ENGINEERING Agriculture
https://doi.org/10.15302/J-FASE-2027723
Header: Samuel E. PIZARRO et al., ENGINEERING Agriculture, 2027, 14(2): 27723
Footer: https://journal.hep.com.cn/fase
RESEARCH ARTICLE

Local calibration of bulk density models for agricultural soils in an inter-Andean valley of the Peruvian Central Highlands

Samuel E. PIZARRO (✉), Edilson REQUENA, Itala FLORES, Erika GARCIA, Esthefany GAVINO, Dennis CCOPI

Santa Ana Agricultural Experimental Station, Directorate of Strategic Agricultural Services, National Institute of Agrarian Innovation (INIA), Carretera Saños Grande – Hualahoyo Km 8 Santa Ana, Huancayo, Junín 12006, Peru.

Received October 22, 2025;
Accepted May 7, 2026.
Correspondences: samuel.pizarro@untrm.edu.pe

SUPPLEMENTARY MATERIALS

Table S1 compiles 66 pedotransfer functions (PTFs) and empirical models developed under different pedoclimatic conditions, relating BD to variables such as organic carbon (OC/OM), textural fractions (sand, silt, and clay), and, in some cases, soil depth. These equations provide a reference framework for comparing the performance of the locally calibrated models developed for the studied inter-Andean valley.

Table S1 Empirical equations reported in the literature for estimating soil bulk density (BD)

Nº	Author (Year)	Equation
1	Abdelkader (2016)[1]	$BD = 1.449 \times e^{(-0.03 \times OC)}$
2	Adams (1973)[2]	$BD = \dfrac{100}{\dfrac{OM}{0.244} + \dfrac{100 - OM}{1.27}}$
3	Akpa et al. (2016)[3]	$BD = 1.177 + 0.00263 \times Sa - 0.0439 \times \ln(Si) + 0.00208 \times Si$
4	Alexander (1980) upland[4]	$BD = 1.66 - 0.308 \times \sqrt{OC}$
5	Alexander (1980) alluvial[4]	$BD = 1.72 - 0.294 \times \sqrt{OC}$
6	Al-Qinna & Jaber (2013)[5]	$BD = 1.228 - 0.155 \times \log_{10}(OC) + 0.008 \times Sa$
7	Benites et al. (2007)[6]	$BD = 1.5688 - 0.0005 \times (Cl \times 10) - 0.009 \times (OC \times 10)$
8	Bernoux et al. (1998)[7]	$BD = 1.398 - 0.0047 \times Cl - 0.042 \times OC$
9	Beutler et al. (2017)[8]	$BD\left(1.6179 - 0.018 \times (C + 1)^{0.46} - 0.0398 \times (OC^{0.55})\right)^{1.33}$

