# Quantifying and Mapping Soil Organic Carbon in Sub-Saharan Africa using the Bayesian Maximum Entropy Approach


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## Background

- The Sudano-sahelian region supports a diverse agroeco-system comprising plant species essential for the livelihood of humans as well as for the global carbon cycle.
- Severe droughts coupled with unsustainable exploitation of woody plants as well as overgrazing have contributed to accelerated land degradation and marginalization of a substantial part of the region.
- The increase of soil carbon in Sahel, is entirely possible and certainly desirable to improve food security and mitigate the effects of land degradation and desertification.
- How to accurately estimates soil carbon in Sahelian Agroforestry systems?
- Standard geospatial analysis tools (i.e. Kriging methods, cokriging) present some limitations (Goovearts,1997).
- The Bayesian Maximum Entropy (BME) procedure was used to integrate soil carbon content (0-20cm) with class interval data (clay, carbon 20-40cm) for improved prediction.

## Objectives

1. To quantify and map the spatial distribution of soil organic carbon.
2. To compare standard geostatistics prediction with Bayesian Maximum Entropy.
3. To provide the reliability of estimations - Mean Squared Error(MSE) and Mean Error(ME)

## The Data Set

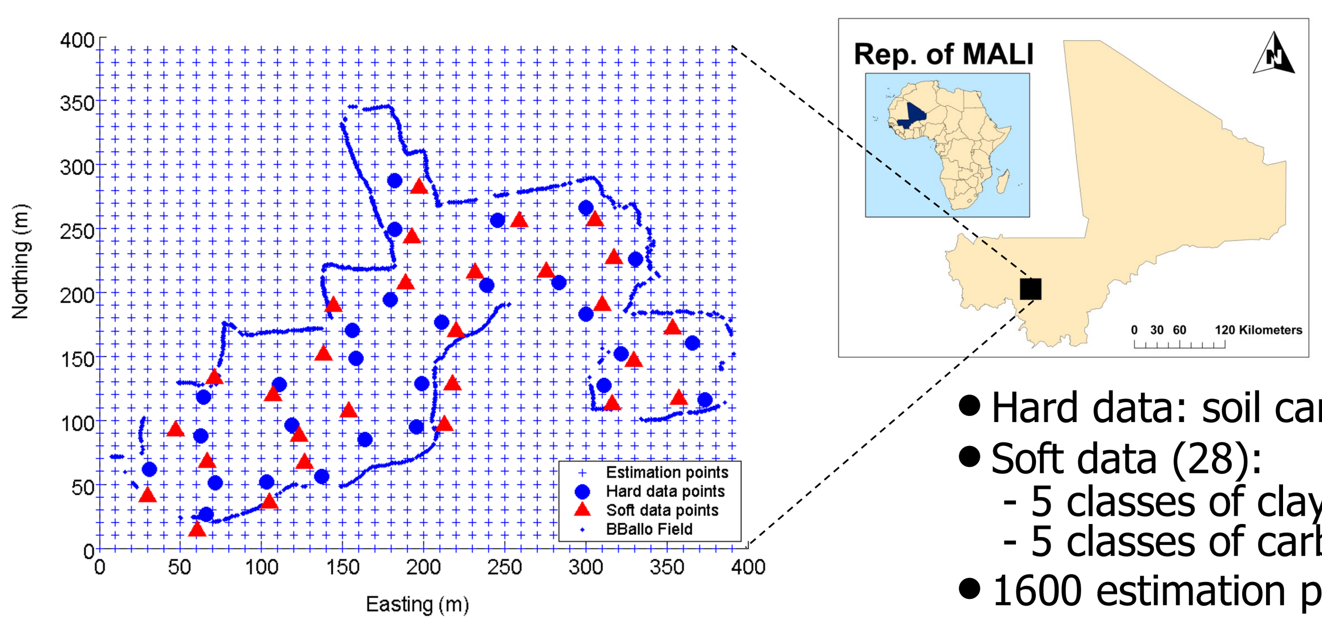
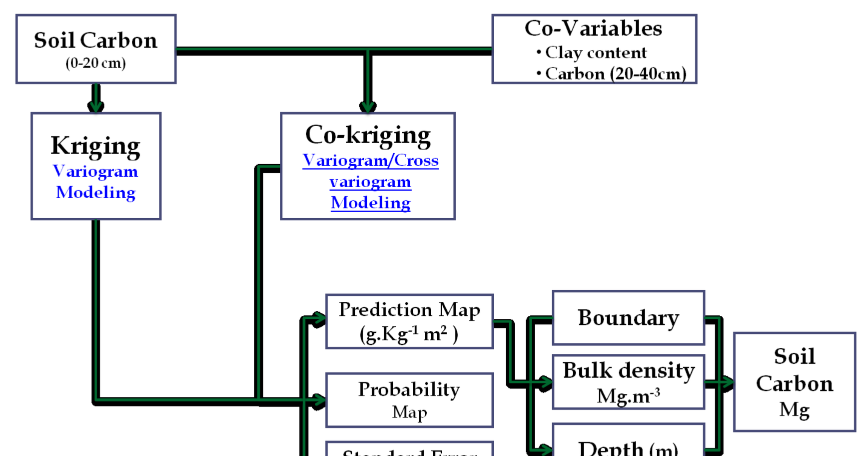



