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Climate Modeling Using Mahalanobis-Taguchi System For Soil Carbon Analysis

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Abstract

Soil is an important element of the terrestrial carbon sequestration system. Soil is estimated to store more carbon than the atmosphere [1] or the ocean surface and can play a significant role in mitigating the effects of climate change. The amount of organic carbon in soil and the net carbon sequestered are affected by a number of factors. The Mahalanobis-Taguchi System (MTS), a multivariate data analysis approach, was used to identify the variables most influential in affecting soil organic carbon levels. Since land-use changes substantially impact soil greenhouse gas fluxes, these changes have also been explored by simulating different land-use scenarios using climate models.

Methodology

- Global soil data for the MTS experiments was collected from the Harmonized World Soil Database (HWSD) [2] and NASA'S Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) [3]
- The Mahalanobis Distance (MD) (the first component of the MTS experiment) was computed for the datasets. The MD is used to determine the outliers for a given data. In this case the outliers were the variables that provided the greatest distance/separation between the MD of the reference group (MD of the reference group has to be near 1) and the test group.
- Based on different soil property variables, the dataset was classified into a reference and test group. A number of Mahalanobis experiments using the R-program [4] were then performed to find the variables that gave the largest MD separation between the reference group and test group. Linearly dependent variables were discarded using the R-program.

Table 1: Variables tested in the MTS experiment

Variable	MD	Taguchi
Organic Carbon (HWSD, ORNL DAAC)	✔	✔
Calcium Carbonate (HWSD)	✔	✔
Bulk Density, Base Saturation, Total Exchangeable Bases (HWSD)	Note 1	✔
Gravel, Sand, Silt, Clay (HWSD)	Note 1	✔
PH (HWSD, ORNL DAAC)	✔	✔
Microbial mass (ORNL DAAC)	✔	✔
Nitrogen, Phosphorus	Note 1	✔

Note 1: Variables included in the MD computations but not used as a basis for classifying data into reference group and test group

- The Taguchi analysis (the second component of the MTS experiment) was conducted after a proper separation between the reference and test groups was achieved. The Taguchi method uses the system of orthogonal arrays to identify variables most influential in affecting the MD results.
- Data was gathered from the FAO database[5] for a few land-use scenarios relating to GHG emissions/ removal for the year 2014. The data was used to compute the projected CO_2 parts per million (ppm) and temperature values for the year 2100 using the ISAM climate model [6] under a high Business As Usual (BAU) situation.

Results

Part 1: Soil property analysis applying MTS

Figure 1(a)

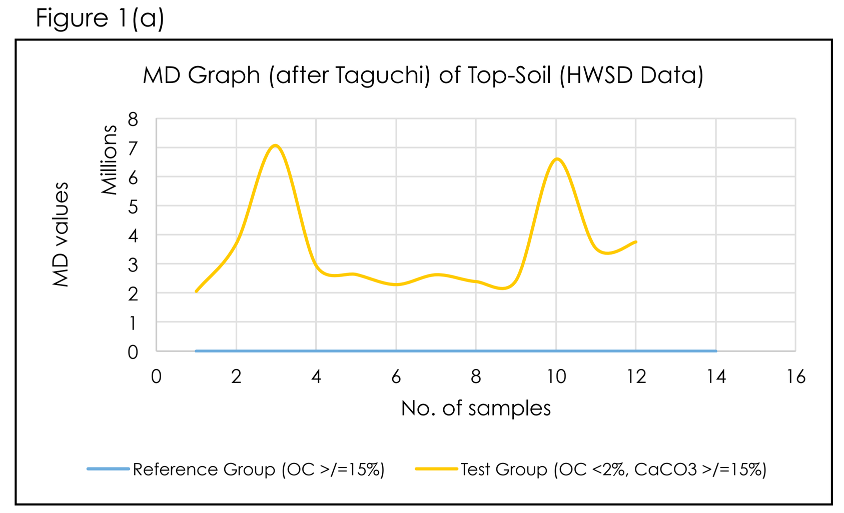


Figure 1(b)