10	Botula et al. (2015)[9]	$BD = 1.64581 - 0.00632 \times Cl - 0.0016 \times Sa - 0.0158 \times OC$
11	Calhoun et al. (2001)[10]	$BD = 1.673 - 0.071 \times OC - 0.0017 \times Si - 0.003 \times Cl$
12	Cienciala et al. (2006)[11]	$BD = \frac{100}{\frac{OM}{0.244} + \frac{100 - OM}{1.41}}$
13	Curtis & Post (1964)[12]	$\log_{10}(BD \times 100) = 2.09963 - 0.00064 \times \log_{10}(OM) - 0.22302 \times (\log_{10}(OM))^2$
14	De Vos et al. (2005b)[13]	$BD = 1.775 - 0.173 \times \sqrt{OM}$
15	Drew (1973)[14]	$BD = \frac{1}{0.6286 + 0.0361 \times OM}$
16	Eschner et al. (1957)[15]	$BD = 1.8014 - 0.8491 \times log_{10}(OM + 2) + 0.0026 \times Cl$
17	Federer (1983)[16]	$BD = \mathrm{e}^{\left(-2.314 - 1.0788 \times \ln\left(\frac{OM}{100}\right) - 0.1132 \times \left(\ln\left(\frac{OM}{100}\right)\right)^2\right)}$
18	Federer et al. (1993)[17]	$BD = \frac{0.111 \times 1.45}{\left(\left(\frac{1.45 \times OM}{100}\right) + 0.111 \times \left(\frac{1 - OM}{100}\right)\right)}$
19	Grigal et al. (1989)[18]	$BD = 0.075 + 1.301 \times \mathrm{e}^{(-0.06 \times OM)}$
20	Hallett et al. (1998)[19]	$BD = 1.46 + 0.0254 \times \ln(Cl) + 0.0279 \times \ln(Sa) - 0.261 \times \ln(OC)$
21	Harrison & Bocock (1981)[20]	$BD = 1.558 - 0.728 \times \log_{10}(OM)$
22	Heuscher et al. (2005) (OC poly)[21]	$BD = 1.711 - 0.0487 \times OC^2 + 0.0059 \times OC^3 + 0.002 \times Cl$
23	Heuscher et al. (2005) (texture)[21]	$BD = 1.674 - 0.31 \times \sqrt{OC} + 0.015 \times Cl - 0.000241 \times Si^2$
24	Hollis et al. (2012) depth[22]	$BD = 1.780 - 0.379 \times \sqrt{OM} + 0.00123 \times \mathrm{depth}$
25	Hollis et al. (2012) model 1[22]	$BD = 0.80806 + 0.823844 \times \mathrm{e}^{(-0.27993 \times OC)} + 0.0014065 \times Sa - 0.0010299 \times Cl$
26	Hollis et al. (2012) model 2[22]	$BD = 0.69794 + 0.750636 \times \mathrm{e}^{(-0.230355 \times OC)} + 0.0008687 \times Sa - 0.0005164 \times Cl$
27	Hollis et al. (2012) model 3[22]	$BD = 1.4903 - 0.33293 \times \ln(OC)$
28	Honeysett & Ratkowsky (1989)[23]	$BD = \frac{1}{0.564 + 0.556 \times OM}$
29	Hong et al. (2013)[24]	$BD = \frac{100}{\left(\left(\frac{OM}{0.224}\right) + \left(\left(\frac{100 - OM}{1.017}\right)\right)\right) + 0.0032 \times Sa + 0.054 \times \log_{10}(\mathrm{depth})}$
30	Hossain et al. (2015)[25]	$BD = 0.701 + 0.952 \times \mathrm{e}^{(-0.29 \times OC)}$
31	Huntington et al. (1989)[26]	$BD = \mathrm{e}^{\left(-2.39 - 1.316 \times \ln\left(\frac{OM}{100}\right) - 0.167 \times \left(\ln\left(\frac{OM}{100}\right)\right)^2\right)}$
32	Jeffrey (1970)[27]	$BD = 1.482 - 0.6786 \times \log_{10}(OM)$
33	Kaur et al. (2002)[28]	$BD = \mathrm{e}^{(0.313 - 0.191 \times OC + 0.02102 \times Cl - 0.000476 \times Cl^2 - 0.00432 \times Si)}$
34	Keller & Håkansson (2010)[29]	$BD = \mathrm{modelocuadráticocompleto}$
35	Kobal et al. (2011)[30]	$BD = 1.4842 - 0.1424 \times OC$
36	Leonaviciute (2000)[31]	$BD 1.70398 - 0.00313 \times Si + 0.00261 \times Cl - 0.11245 \times OC$
37	Manrique & Jones (1991)[32]	$BD = 1.51 - 0.113 \times OC$

