Digital soil mapping using legacy soil data in Korea

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Abstract
Soil carbon storage and available water capacity are important properties for land management, plant production and environment and ecosystem management. This paper will apply the digital soil mapping concept for mapping these two properties in South Korea. A Korean soil database was compiled, which includes chemical and physical properties such as particle size, moisture retention, organic matter, cation exchange capacity, and a limited number of bulk density data based on 380 soil series. The first step is to estimate bulk density for estimation of both C storage and available water capacity. Bulk density at different depths of soils was predicted by deriving a pedotransfer function model with sand, depth, and organic matter, based on Adams' model (1973). Organic C distribution with depth was first derived by converting from mass basis C (kg/kg) to volume basis C (kg/m^3). C storage (kg/m^2) was first calculated by multiplying C on the volume basis to the thickness of each soil layer (m), and finally integrated to a depth of 1 m for each soil series. Mapping available water capacity was more challenging as only half of the database contains measurement of water retention at -33 and -1500 kPa. Field capacity was calculated from clay content and predicted bulk density and adjusted by taking into account porosity. Wilting point was calculated from clay content and adjusted for any discrepancy with predicted field capacity and porosity. Available water capacity (mm) to a depth of 1 m was estimated by multiplying the amount of water stored between field capacity and wilting point and the thickness of the layer. The carbon storage and available water capacity from surface to a depth of 1 m for the south part of whole Korean peninsula were mapped using the estimated parameters in a soil series map unit (1:25,000). Mean value of carbon density of Korea is approximately 5 kg/m^2 and available water capacity is approximately 154 mm. Total soil carbon storage of agricultural land in Korea is approximately 174 Gg.

Key Words
Soil information, carbon storage, available water capacity, Korea, digital soil mapping.

Introduction
The need for accurate, up-to-date, and spatially referenced soil information, which is important for land management, food production, and ecosystem management, has been identified by policy and decision makers, land users, farmers, and researchers. "This need coincides with an enormous leap in technologies that allow accurate collecting and predicting soil properties. Accordingly, there is a need for making a new digital soil map of the world using state-of-the-art and emerging technologies for soil mapping and predicting soil properties at fine resolution" (www.globalsoilmap.net). Minasny *et al.* (2006) showed the application of digital soil mapping for mapping the depth functions of soil carbon in Australia. Hong *et al.* (2009a, 2009b) introduced Korean soils and information systems and also mapped soil carbon storage and water capacity using soil profile and soil series information.

An Asian soil information working group was also organized during the workshop on "A new approach to soil information systems for natural resources management in Asian countries" which was held in Japan in 2008 initiated by Food & Fertilizer Technology Center (FFTC). The objectives of the workshop were to review the current status of SIS (or available soil data such as soil maps) in participating Asian countries, to exchange relevant information on appropriate SIS for the participating countries, to share technological know-how relevant for establishing a SIS for sustainable crop production among the participant countries, and to discuss the possibility of establishment of an appropriate regional SIS for sustainable crop production in the Asian and Pacific Council (ASPAC).

The objectives of this study were to estimate and map soil carbon storage and available water capacity of Korea using the digital soil mapping approach which has been defined as, "the creation and population of spatial soil information systems by numerical models inferring the spatial and temporal variations of soil types and soil properties from soil observation and knowledge and from related environmental variables" (Lagacherie and McBratney 2007).