Figure 1. Map of Hard, Soft and Estimation Points [BBallo field—2006]

- Mali - West Africa
- BBallo Field - 4.77 ha
- Sampling period 2002, 2004, 2006
- 164 Soil Samples
- Hard data: soil carbon(0-20cm)
- Soft data (28):
  - 5 classes of clay (%)
  - 5 classes of carbon(20-40cm) (g $kg^{-1}$)
- 1600 estimation points
- 10 x 10 meters grid

## Approach Summary

### Standard Geostatistics (Kriging methods)




(Goovearts, 1997)

### Bayesian Maximum Entropy (BME)

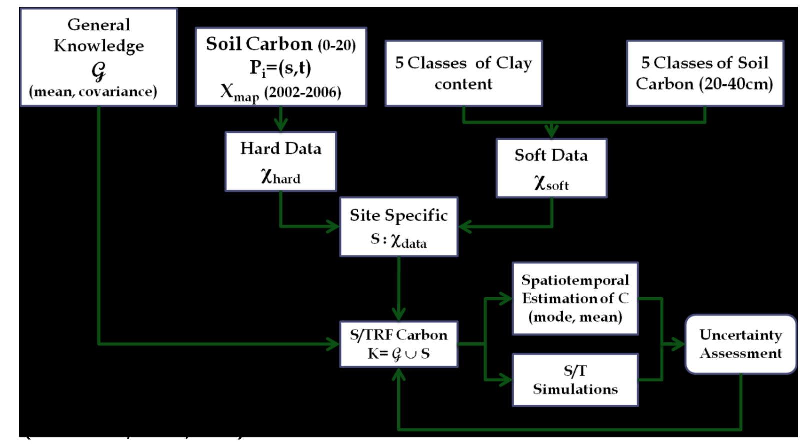



Figure 2. Flowchart of Soil Carbon Estimation Using Standard Geospatial Analysis (left) and BME (right).

### Ordinary Kriging

$$Z^*_{ok}(u) = \sum_{\alpha=1}^{n(u)} \lambda_\alpha^{OK}(u) Z(u_\alpha)$$

$$\sum_{\alpha=1}^{n(u)} \lambda_\alpha^{OK}(u) = 1$$

### Co-Kriging

$$\hat{Z}_u(x_0) = \sum_{i=1}^{v} \sum_{i=1}^{n} \lambda_{i1} Z_l(x_i)$$

$$\sum_{\alpha=1}^{n1(u)} \lambda_{\alpha 1}^{OCK}(u) + \lambda_2^{OCK}(u) = 1$$

$$E\{Z^*_{ok}(u) - Z(u_\alpha)\} = 0$$

- Best linear unbiased estimator
- Minimize the error variance
- Kriging — Hard data only
- Cokriging— Hard and secondary information