38	Men et al. (2008)[33]	$BD = 1.386 - 0.078 \times OC + 0.001 \times Si + 0.001 \times Cl$
39	Valzano et al. (2005)[34]	$BD = 1.608 - 0.0872 \times OC$
40	Minasny & Hartemink (2011)[35]	$BD = \text{modeloprofundidadtextura}$
41	Nanko et al. (2014)[36]	$BD = \frac{100}{\frac{OM}{1.14} + \frac{100 - OM}{1.153}}$
42	Palladino et al. (2022)[37]	$BD = 1.131 + 0.00299 \times Sa + 0.00512 \times Cl - 0.03881 \times OC$
43	Perie & Ouimet (2008)[38]	$BD = \text{fracciónorgánica}$
44	Prévost (2004)[39]	$BD = \mathrm{e}^{\left(-1.81 - 0.892 \times \ln\left(\frac{OM}{100}\right) - 0.092 \times \left(\ln\left(\frac{OM}{100}\right)\right)^2\right)}$
45	Rawls et al. (2004)[40]	$x = -1.2141 + 4.23123 \times Sa/100;$ $y = -1.70126 + 7.55319 \times Cl/100;$ $z = -1.55601 + 0.507094 \times OM;$ $w = -0.0771892 + 0.256629 \times x + 0.256704 \times x2 - 0.140911 \times x3 - 0.0237361 \times y - 0.098737 \times x2 \times y - 0.140381 \times y2 + 0.0140902 \times x \times y2 + 0.0287001 \times y3;$ $BD = 1.36411 + 0.185628 \times (0.0845397 + 0.701658 \times w - 0.614038 \times w2 - 1.18871 \times w3 + 0.0991862 \times y - 0.301816 \times w \times y - 0.153337 \times w2 \times y - 0.072242 \times y2 + 0.392736 \times w \times y2 + 0.0886315 \times y3 - 0.601301 \times z + 0.651673 \times w \times z - 1.37484 \times w2 \times z + 0.298823 \times y \times z - 0.192686 \times w \times z \times y + 0.0815752 \times y2 \times z - 0.0450214 \times z2 - 0.179529 \times w \times z2 - 0.0797412 \times y \times z2 + 0.00942183 \times z3)$
46	Reidy et al. (2016)[41]	$BD = 1.7059 - 0.3425 \times \sqrt{OC}$
47	Ruehlmann & Körschens (2009)[42]	$BD = (2.684 - 140.943 \times 0.008) \times \mathrm{e}^{(-0.008 \times OC \times 10)}$
48	Saini (1966)[43]	$BD = 1.53 - 0.05 \times OM$
49	Sevastas et al. (2018) (1)[44]	$BD = 2.268 - 0.179 \times \ln(Sa) - 0.345 \times \ln(OC)$
50	Sevastas et al. (2018) (2)[44]	$BD = 2.039 - 0.563 \times OC + 0.103 \times OC^2$
51	Song et al. (2005) (1)[45]	$BD = 1.3565 \times \mathrm{e}^{(-0.0046 \times OC \times 10)}$
52	Song et al. (2005) (2)[45]	$BD = 1.377 \times \mathrm{e}^{(-0.0048 \times OC \times 10)}$
53	Tamminen & Starr (1994)[46]	$BD = 1.565 - 0.2298 \times \sqrt{OM}$
54	Tomasella & Hodnett (1998)[47]	$BD = 1.578 - 0.054 \times OC - 0.006 \times Si - 0.004 \times Cl$
55	Tranter et al. (2007)[48]	$BD = 1.35 + 0.0045 \times Sa + (44.7 - Sa)^2 \times 6 \times 10^{-5} + 0.060 \times \ln(\text{depth})$
56	Tremblay et al. (2002)[49]	$BD = \text{mezclamineral} - \text{orgánica}$
57	Williams (1971)[50]	$BD = 1.37 - 0.076 \times OC$
58	Wu et al. (2003)[51]	$BD = 1.2901 - 0.1229 \times \ln(OC)$
59	Yang et al. (2007)[52]	$BD = 0.29 + 1.2033 \times \mathrm{e}^{(-0.075 \times OC)}$
60	Zinke et al. (1986)[53]	$BD = 1.446 - 0.000645 \times \text{depth} - 0.344 \times \log_{10}(OC)$
61	Dexter (2004)[54]	$BD = \frac{1}{0.59 + 0.00163 \times Cl + 0.0253 \times OM}$
62	Hallett et al. (1998)[19]	$BD = 0.87 + 0.071 \times \ln(Cl) + 0.093 \times \ln(Sa) - 0.254 \times \ln(OC)$
63	Han et al. (2012)[55]	$BD = \mathrm{e}^{(0.5379 - 0.0653 \times \sqrt{OM})}$

