# USING ARTIFICIAL NEURAL NETWORKS TO PREDICT SOIL BULK DENSITY

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## Introduction

Soil bulk density ($\rho_b$) is a key soil property in soil physics and hydrology. In the absence of field measurements, the $\rho_b$ values are typically estimated using PedoTransfer Functions (PTFs). Recently, because of the progress of Artificial Neural Network (ANN) techniques, the suitableness of ANN to develop PTFs for predicting $\rho_b$ needs further study. Therefore, the objective of this study was to use a hierarchical approach to develop a series of PTFs using ANN techniques for predicting $\rho_b$ and compare the estimates with those obtained using 10 existing PTFs.

## Materials and Methods

The soil samples (1,007) used in this study came from a series of soil surveys in Central Chile. The hierarchical approach for predicting $\rho_b$ using ANN was developed by building six different types of networks (named A to F) based on the number of input parameters collected from the literature. The first network (A) used sand, silt, and clay content as inputs, whereas the second network (B) used only organic matter content (OM) as input. The network C was a combination of networks A and B: it used sand, silt, and clay content in addition to the OM content. Networks D, E, and F used the same parameters as network C but included pH, basic cations, and soil depth and $\theta_{1500}$, respectively, as inputs. The networks were evaluated in accuracy (Nash-Sutcliffe model efficiency, ME), and reliability (Root Mean Square Error, RMSE).

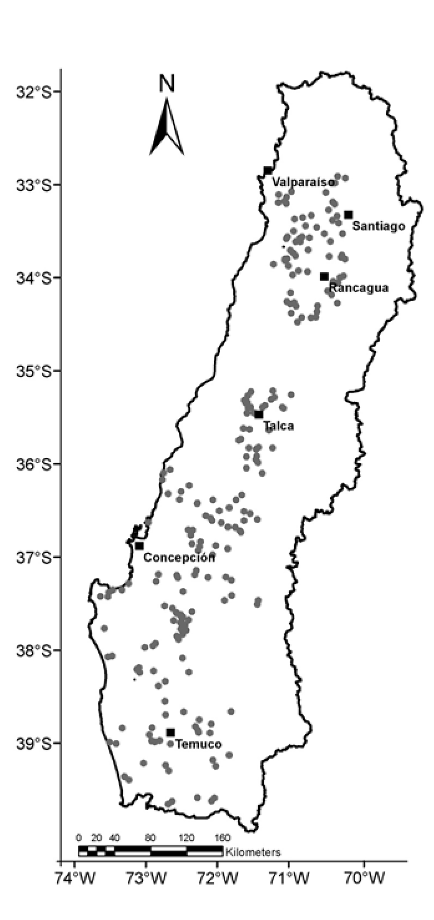


Figure 1. Location of the soil data points in central Chile.