Methods

Soil database

A Korean database used in this study was compiled based on the "Taxonomical Classification of Korean Soils" (NIAST, RDA, 2000), which was mostly collected in the 1970s for soil profile description. It includes soil chemical and physical properties of each horizon (n=1,559) such as particle size, moisture retention, organic matter, cation exchange capacity, and a limited number of bulk density data (n=108) based on 380 soil series. When described using the Soil Taxonomy of the USDA, soils in Korea are classified into seven Soil Orders which are then further divided into 14 Sub-Orders according to moisture regimes. Among those seven Soil Orders, the younger soils, Entisols and Inceptisols, are dominant. Entisols are the youngest soils, followed by Inceptisols. Alfisols and Ultisols . The working unit of soil classification is the Soil Series. So far 390 Soil Series have been identified in the country. Table 1 is a summary of the areal extent of the different Soil Orders and the number of Soil Series within them. Table 1 clearly shows that abundance of younger soils (Entisols and Inceptisols). This is a result of the influences of both Korea's unique climate, with concentrated rainfall in summer, and rugged topography as characterized by the wide occurrence of highly-sloped mountains. This strongly suggests that, if the soil resources are to be adequately conserved, serious attention must be paid to development of measures to minimize the soil erosion in hilly lands.

Table 1. Major soil orders/sub-orders, number of soil series occurring within them and the areal extent of soil orders in Korea.

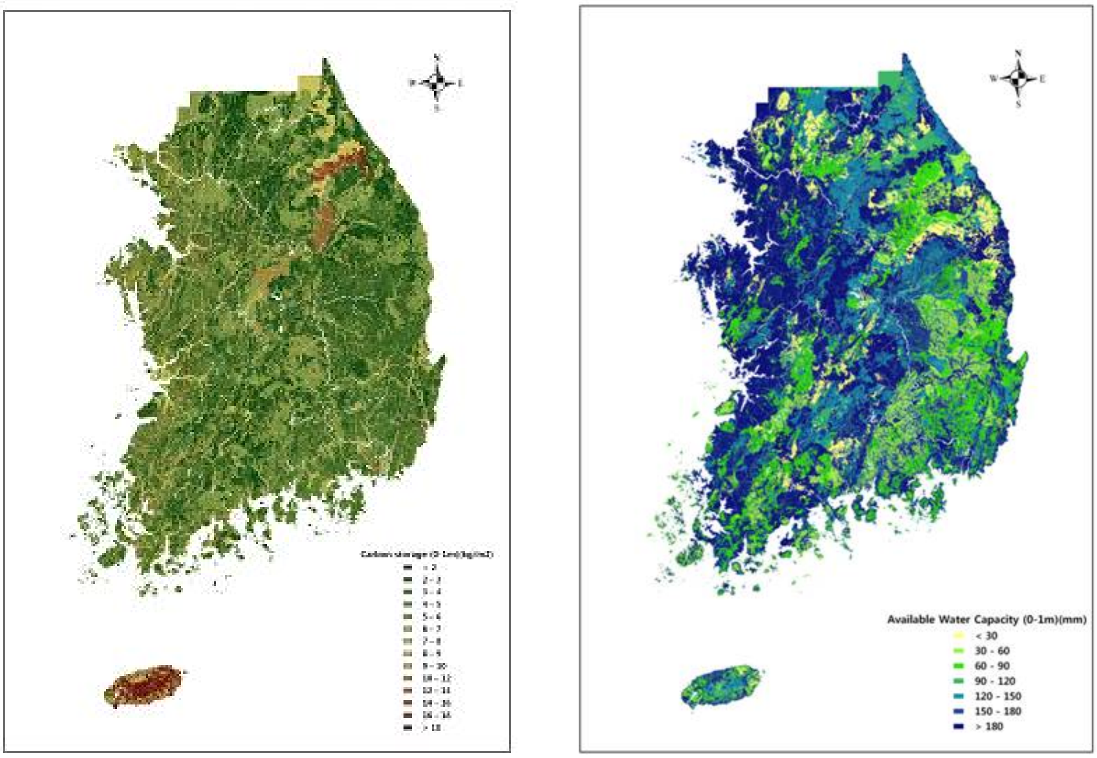
Soil Orders	Sub orders	No. of Soil Series	Area-10^3 ha (%)
Inceptisols	Aquepts	77	6,668 (69.2)
	Udepts	133	
Entisols	Aquents	14	1,315 (13.7)
	Fluvents	13	
	Orthents	17	
	Psamments	20	
Ultisols	Udults	28	398 (4.2)
Alfisols	Aqualfs	7	276 (2.9)
	Udalfs	37	
Andisols	Udands	39	129 (1.3)
	Vitrands	1	
Mollisols	Udolls	2	5 (0.1)
Histosols	Saprists	1	0.4 (0)
	Hemists	1	
		390	