64	Bashir et al. (2025)[56]	$BD = 1.757 - 1.782 \times \log_{10}(OM) + 0.00797 \times \left(\frac{Cl}{OM}\right)$
65	Salamanca Jiménez et al. (2005) (1)[57]	$BD = 1.79 - 0.02 \times HCC + 0.00008 \times HCC^2$
66	Salamanca Jiménez et al. (2005) (2)[57]	$BD = 1.77 - 0.14 \times OM + 0.006 \times OM^2 - 0.00008 \times OM^3$

Note: BD, bulk density; OM, soil organic matter; OC, organic carbon; C, carbon; Sa, sand; Si, silt; Cl, clay; depth, soil depth; and HCC, hygroscopic coefficient of humidity.

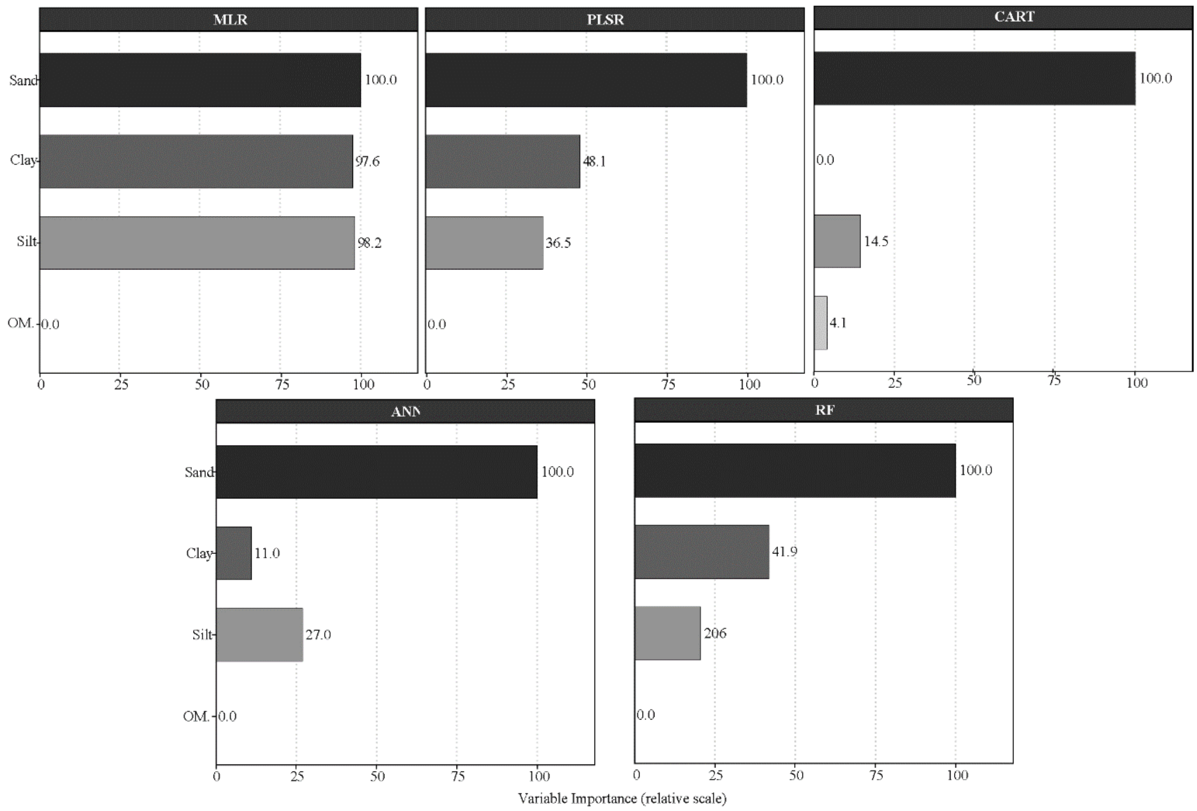

Fig. S1 Relative importance of predictor variables across five models evaluated for soil bulk density (BD) estimation: multiple linear regression (MLR), partial least squares regression (PLSR), classification and regression tree (CART), artificial neural network (ANN), and random forest (RF). Variable importance is expressed on a relative scale (0–100).