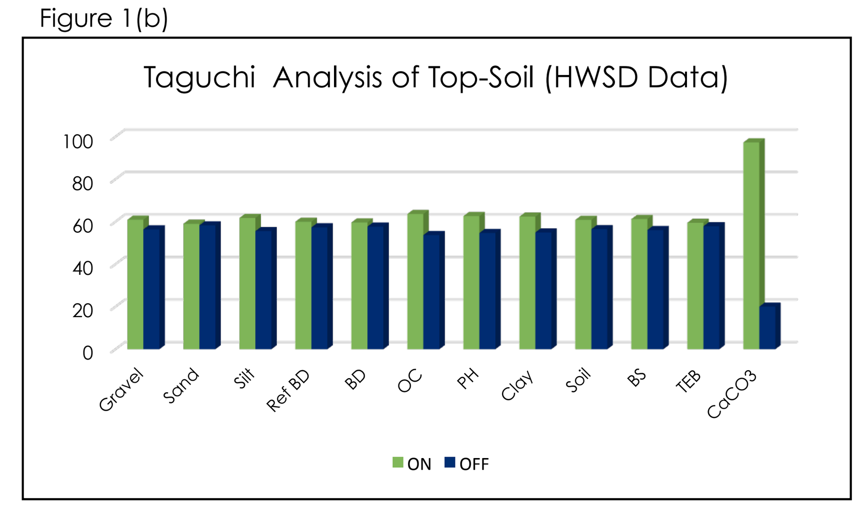


Figure 2(a)

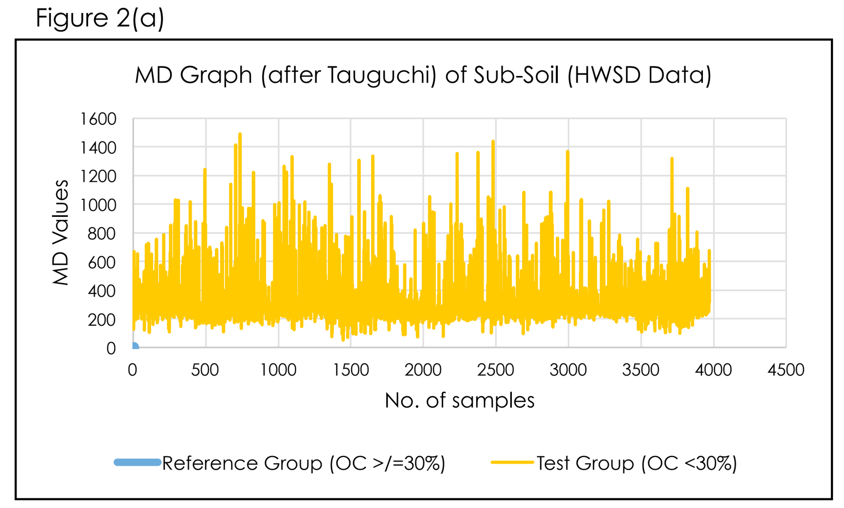


Figure 2(b)

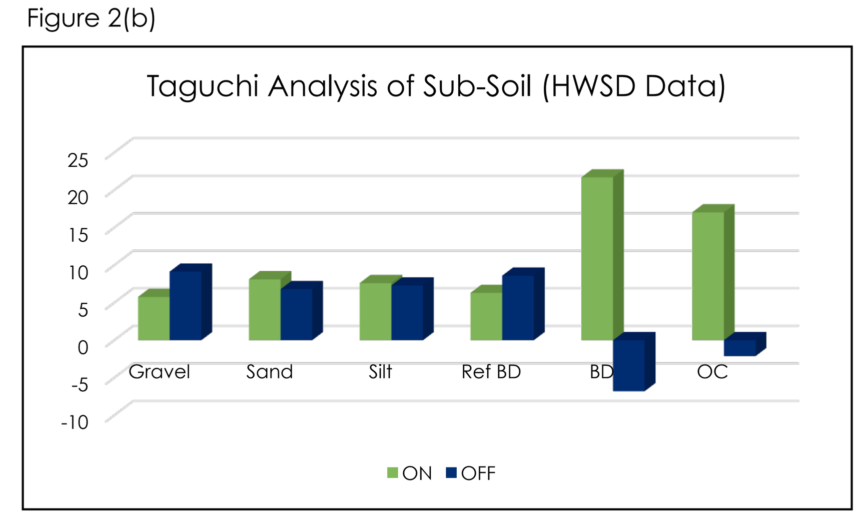


Figure 3(a)