### BME

**General Knowledge:** mean, covariance

**Site specific data:** $\chi_{data} = (\chi_{hard}, \chi_{soft})$
Hard Data— Soil carbon (0-20cm)
Soft Data — 5 Interval classes [clay & carbon(20-40)]

**BME Posterior Integration**

$$f_k^{bc}(\chi_\kappa) = A^{-1} \int d\Xi_S(\chi_{soft}) f_G(\chi_{map})$$

**BME Estimation**

$$\hat{\chi}_{k,mode} : \max_{\chi_k} f_K^{bc}(\chi_k) \quad \Big| \quad \hat{\chi}_{k,mean} : \int d\chi_k \chi_k f_K^{bc}(\chi_k)$$

- Linear /non-linear (no restrictions)
- Knowledge integration/ Processing
- Hard and Soft data (interval, probabilistic, expert assessment ...)

## Results

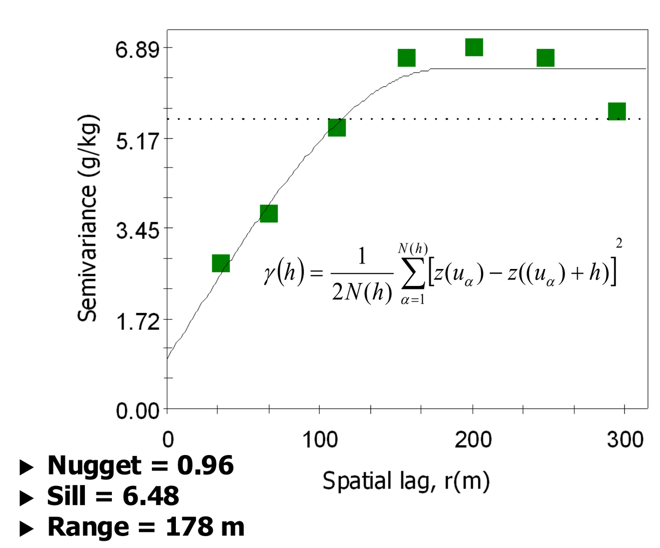



Figure 3. Experimental Variogram of Soil Carbon.

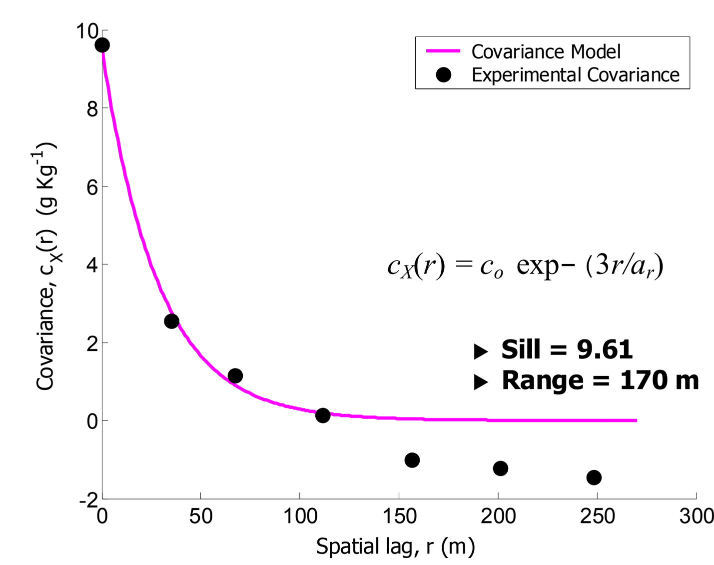



Figure 4. Covariance Model of Soil Carbon.