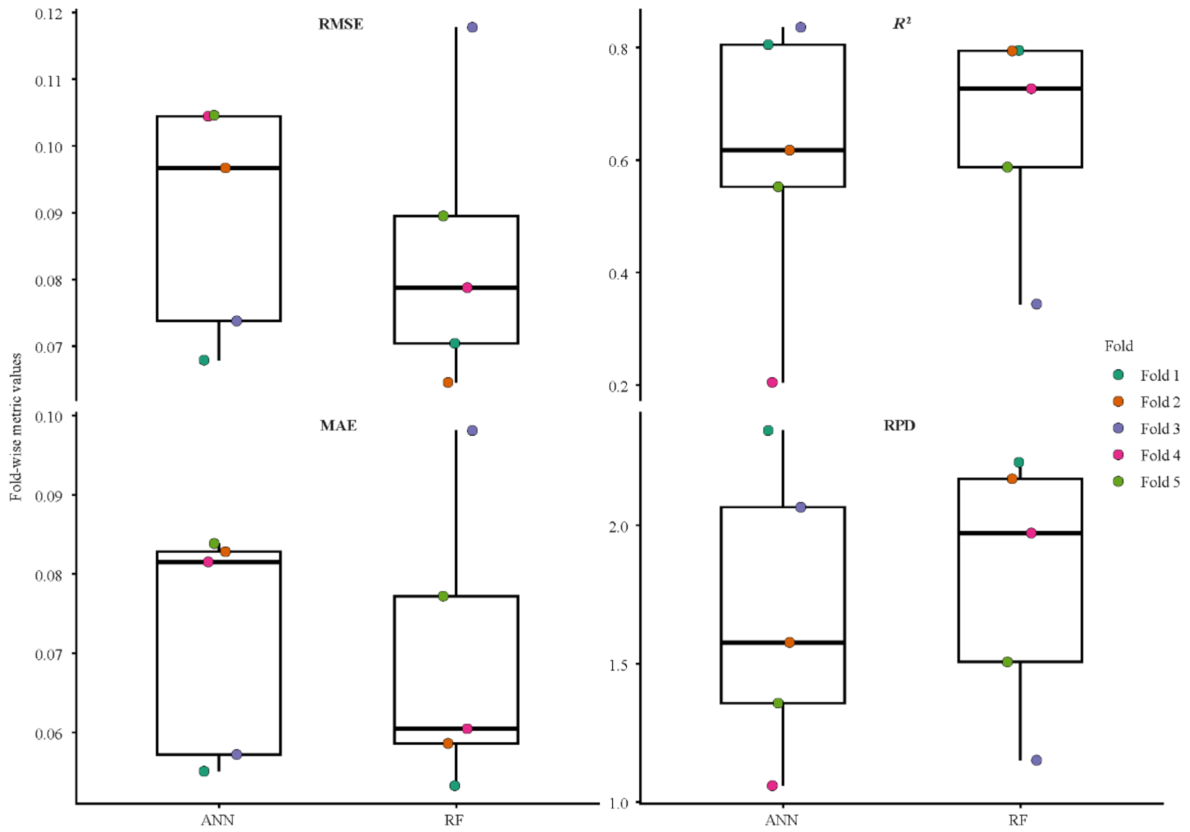

Fig. S2 Distribution of root mean square error (RMSE), coefficient of determination (R^2), mean absolute error (MAE), and ratio of performance to deviation (RPD) across the five folds for the artificial neural network (ANN) and random forest (RF) models under fivefold cross-validation. Colored points represent individual fold results (Folds 1–5)**.**

