Predicting Carbon Stock of *Acacia mangium* Plantation Using Geostatistics

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1. Introduction
Quantifying carbon stock of a forest ecosystem has gained more importance recently, especially to provide reliable estimates required for implementing the Kyoto Protocol mechanism. Commonly, carbon stock estimation is conducted by applying a non-spatial sampling technique (e.g. stratified random or systematic sampling). Such sampling technique, however, has a main drawback because it can not provide spatial information regarding the carbon stock distribution over forest area. One of the promising methods to spatially predicting the carbon stock is geostatistics. This method provides a means to predict the carbon stock at un-sampled locations based on spatial correlation among sample plots (Webster & Oliver, 2001). Applicability of this method for predicting the carbon stock needs to be further explored. This study, therefore, was intended to develop the geostatistics as an alternative method for predicting and mapping carbon stock distribution of an *Acacia mangium* plantation.

2. Methods
This study was conducted at 1466.44 ha of *A. mangium* plantation in Tenjo district, Bogor, Indonesia. The carbon stock data obtained in 2005 from 248 sample plots with various sizes: 0.02 ha (for stand age of 1 to 2 years), 0.04 ha (for stand age of 3 to 4 years) and 0.10 ha (for stand age of 5 to 12 years). Spatial correlation of the carbon stocks was analyzed by using variogram models (i.e. spherical, exponential and Gaussian). The best fitted variogram model then was used for Ordinary Kriging (OK) to interpolate the carbon stocks at un-sample locations by assuming that there was no a strong trend in the geographic coordinates. To confirm such assumption, we also applied Universal Kriging (UK) by incorporating the geographic coordinates (UTM, zone 48S) as an auxiliary variable that was expected to improve the prediction accuracy. Both the krigings produced estimates and maps of the carbon stocks in the study area.

Accuracy of the kriging predictions were assessed by using cross-validation procedure (Webster & Oliver, 2001).

3. Results and Discussion
The spatial correlation of carbon stocks of *A. mangium* can be well modeled with the exponential variogram. This model revealed that the spatial correlation would still exist until the range of 3300 m, which implies that it is much longer than the sampling interval of 200 m, with total variance (sill) of 192 (t C/ha)$^2$. There was a high nugget effect, i.e. 88.65 (t C/ha)$^2$, which might be caused by the high variance within each sample plot. There was also a strong anisotropy pattern, where the maximum spatial correlation occurred at azimuth of 135° (with the long range of 6400 m) and minimum at azimuth of 225° (with the short range of 2200 m). Accordingly, the spatial interpolation using the OK and UK methods were performed based on the anisotropic exponential model. Prediction using the OK produced a carbon stock map (Fig. 1), which was not differ significantly than that obtained from the UK method. The cross-validation test revealed that both kriging methods produced similar accuracy as indicated by their root mean squared errors (RMSE) values, i.e. 10.69 for OK and 10.65 for UK. Apparently, the weak trend in the geographic coordinates ($R^2 = 15.9\%$) did not improve significantly the UK prediction. Similar finding has been reported by Musio et al. (2004). These results suggested that spatial prediction of the carbon stocks can be performed by only using the OK method, which can give an advantage of its simple calculation method.

Based on the OK prediction, the carbon stocks of *A.mangium* plantation were varied from 12.75 to 37.57 t C/ha (1st and 99th percentiles) with standard deviation varying from 10.45 to 12.35 t C/ha. The wider estimates of the OK prediction seem to be realistic because such method has taken into account variations of the carbon stocks which might vary within the forest area. This study confirmed that the geostatistics could be used as an alternative method for predicting and mapping spatial distribution of the carbon stocks. However, this method would less appropriate for a sparse population and if the sampling units were not evenly distributed (Payn et al., 1999).

Fig. 1. Carbon stock map of *A. mangium*

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