Digital mapping of soil C storage and available water capacity

The first step was to estimate bulk density for estimation of both C storage and available water capacity. Bulk density at different depths of soils was predicted by deriving a pedotransfer function model with sand and depth. Adjustment for organic matter content was based on Adams' model (1973). Organic C distribution with depth was first derived by converting from mass basis C (kg/kg) to volume basis C (kg/m^3). C storage (kg/m^2) was first calculated by multiplying C on the volume basis to the thickness of each soil layer (m), and finally integrated to a depth of 1 m for each soil series. Mapping available water capacity was more challenging as only half of the database contains measurement of water retention at -33 and -1500 kPa. Furthermore measurement of water retention is in mass basis and based on disturbed soil samples. Pedotransfer functions were derived for volumetric water content at field capacity (-33 kPa) and wilting point (-1500 kPa). Further adjustments based on total soil porosity are required as the field capacity values were derived from disturbed soil samples. Field capacity was calculated from clay content and predicted bulk density and adjusted by taking into account porosity. Wilting point was calculated from clay content and adjusted for any discrepancy with predicted field capacity and porosity. Available water capacity (mm) to a depth of 1 m was estimated by multiplying the amount of water stored between field capacity and wilting point and the thickness of the layer. The carbon storage and available water capacity from surface to a depth of 1 m for the south part of whole Korean peninsula were mapped using the estimated parameters in a soil series map unit (1:25,000). Total carbon storage and available water capacity were summarized by land use type using land cover map provided by Ministry of Environment.

Results

Figure 1 shows the distribution of soil carbon storage (kg/m^2) and available water capacity (mm) of Korea. The distribution map of the soil properties was made by calculating mean soil organic carbon values and available water capacity to 1 meter depth for each soil series from Korean database and allotted the mean value calculated of soil properties to each of the detailed Korean soil map (1:25,000). The mean value (to 1 m depth) of carbon density of Korea is approximately 5 kg/m^2 and available water capacity is approximately 154 mm. Soil C density in grass and agricultural land were higher as 8.82 and 6.77 kg/m^2, respectively, than other land use types and available water capacity of soil was the highest as 203 mm in agricultural land as shown in Table 2. Total carbon storage and available water capacity were summarized by land use type using the land cover map provided by Ministry of Environment. Total soil carbon storage of agricultural land in Korea is approximately 174 Gg.



a) Soil carbon storage **b) Available water capacity**

Figure 1. Soil carbon storage and available water capacity map of Korea.

Table 2. Amount of soil carbon storage and available water capacity by land use type in Korea.

C storage	Forest	Agr. Field	Grass	Wetland	Barren
Land use (km^2)	61,394	25,648	1,858	1,780	1,439
Available Water Capacity (AWC, mm)	123.6	203.1	142.9	47.8	137.7
C density (kg/m^2)	4.05	6.77	8.82	1.10	4.24
Total C storage (Gg)	249	174	16	2	6

Conclusion

Soil carbon storage and available water capacity in Korea, which are important for land management, food production and environment and ecosystem management, were predicted and mapped based on a Korean database for soil profile description that mostly collected in the 1970s. Mean value (1 m depth) of carbon density of Korea is approximately 5 kg/m^2 and available water capacity is approximately 154 mm. Total carbon storage and available water capacity were summarized by land use type using land cover map provided by Ministry of Environment. Total soil carbon storage of agricultural land in Korea is approximately 174 Gg. Further work is required to verify this amount with recent soil data.

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