REFERENCES

1. Abdelbaki A M. Using automatic calibration method for optimizing the performance of pedotransfer functions of saturated hydraulic conductivity. *Ain Shams Engineering Journal, 2016*, **7**(2): 653–662
2. Adams W A. The effect of organic matter on the bulk and true densities of some uncultivated podzolic soils. *Journal of Soil Science*, 1973, **24**(1): 10–17
3. Akpa S I C, Ugbaje S U, Bishop T F A, Odeh I O A. Enhancing pedotransfer functions with environmental data for estimating bulk density and effective cation exchange capacity in a data-sparse situation. *Soil Use and Management,* 2016, **32**(4): 644–658
4. Alexander E B. Bulk densities of California soils in relation to other soil properties. *Soil Science Society of America Journal*, 1980, **44**(4): 689–692
5. Al-Qinna M I, Jaber S M. Predicting soil bulk density using advanced pedotransfer functions in an arid environment. *Transactions of the ASABE*, 2013, **56**(3): 963–976
6. Benites V M, Machado P L O A, Fidalgo E C C, Coelho M R, Madari B E. Pedotransfer functions for estimating soil bulk density from existing soil survey reports in Brazil. *Geoderma*, 2007, **139**(1–2): 90–97
7. Bernoux M, Cerri C, Arrouays D, Jolivet C, Volkoff B. Bulk densities of Brazilian Amazon soils related to other soil properties. *Soil Science Society of America Journal*, 1998, **62**(3): 743–749
8. Beutler S J, Pereira M G, de Souza Tassinari W, de Menezes M D, Valladares G S, dos Anjos L H C. Bulk density prediction for histosols and soil horizons with high organic matter content. *Revista Brasileira de Ciência do Solo*, 2017, **41**: e0160158

9. Botula Y D, Nemes A, Van Ranst E, Mafuka P, De Pue J, Cornelis W M. Hierarchical pedotransfer functions to predict bulk density of highly weathered soils in central Africa. *Soil Science Society of America Journal,* 2015, **79**(2): 476–486
10. Calhoun F G, Smeck N E, Slater B L, Bigham J M, Hall G F. Predicting bulk density of Ohio soils from morphology, genetic principles, and laboratory characterization data. *Soil Science Society of America Journal,* 2001, **65**(3): 811–819
11. Cienciala E, Exnerová Z, Macků J, Henžlík V. Forest topsoil organic carbon content in Southwest Bohemia region. *Journal of Forest Science,* 2006, **52**(9): 387–398
12. Curtis R O, Post B W. Estimating bulk density from organic-matter content in some Vermont forest soils. *Soil Science Society of America Journal,* 1964, **28**(2): 285–286
13. De Vos B, Van Meirvenne M, Quataert P, Deckers J, Muys B. Predictive quality of pedotransfer functions for estimating bulk density of forest soils. *Soil Science Society of America Journal,* 2005, **69**(2): 500–510
14. Drew L A. Bulk density estimation based on organic matter content of some Minnesota soils. *University Digital Conservancy,* 1973. Available at University of Minnesota Digital Conservancy on May 14, 2026
15. Eschner A R, Jones B O, Moyle R C. Station Paper NE-89. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, *Northeastern Forest Experiment Station,* 1957. Available at USDA Forest Service website on May 14, 2026
16. Federer C A. Nitrogen mineralization and nitrification: depth variation in four New England forest soils. *Soil Science Society of America Journal,* 1983, **47**(5): 1008–1014
17. Federer C A, Turcotte D E, Smith C T. The organic fraction–bulk density relationship and the expression of nutrient content in forest soils. *Canadian Journal of Forest Research, 1993,* **23**(6): 1026–1032
18. Grigal D F, Brovold S L, Nord W S, Ohmann L F. Bulk density of surface soils and peat in the north central United States. *Canadian Journal of Soil Science,* 1989, **69**(4): 895–900
19. Hallett S H, Hollis J M, Keay C A. Derivation and evaluation of a set of pedogenically-based empirical algorithms for predicting bulk density in British soils. Cranfield, UK: National Soil Resources Institute, *Cranfield University,* 1998. Available at LandIS website on May 14, 2026
20. Harrison A F, Bocock K L. Estimation of soil bulk-density from loss-on-ignition values. *Journal of Applied Ecology,* 1981, **18**(3): 919–927
21. Heuscher S A, Brandt C C, Jardine P M. Using soil physical and chemical properties to estimate bulk density. *Soil Science Society of America Journal*, 2005, **69**(1): 51–56
22. Hollis J M, Hannam J, Bellamy P H. Empirically-derived pedotransfer functions for predicting bulk density in European soils. *European Journal of Soil Science,* 2012, **63**(1): 96–109
23. Honeysett J L, Ratkowsky D A. The use of ignition loss to estimate bulk density of forest soils. *Journal of Soil Science,* 1989, **40**(2): 299–308
24. Hong S Y, Minasny B, Han K H, Kim Y, Lee K. Predicting and mapping soil available water capacity in Korea. *PeerJ*, 2013, **1**: e71
25. Hossain M F, Chen W, Zhang Y. Bulk density of mineral and organic soils in Canada's Arctic and sub-Arctic. *Information Processing in Agriculture,* 2015, **2**(3–4): 183–190
26. Huntington T G, Johnson C E, Johnson A H, Siccama T G, Ryan D F. Carbon, organic matter, and bulk density relationships in a forested Spodosol. *Soil Science*, 1989, **148**(5): 380–386
27. Jeffrey D W. A note on the use of ignition loss as a means for the approximate estimation of soil bulk density. *Journal of Ecology*, 1970, **58**(1): 297–299
28. Kaur R, Kumar S, Gurung H P. A pedo-transfer function (PTF) for estimating soil bulk density from basic soil data and its comparison with existing PTFs. *Australian Journal of Soil Research*, 2002, **40**(5): 847–857
29. Keller T, Håkansson I. Estimation of reference bulk density from soil particle size distribution and soil organic matter content. *Geoderma*, 2010, **154**(3–4): 398–406
30. Kobal M, Urbančič M, Potočić N, De Vos B, Simončič P. Pedotransfer functions for bulk density estimation of forest soils. *Šumarski list*, 2011, **135**(1–2): 19–27. Available at SciSpace website on May 14, 2026