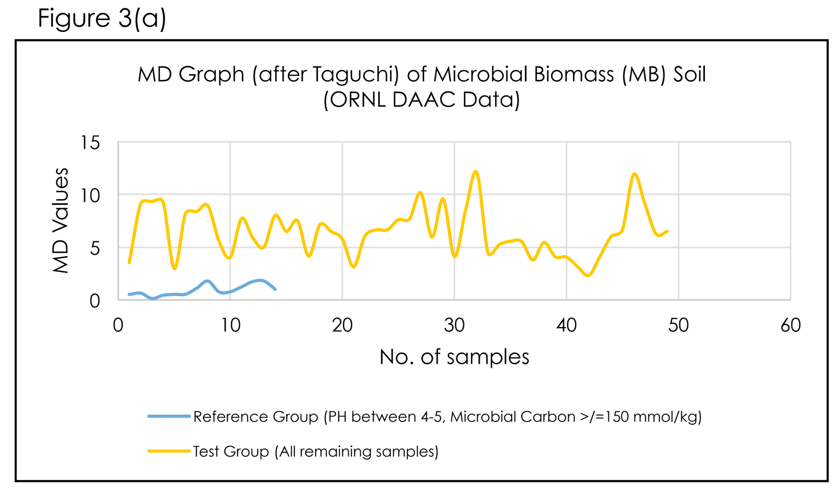
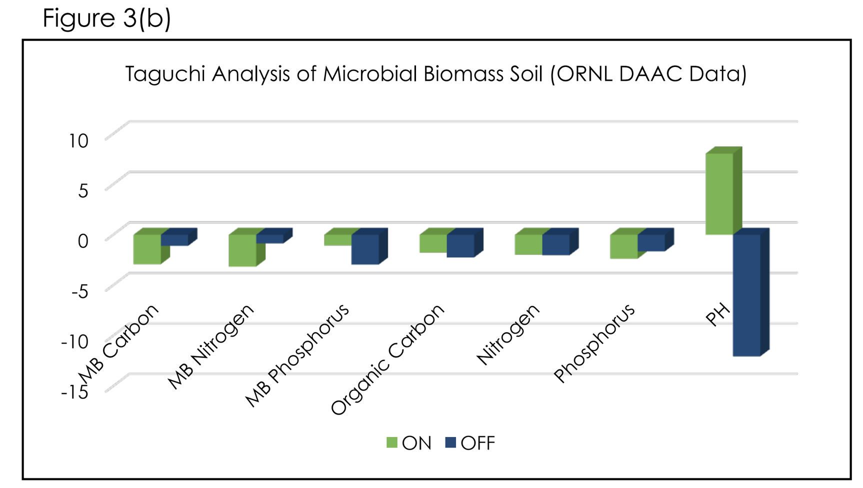


Figure 3(b)



- A large separation between the reference group and the test group was achieved with the HWSD dataset and a moderate separation was achieved with the ORNL DAAC dataset.
- The reference group (healthy soils) required a range of 15% or higher organic carbon content and very low $CaCO_3$. High $CaCO_3$ levels was more relevant for top-soil than for subsoil
- PH levels and microbial carbon impact soils containing microbial biomass.

Part 2: Soil sequestration analysis using ISAM model

Figure 4(a)