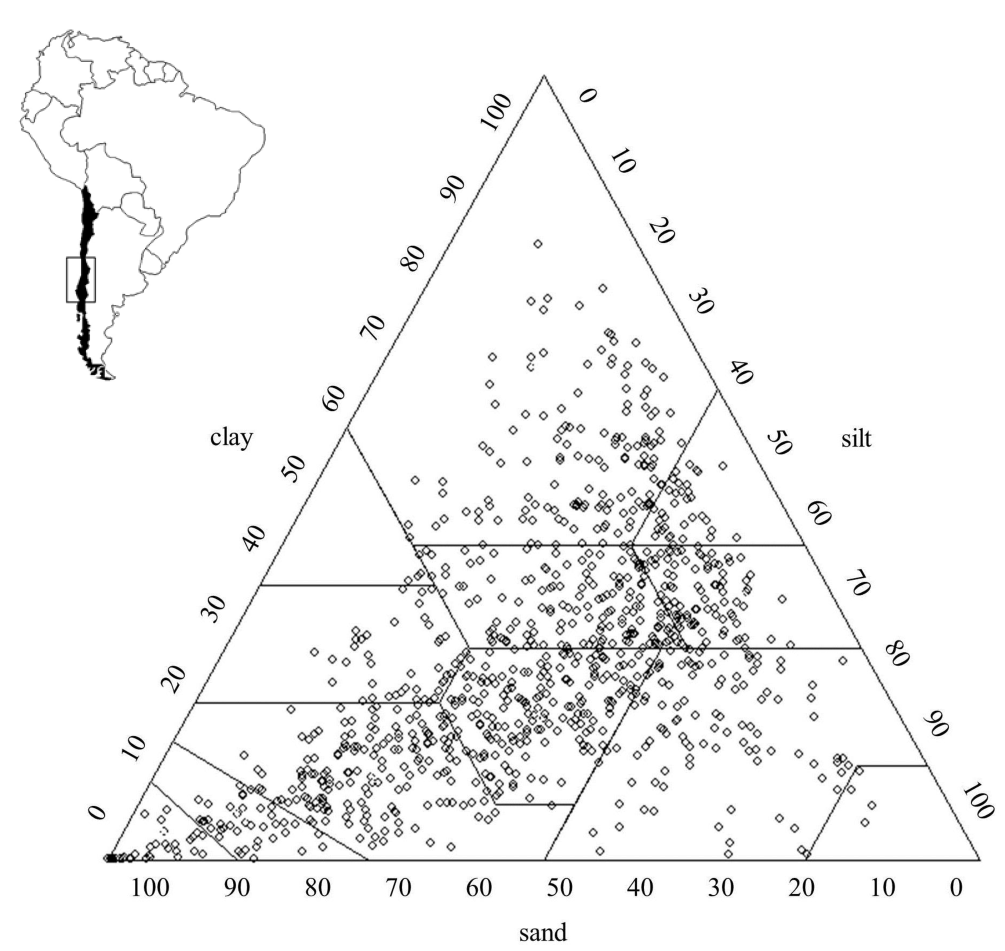


Figure 2. Soil texture distribution among the 1,007 soil samples used in the study

## Results and Discussion

The lowest performance was observed when using network A (sand, silt, and clay contents as inputs; ME=0.22). The results demonstrated that network B (based on organic carbon content ; OC) predicted the $\rho_b$ values more effectively than those based on soil particle size distribution, even when used to predict $\rho_b$ for soils with a low OC (ME=0.38). Using network C the prediction improved (ME=0.44) Moreover, adding the pH and basic cations as inputs increased the accuracy of the estimates (ME=0.49 and 0.55, respectively). The highest performance was found when using sand, silt, clay, OC, soil depth, and water content at wilting point as inputs (ME=0.72). With the same input parameters, the equations developed with ANN technique enhanced the quality of estimates compared with the 10 PTFs evaluated in this study (see Table 1).

Table 1. Evaluation for equations A through F developed with the Artificial Neural Network techniques

| | Entire set | | | Testing set | | | Training set | | | Validation set | | | Improvement* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equation | N | ME | RMSE | N | ME | RMSE | N | ME | RMSE | N | ME | RMSE | N | ME | RMSE |
| A | 1,007 | 0.22 | 0.32 | 705 | 0.20 | 0.32 | 151 | 0.22 | 0.32 | 151 | 0.28 | 0.31 | 1,007 | 0.05[a] | 0.01[a] |
| B | 1,007 | 0.38 | 0.28 | 705 | 0.40 | 0.28 | 151 | 0.39 | 0.28 | 151 | 0.33 | 0.29 | 1,007 | 0.02[b] | 0.01[b] |
| C | 1,007 | 0.44 | 0.27 | 705 | 0.39 | 0.29 | 151 | 0.47 | 0.26 | 151 | 0.36 | 0.28 | 1,007 | 0.05[c] | 0.01[c] |
| D | 997 | 0.49 | 0.26 | 697 | 0.40 | 0.29 | 150 | 0.50 | 0.25 | 150 | 0.49 | 0.25 | 997 | 0.06[d] | 0.01[d] |
| E | 880 | 0.55 | 0.24 | 616 | 0.47 | 0.26 | 132 | 0.57 | 0.23 | 132 | 0.56 | 0.26 | 880 | 0.14[e] | 0.04[e] |
| F | 754 | 0.72 | 0.17 | 528 | 0.69 | 0.19 | 113 | 0.72 | 0.17 | 113 | 0.76 | 0.16 | 754 | 0.05[f] | 0.02[f] |

*Compared to the 10 published PTFs with the same input parameters. [a]With Saxton et al. (1986). [b]With Adams (1973). [c]With Tomasella and Hodnett (1998), Kaur et al. (2002), Rawls et al. (2004), and Hollis et al. (2012). [d]With Bernoux et al. (1998), and Brahim et al. (2012). [e]With Benites et al. (2007). [f]With Heuscher et al. (2005).