31. Leonaviciute N. Predicting soil bulk and particle densities by pedotransfer functions from existing soil data in Lithuania. *Geografijosmetraštis*, 2000, **33**: 317–330
32. Manrique L A, Jones C A. Bulk density of soils in relation to soil physical and chemical properties. *Soil Science Society of America Journal*, 1991, **55**(2): 476–481
33. Men M, Peng Z, Hao X, Yu Z. Investigation on pedotransfer function for estimating soil bulk density in Hebei Province. *Chinese Journal of Soil Science*, 2008, **39**(1): 20–24 (in Chinese)
34. Valzano F, Murphy B, Koen T. The impact of tillage on changes in soil carbon density with special emphasis on Australian conditions. National Carbon Accounting System Technical Report No. 43. Canberra, Australia: *Australian Greenhouse Office*, 2005. Available at Department of Climate Change, Energy, the Environment and Water website on May 14, 2026
35. Minasny B, Hartemink A E. Predicting soil properties in the tropics. *Earth-Science Reviews*, 2011, **106**(1–2): 52–62
36. Nanko K, Ugawa S, Hashimoto S, Imaya A, Kobayashi M, Sakai H, Ishizuka S, Miura S, Tanaka N, Takahashi M, Kaneko S. A pedotransfer function for estimating bulk density of forest soil in Japan affected by volcanic ash. *Geoderma*, 2014, **213**: 36–45
37. Palladino M, Romano N, Pasolli E, Nasta P. Developing pedotransfer functions for predicting soil bulk density in Campania. *Geoderma*, 2022, **412**: 115726
38. Périé C, Ouimet R. Organic carbon, organic matter and bulk density relationships in boreal forest soils. *Canadian Journal of Soil Science*, 2008, **88**(3): 315–325
39. Prévost M. Predicting soil properties from organic matter content following mechanical site preparation of forest soils. *Soil Science Society of America Journal*, 2004, **68**(3): 943–949
40. Rawls W J, Nemes A, Pachepsky Y. Effect of soil organic carbon on soil hydraulic properties. In: Pachepsky Y, Rawls W J, eds. Development of pedotransfer functions in soil hydrology. Amsterdam: *Elsevie*r, 2004, 95–114
41. Reidy B, Simo I, Sills P, Creamer R E. Pedotransfer functions for Irish soils: estimation of bulk density (ρb) per horizon type. *Soil*, 2016, **2**(1): 25–39
42. Ruehlmann J, Körschens M. Calculating the effect of soil organic matter concentration on soil bulk density. *Soil Science Society of America Journal*, 2009, **73**(3): 876–885
43. Saini G R. Organic matter as a measure of bulk density of soil. *Nature*, 1966, **210**(5042): 1295–1296
44. Sevastas S, Gasparatos D, Botsis D, Siarkos I, Diamantaras K I, Bilas G. Predicting bulk density using pedotransfer functions for soils in the Upper Anthemountas basin, Greece. *Geoderma Regional*, 2018, **14**: e00169
45. Song G, Li L, Pan G, Zhang Q. Topsoil organic carbon storage of China and its loss by cultivation. *Biogeochemistry*, 2005, **74**(1): 47–62
46. Tamminen P, Starr M. Bulk density of forested mineral soils. *Silva Fennica*, 1994, **28**(1): 53–60
47. Tomasella J, Hodnett M G. Estimating soil water retention characteristics from limited data in Brazilian Amazonia. *Soil Science*, 1998, **163**(3): 190–202
48. Tranter G, Minasny B, McBratney A B, Murphy B, McKenzie N J, Grundy M, Brough D. Building and testing conceptual and empirical models for predicting soil bulk density. *Soil Use and Management*, 2007, **23**(4): 437–443
49. Tremblay S, Ouimet R, Houle D. Prediction of organic carbon content in upland forest soils of Quebec, Canada. *Canadian Journal of Forest Research*, 2002, **32**(5): 903–914
50. Williams R J B. Relationships between the composition of soils and physical measurements made on them. In: Rothamsted Experimental Station Report for 1970, Part 2. Harpenden, UK: *Rothamsted Experimental Station*, 1971, 5–35
51. Wu H, Guo Z, Peng C. Land use induced changes of organic carbon storage in soils of China. *Global Change Biology*, 2003, **9**(3): 305–315
52. Yang Y, Mohammat A, Feng J, Zhou R, Fang J. Storage, patterns and environmental controls of soil organic carbon in China. *Biogeochemistry*, 2007, **84**(2): 131–141