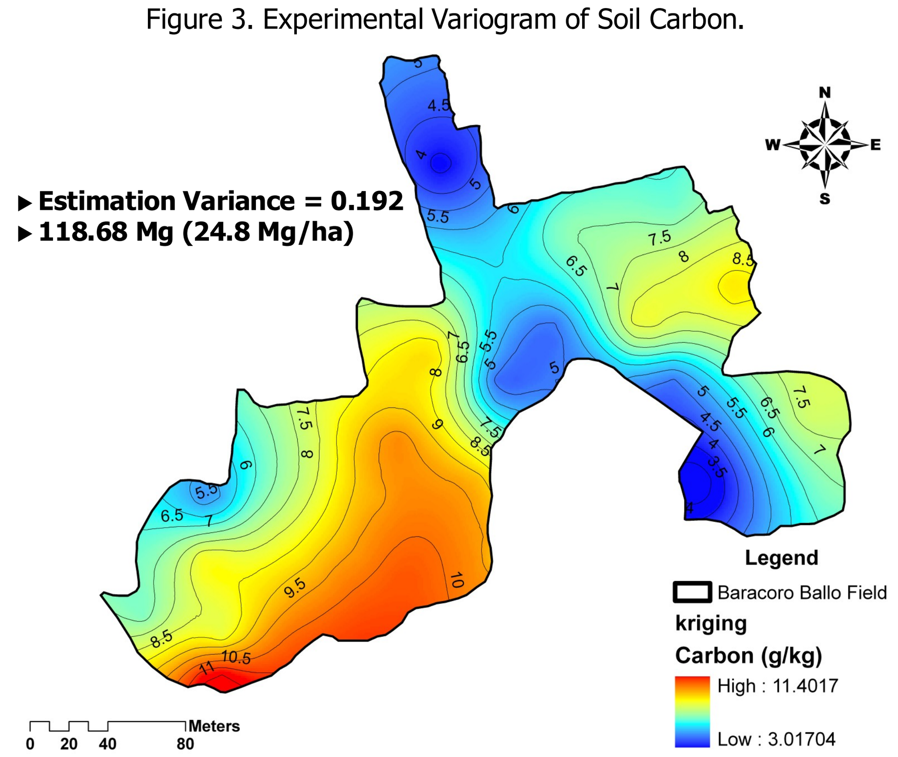



Figure 5. Kriging Estimate of Soil Carbon.

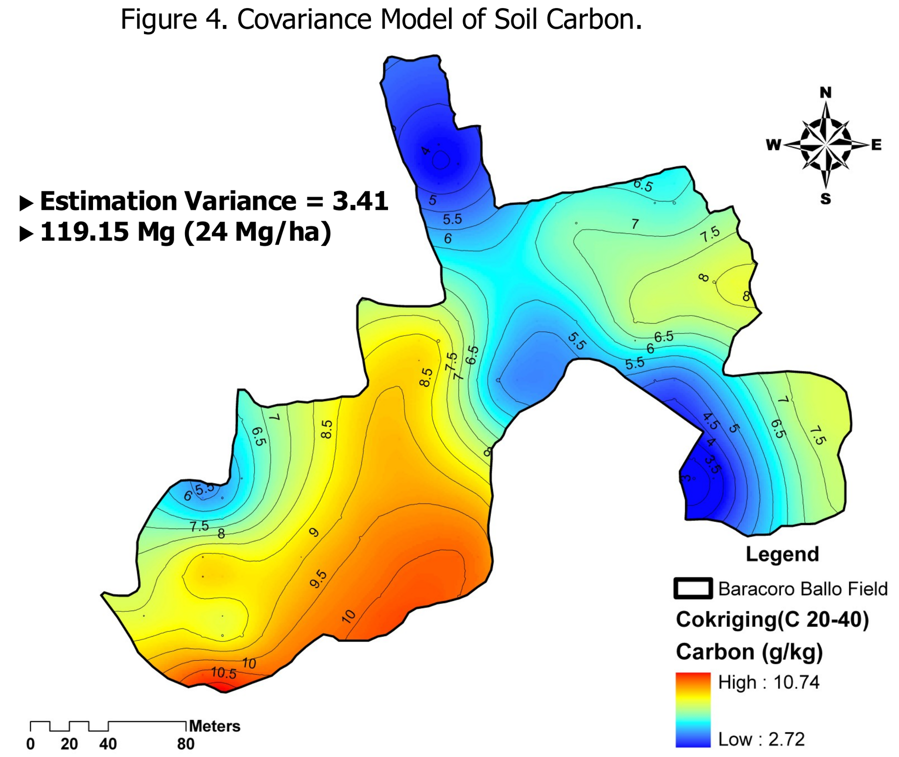



Figure 6. Cokriging Estimate of Soil Carbon, with Carbon 20-40 cm as Co-variable.