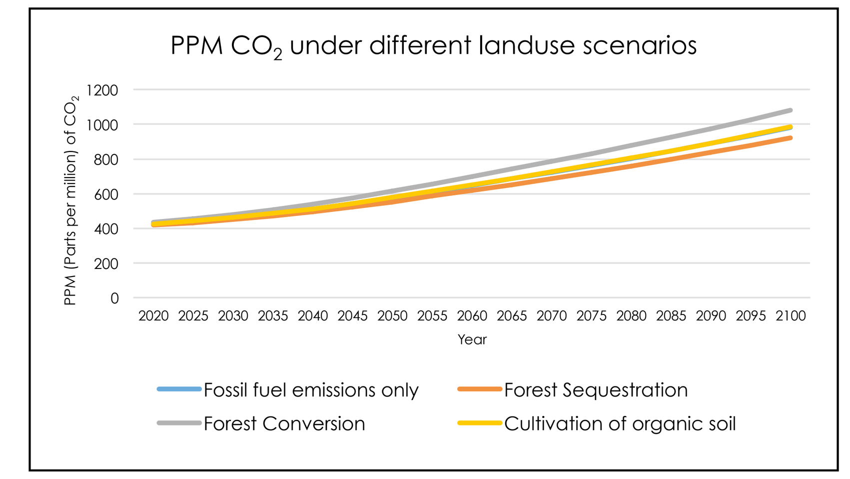


Figure 4(b)

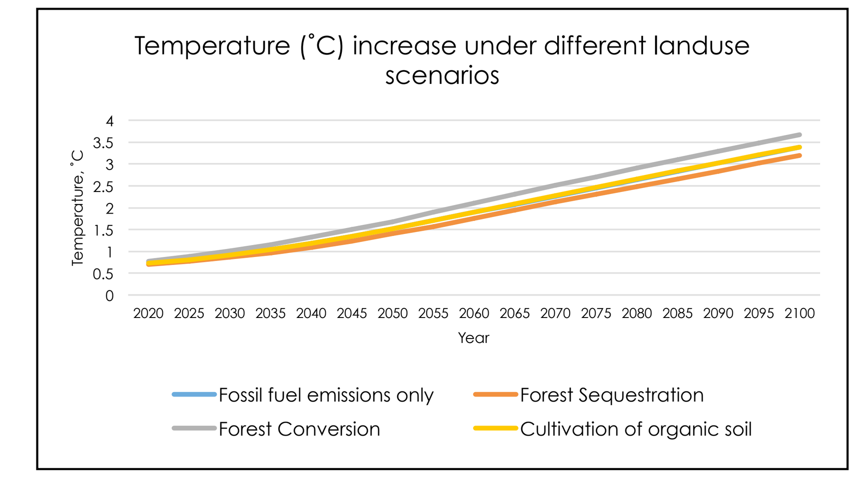


Table 2: GHG emissions/removals) as computed from FAO data

Land-use Scenario	Gton/yr
Forest sequestration	-1.85
Forest conversion	3.05
Cultivation of organic soils	0.13

- The ISAM simulation results show that forest sequestration and forest conversion have the largest impact. The projected CO2 ppm in 2100 under a high BAU fossil fuel use scenario is 980.98. However, forest sequestration can decrease it to 922.05 (-58.98 ppm reduction) and forest conversion can increase it to 1081.58 (+100.6 ppm rise) respectively. Projected temperature increases for 2100 are also impacted by -0.2˚C under forest sequestration and +0.3˚C under forest conversion.

Conclusion

Certain soil properties have a significant impact on soil organic carbon levels. Further study needs to be done to determine how soil organic carbon and other soil properties affect soil gas fluxes under different land use scenarios globally. Furthermore, various soil databases need to be consolidated for this purpose for a more uniform data source. The role of inorganic carbon, soil moisture and soil temperature have not been included in this study and these variables also need to be explored.

[1] Globe Carbon Cycle. *University of New Hampshire.* 2008. http://globecarboncycle.unh.edu/CarbonPoolsFluxes.shtml
[2] FAO/IIASA/ISRIC/ISSCAS/JRC, 2012. *Harmonized World Soil Database (version 1.2)*. FAO, Rome, Italy and IIASA, Laxenburg, Austria. URL http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/HWSD_Data.html?sb=4
[3] Xu, X., P.E. Thornton, and W.M. Post. 2014. A Compilation of Global Soil Microbial Biomass Carbon, Nitrogen, and Phosphorus Data. Data set. Available on-line [http://daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, USA http://dx.doi.org/10.3334/ORNLDAAC/1264
[4] R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.
[5] FAO. FAOSTATS Domains. Emissions - Landuse/Agriculture. URL http://faostat3.fao.org/home/E
[6] Jain, K. Atul. 2016. ISAM Integrated Impacts of Climate Change. University of Illinois. URL http://climate.atmos.uiuc.edu/atuljain/groupMembers.html