53. Zinke P J, Millemann R E, Boden T A. Worldwide organic soil carbon and nitrogen data. Oak Ridge, Tennessee, USA: Carbon Dioxide Information Analysis Center, *Oak Ridge National Laboratory*, 1986. Available at ORNL DAAC website on May 14, 2026
54. Dexter A R. Soil physical quality. Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. *Geoderma*, 2004, **120**(3–4): 201–214
55. Han G Z, Zhang G L, Gong Z T, Wang G F. Pedotransfer functions for estimating soil bulk density in China. *Soil Science*, 2012, **177**(3): 158–164
56. Bashir O, Ahmad Bangroo S, Amjid S, Nasta P, Shafai S, Palladino M, Senesi N, Rasool R, Choudhury B U, Jha P K, Abrol V, Spalevic V, Sestras P, Omidvar N, Ercişli S, Jaufer L, Benzougagh B, Bammou Y, Mohamed K, Lukić T, Kader S. Soil bulk density estimation by a novel pedotransfer function tailored on hilly terrains. *Earth Systems and Environment*, 2025, **9**(3): 1615–1633
57. Salamanca Jiménez A, Sadeghian Khalajabadi S. Bulk density and its relationship with other properties in soils of the Colombian coffee-growing region. *Cenicafé Journal*, 2005, **56**(4): 381–397 (in Spanish)