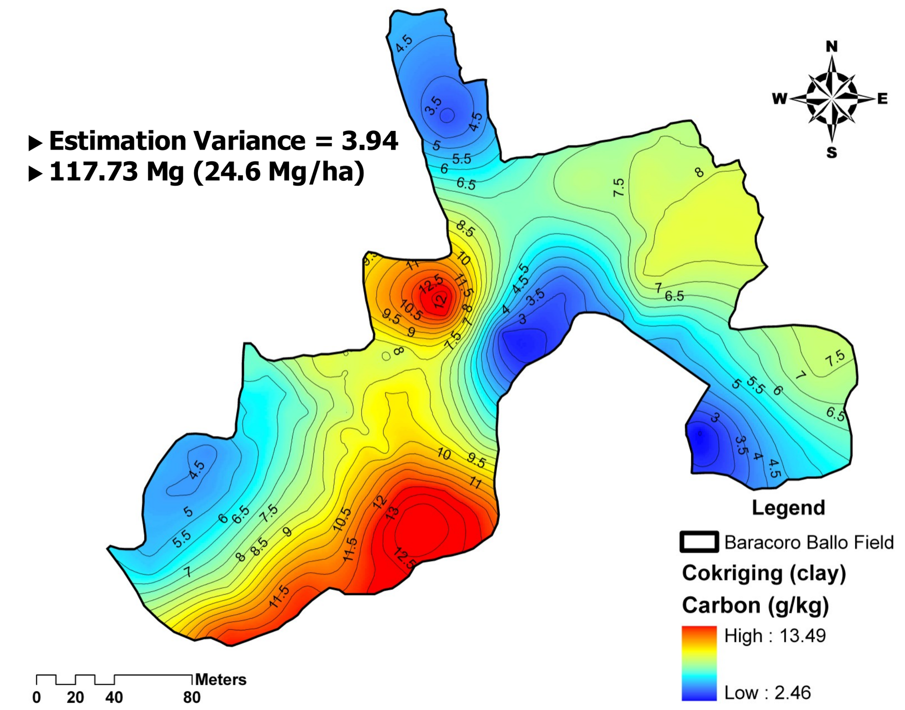



Figure 7. Cokriging estimate of Soil Carbon, with Clay as Covariable.

