ABSTRACT

Since the inception of the Universal Soil Loss Equation (USLE) in 1978, methods based primarily on weighing factors of rainfall energy, slope, surface cover, and soil quality have been used to predict rates of soil erosion over small areas. It is widely recognized, however, that the USLE and similar equations (e.g., the Revised USLE and the Soil Loss Equation Model for Southern Africa) fail to provide accurate predictions of soil loss for larger, more heterogeneous areas and thus, in such instances, they can only be treated qualitatively. They also require expensive laboratory analysis of soils and detailed field measurements, putting them beyond the reach of many farmers; this is especially true in developing countries, where such assessments are most needed.

Relying on a large (~40 km^2) Tanzanian village as a case study, this paper presents methods derived from the USLE and its relatives for rapid, qualitative assessment of soil loss using two multispectral ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) images and digital elevation model (DEM), and diffuse reflectance spectrometry (DRS) in the field. Soil loss estimates generated using this methodology are integrated with socioeconomic data (collected from farmer surveys), land use estimates, and soil quality indicators to generate a set of recommendations for soil conservation and agroforestry in the village, which are intended to reduce soil loss to tolerable levels.

The village of Kambi ya Simba is located in northern Tanzania's Rift Valley highlands, in the Karatu District of the Arusha Region. It was settled by the agro-pastoralist Iraqw at the end of WWII and expanded slowly until the early 1970's

when the Tanzanian government implemented a national program of compulsory resettlement and land reform in rural areas (“villigization”). Kambi ya Simba was selected for villigization, received a large influx of emigrants, and most of the village’s arable land was reappropriated and/or cleared for cultivation in the span of two years (1974-1976). The population has grown rapidly during the past two decades and, as result, land shortages have become increasingly pressing and crop productivity for the village’s two major crops—wheat and maize—has declined markedly.

Farmer surveys (n = 50) were collected during July 2003 to assess the current situation in terms of farmer socioeconomics, crop productivity, and land husbandry practices. These results show that there are substantial socioeconomic inequities in terms of the amount of land and livestock owned; crop productivity is significantly higher in certain regions/soil types of the village ($p < 0.005$); and certain management practices (i.e., contour ridges, manure usage) and field attributes (i.e., age and size) appear to have significant, positive correlations to crop productivity ($p < 0.025$).

The ASTER images of Kambi ya Simba—one taken before (June 2002) and one taken after harvests (October 2002)—were used to map the village’s soil types, land uses, and to provide cover estimates for input into the soil loss equation. The village’s soil types, defined by Tanzania’s National Soil Service (1989), are distinguished mainly by physiological properties, i.e., climate, slope, and stoniness. Land use categories are based on the agro-pastoral functions they serve: cultivation, grazing (i.e., open woodland), and forest resources (i.e., dense bush). Cover estimates were calculated using a vegetation index designed specifically for this study, SLA-

NDVI (Soil Line Adjusted Normalized Difference Vegetation Index), which is more sensitive than other commonly used indices to changes in vegetations' reflectance that occur over altitude. A modified version of SLA-NDVI may prove useful in other remote sensing applications. The DEM, derived photogrammetrically from the October ASTER image, was used to generate the altitude parameter in SLA-NDVI, as well as to calculate the rainfall intensity and slope-based factors required by the soil loss equation.

The last factor included in the soil loss equation relies on several soil properties to estimate erodibility, all of which were predicting using DRS. First, georeferenced topsoil samples were collected from the village in July 2003 and scanned under a spectroradiometer at the World Agroforestry Centre (ICRAF) in Nairobi to produce a spectral plot for each sample (350 – 2500 nm). Laboratory analysis of soil properties—clay content, organic carbon, nitrogen, and exchangeable potassium—was performed on a small subset of the population and results were calibrated to the soils' spectral data using a statistical algorithm known as Partial Least Squares (PLS) regression. Calibrations yielded generally good fits (r^2 = 0.84 – 0.98) for all soil properties, and were used to predict values for the remainder of the population. These were then used to gauge soil quality and degradation when combined with soil sample site descriptions. Soil properties were also assessed by soil type/land use, where there are correlations to crop productivity, and averaged values for clay and organic matter content were used to calculate the soil erodibility factor in the soil loss equation.

Based on the DRS-predicted soil property averages and ASTER-derived values for the additional parameters in the USLE, a soil loss estimate was generated for each pixel contained in the ASTER images (15 x 15 m^2 ground resolution at nadir). Results show strong correspondence in terms of identifying areas where severe erosion is likely to occur and has occurred (based on ground truth observations), crop productivity significantly suffers from a lack of conservation measures, crop density is greatest, and soil nutrients appear to be most depleted. The strength of these correlations show that, despite a lack of comprehensive *in situ* field measurements and other limitations, this method of soil loss estimation has potential to characterize and influence land use development in rural areas. Although soil loss falls within the tolerable range for most fields in the village, there are several large areas where soil erosion is estimated to be quite severe. These are areas that should be targeted for expanding agroforestry and soil conservation so as to safeguard against further declines in soil quality and crop productivity.