectroscopy provides accurate quantification of the main physical and chemical soil properties and that it is a useful tool for digital soil mapping and for precision agriculture applications. This is because vis–NIR spectra of soils contain large sets of spectral information representing broad bands of overtones and combinations of fundamental vibrations occurring in the mid infrared (MIR) range of the electromagnetic spectrum (Stenberg, Viscarra Rossel, Mouazen, & Wetterlind, 2010). Quantitative information on CEC can be extracted with suitable multivariate regression methods, which have an advantage over simple bivariate relationships and are suitable for peak intensity measurements such as those existing in MIR range (Soriano-Disla, Janik, Viscarra-Rossel, MacDonald, & McLaughlin, 2014). Partial least squares (PLS) regression is the most common technique adopted to model the relationships between infrared spectral intensity characteristics of soil components and soil properties through derived PLS loadings, scores and regression coefficients (Janik, Forrester, & Rawson, 2009). So far, the use of vis–NIR spectroscopy for the determination of soil CEC has achieved varying degrees of success, depending on the conditions, under which the evaluations were carried out (e.g., in the laboratory or on-line in the field) (Bilgili, Van Es, Akbas, Durak, & Hively, 2010; Cañasveras-Sánchez, Barrón, del Campillo, & Viscarra-Rossel, 2012; Leone, Viscarra-Rossel, Amenta, & Buondonno, 2012; Marin-Gonzalez, Kuang, Quraishi, Munóz-García, & Mouazen, 2013; Savvides, Corstanje, Baxter, Rawlins, & Lark., 2010). Previous studies showed that the accuracy for CEC assessment under laboratory scanning conditions varied widely in the prediction set ( $r^2 = 0.13–0.90$ ; RMSEP = 1.22–10.43 cmol kg<sup>-1</sup>;

RPD = 0.60–2.7) (e.g., Awiti, Walsh, Shepherd, & Kinyamario, 2008; Ben-Dor & Banin, 1995; Chang, Laird, Mausbach, & Hurburgh, 2001; Mouazen, De Baerdemaeker, & Ramon, 2006; Waruru, Shepherd, Ndegwa, Kamoni, & Sila, 2014). There are several reasons for the different results reported, which include the type of spectrophotometer, variability of CEC in the dataset, modelling technique applied and soil type. Marin-Gonzalez et al. (2013) reported moderately good prediction of CEC ( $r^2 = 0.62$ ; RMSEP = 0.97 cmol kg<sup>-1</sup>, and RPD = 1.61) for on-line measurement in a field in Bedfordshire in the UK. Kweon, Lund, and Maxton (2013) reported successful on-line measurements of six out of nine fields with  $r^2$  of 0.86 or higher and RPD of 2.78 or greater. To the best of our knowledge, no report of on-line measurement of CEC in arid and semi-arid environments has been presented in the literature.

The aim of this study was to evaluate the accuracy of an on-line vis–NIR spectroscopy sensor to assess and map the CEC of the soil in two fields located in semi-arid regions of Turkey. The paper also compared modelling results and maps developed for CEC with individual- and mixed-field datasets.

## 2. Materials and methods

### 2.1. Experimental sites

This study was carried out in two fields in Turkey in 2014, one located in the village of Karacabey in Bursa Province (F1; 10.06 ha; Latitude: 40°09'10.8"N and Longitude: 28°23'01.0"E), and the second field a circular one located in the village of Ayrancı in Karaman Province (F2; 50 ha; Latitude: 37°32'39.1"N and Longitude: 33°40'43.6"E). Both fields were irrigated. According to soil maps of the General Directorate of Rural Service of Turkey, the soil types of Karacabey field and Ayrancı field are classified as vertisols and fluvisols (Alluvial), respectively. Karacabey field is of a clay soil texture, whereas Ayrancı field is of a clay loam texture (Table 1). The crops cultivated in 2014 in Karacabey and Ayrancı fields were barley and wheat, respectively.

### 2.2. On-line soil sensor and measurement

The on-line soil sensor consisted of a subsoiler with an optical probe attached to a chisel (Mouazen, 2006). The subsoiler, acting as a soil-cutting tool, together with the optical probe were installed on a frame (Mouazen, De Baerdemaeker, & Ramon, 2005), which had been manufactured at Uludag University. This on-line sensor was mounted on the three-point linkage of a tractor for field measurements (Fig. 1). An AgroSpec mobile, fibre-type vis–NIR spectrophotometer (Tec5 Technology for Spectroscopy, Germany) having a spectral range of 350–2200 nm was used in this study. A differential global positioning system (DGPS) (EZ-Guide 250, Trimble, USA) with a sub-metre accuracy was employed to record the position of the measured on-line spectra. An AgroSpec software, a platform for the mobile spectrometer system, was used to acquire soil spectral and DGPS data. More detailed information about the on-line sensor can be found in Quraishi and Mouazen (2013).

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