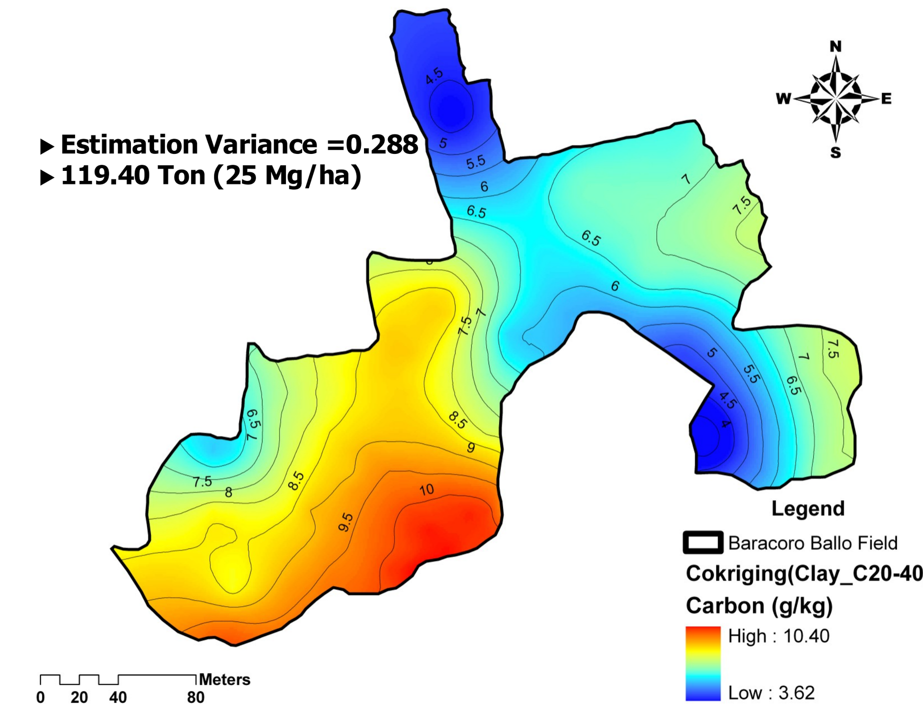



Figure 8. Cokriging (multivariate) estimate, with Clay and Carbon (20-40cm) as Covariables.

Table 1. Comparison of Estimation Methods of Soil Carbon

| Methods | BIAS* | MSE |
|---|---|---|
| Kriging | 0.407 | 1.76 |
| Cokriging (clay, C20-40) | 0.602 | 2.25 |
| BME (C20-40cm) | 0.29 | 1.61 |
| BME (C20-40-clay) | 0.033 | 1.50 |

* BIAS = mean (simulated—methods)

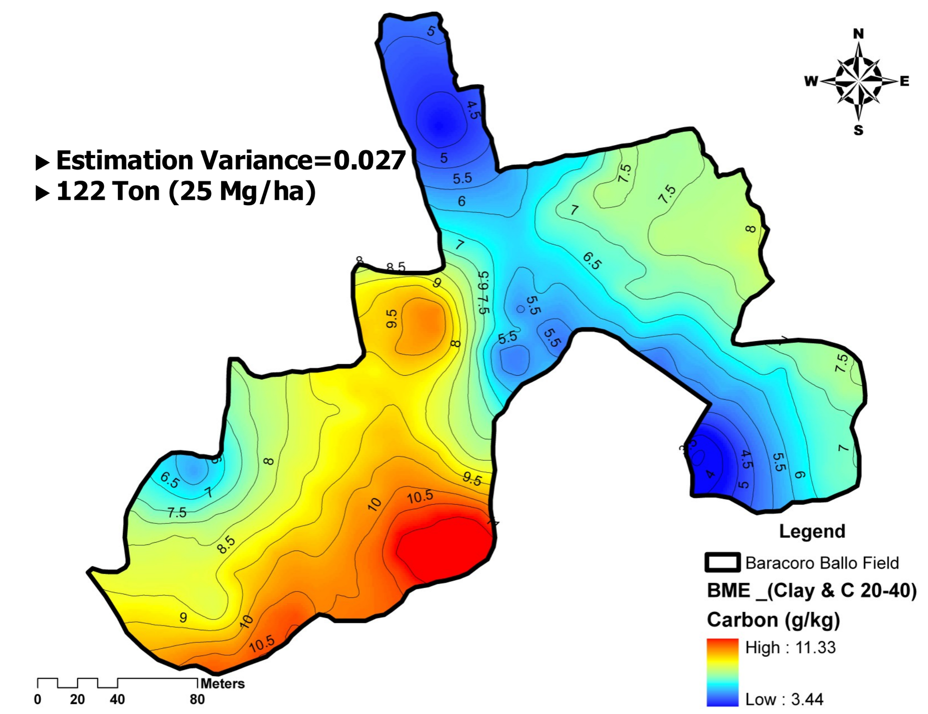



Figure 9. BME Estimate of Soil Carbon with Clay and Carbon interval Classes as Soft Data.

## Conclusions

- BME provided slightly higher, but more accurate and precise global estimates of soil organic carbon.
- The integration of soft data in BME yielded lower BIAS and MSE while cokriging with the same variables failed to improve predictions over kriging.
- Weak correlation between primary (carbon 0-20cm) and secondary variables (clay and C 20-40cm) may have reduced the effectiveness of cokriging ( r=0.5 and 0.197 respectively) .
- BME is a robust framework for quantifying and mapping soil organic carbon hence its use can be considered for improved field and regional scale inventories.

## References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