Soil Organic Carbon Modeling and Mapping in a Semi-Arid Environment Using Thematic Mapper Data

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Abstract
This study evaluated the effectiveness of using Thematic Mapper (TM) data for estimating soil organic carbon (SOC) content in the Zarqa Basin, Jordan, a typical semi-arid environment, and under natural surface conditions by testing a variety of statistical modeling techniques. This is essential for implementing carbon crediting programs for mitigating the effects of global warming. Although none of the developed models was powerful in predicting SOC, a stepwise regression model was selected since it provided the lowest validation root mean square error (RMSE) of 10.4 metric tons per hectare (ton/ha). Using this model, a SOC map for the basin was constructed by applying map algebra. The total SOC content to 0.2 m depth of the basin was calculated to be 9,432,986.4 metric tons with SOC density of 26.3 ton/ha. This study suggested that, in semi-arid environments and using the statistical modeling techniques that were tested, TM-based SOC models cannot be used for implementing carbon crediting programs; however, they can estimate total surface SOC pools in large areas to within a few percent error.

Introduction
Soil carbon management and sequestration is one of several important strategies suggested by Kyoto protocol in 1997 for reducing the concentrations of carbon dioxide, the main greenhouse gas, in the atmosphere as a global warming abatement measure (UN, 1998). This, in turn, has a host of ancillary benefits, including reduced soil erosion, improved overall soil quality, reduced floods' impacts, and improved air and water quality (Reed, 2007). Hence, many countries around the world began considering the development of policy instruments (such as carbon credits) designed to encourage owners of agricultural, grazing, and forest lands to adopt management practices that facilitate withdrawing carbon from the atmosphere and sequestering it in the soil through the natural processes of humification (Lewandrowski et al., 2004). However, in order for carbon sequestered in soil to gain international acceptance as a global warming abatement measure, there is an urgent need to develop simple, accurate, rapid, and inexpensive methods for monitoring spatial and temporal changes in soil carbon stocks (Campbell et al., 2001). Direct field and laboratory measurements of soil carbon pools are very accurate, but are very costly and provide only site-specific information. Conversely, indirect estimation of carbon stock changes utilizing, among other methods, remote sensing and geographic information systems (GIS), is cost-effective and provides spatially continuous information over large areas on a repetitive basis. Therefore, to monitor soil carbon changes over large areas, indirect methods based on relationships developed at the field should be used (Post et al. 2001).

Many studies tried to model the relationship between soil organic carbon (SOC) or soil organic matter (SOM) and spectral information obtained by hyperspectral spectrometers either handheld or mounted on airplanes (e.g., Dalal and Henry, 1986; Gomoz et al., 2008; Huang et al., 2007; Ingleby and Crowe, 2000) or by multispectral satellite and airborne remote sensing sensors (e.g., Agru et al., 1990; Chen et al., 2000; Coleman et al., 1993; Huang et al., 2007; Ishida and Ando, 1999; Van Deventer, 1992; Wilcox et al., 1994; Wu et al., 2009). The use of hyperspectral spectrometers mounted on airplanes showed promising results, but that came with a high price tag of instrumentation and tasking flights across the study areas. In addition, handheld spectrometers provide discrete measurements and cover relatively small areas. Generally, studies that used multispectral satellite remote sensing systems provided poor results. The studies conducted by Chen et al. (2000) and Wilcox et al. (1994) resulted in relatively highly accurate predictions of SOC, but the study areas were relatively small with bare and dry surface conditions. Although these types of studies have their merit, as they are typically in a more controlled environment, they do not produce practical results when the goal is to study large areas repetitively under natural field conditions, which is the goal behind any carbon credit monitoring program. In addition, Agru et al. (1990), Coleman et al. (1993), Ishida and Ando (1999), and Wilcox et al. (1994) built their conclusions on just the calibration stage and did not validate the results using a validation sample. Furthermore, Huang et al. (2007) and Wu et al. (2009) used Enhanced Thematic Mapper Plus (ETM+) imagery that were acquired after 31 May 2003. The authors of this study do not recommend using images acquired by ETM+ sensor after this date, since they suffer from missing data resulted from a permanent mechanical malfunctioning in the...