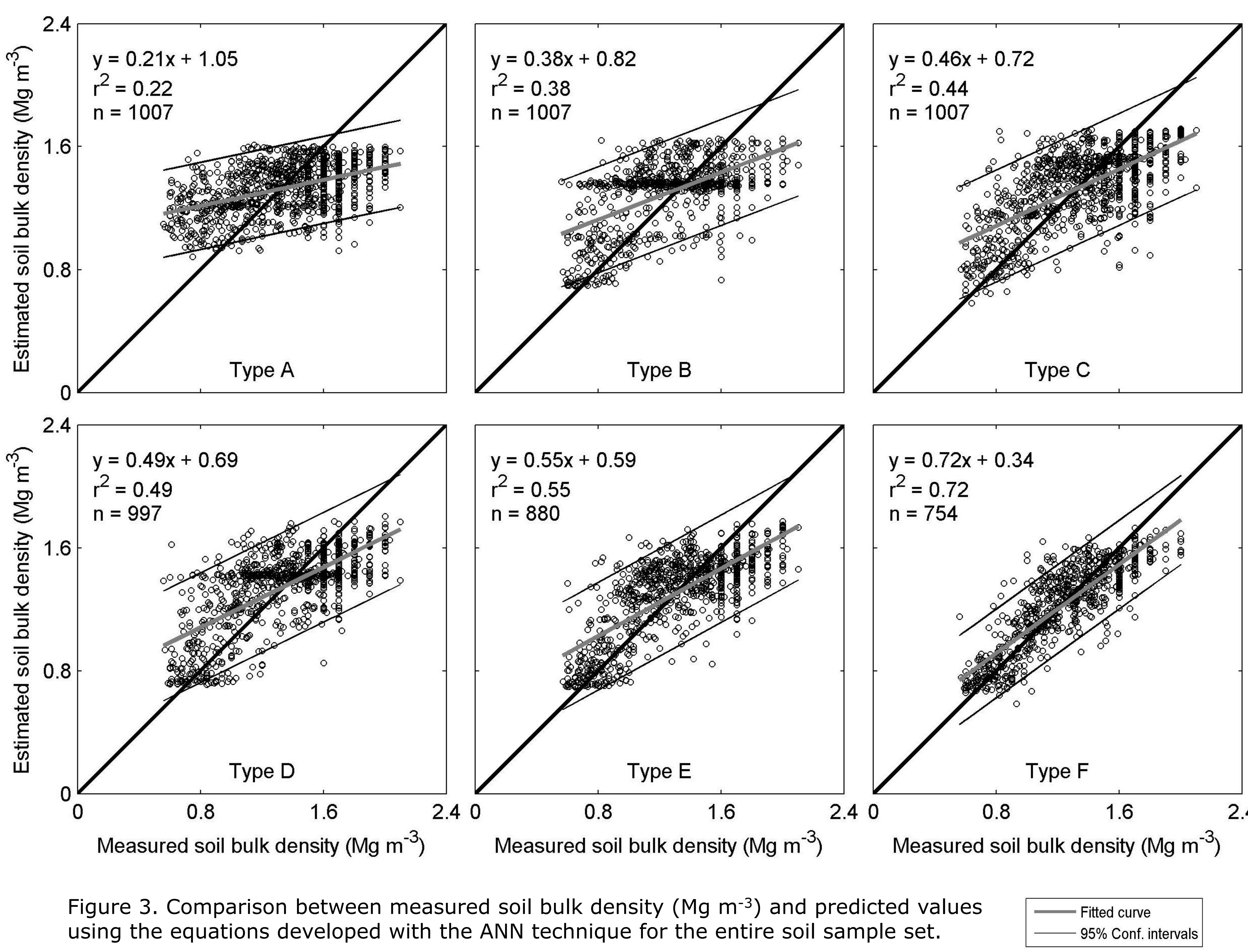


Figure 3. Comparison between measured soil bulk density (Mg $m^{-3}$) and predicted values using the equations developed with the ANN technique for the entire soil sample set.

## Conclusions

The use of ANN technique proved to be a suitable method for building six equations for predicting $\rho_b$ across a wide range of soil types and inputs. The ANN developed in this study were two-layer feed forward networks with 3 nodes.

This study demonstrates that this technique is promissory for predicting soil properties such as bulk density. Although the classical regression relationships are still useful for predicting the soil bulk density because of their simplicity and intuitive formulation, the use of this new set of equations is highly recommended to produce a more robust estimate and reduce the overall error.

## Acknowledgements

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## References

Adams, W.A. 1973. The effect of organic matter on the bulk and true densities of some uncultivated podzolic soils. Journal of Soil Science 24:10-17.

Benites, V.M., P.L.O.A. Machado, E.C.C. Fidalgo, M.R. Coelho, and B.E. Madari. 2007. Pedotransfer functions for estimating soil bulk density from existing soil survey reports in Brazil. Geoderma 139:90–97.

Bernoux, M., D. Arrouays, C. Cerri, B. Volkoff, and C. Jolivet. 1998. Bulk Densities of Brazilian Amazon Soils Related to Other Soil Properties. Soil Sci. Soc. Am. J. 62: 743-749.

Brahim, N., M. Bernoux, and T. Gallali. 2012. Pedotransfer functions to estimate soil bulk density for Northern Africa: Tunisia case. J. Arid Environ. 81:77–83.

Heuscher, S. A, C.C. Brandt, and P.M. Jardine. 2005. Using Soil Physical and Chemical Properties to Estimate Bulk Density. Soil Sci. Soc. Am. J. 69:1–7.

Hollis, J.M., J. Hannam, and P.H. Bellamy. 2012. Empirically-derived pedotransfer functions for predicting bulk density in European soils. Eur. J. Soil Sci. 63:96–109.

Kaur, R., S. Kumar, and H.P. Gurung. 2002. A pedo-transfer function (PTF) for estimating soil bulk density from basic soil data and its comparison with existing PTFs. Aust. J. Soil Res. 40:847–857.

Rawls, W.J., A. Nemes, and Y. Pachepsky. 2004. Effect of soil organic carbon on soil hydraulic properties. Dev. Soil Sci. 30(C):95–114.

Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick. 1986. Estimating generalized soil-water characteristics from texture. Soil Sci. Soc. Am. J. 50:1031-1036.

Tomasella, J., and M.G. Hodnett. 1998. Estimating soil water retention characteristics from limited data in Brazilian Amazonia. Soil Sci. 163:190–202.