# Supplementary data

*Supplementary Table 1. Traits measured and descriptors used in this study. Calculations for derived traits are found in the Supplementary R code.*

|  |  |  |  |
| --- | --- | --- | --- |
| Trait category | Trait description | Method | Units |
| Root size | Root dry mass total | Measured after 3 days at 60℃ | g |
| Total count | DynamicRoots | - |
| Lateral count | DynamicRoots | - |
| Total length | DynamicRoots | mm |
| Primary length | DynamicRoots | mm |
| Extended primary root length | Measured using a ruler | mm |
| Lateral length | DynamicRoots | mm |
| First order lateral length | DynamicRoots | mm |
| Total volume | DynamicRoots | mm3 |
| Lateral volume | DynamicRoots | mm3 |
| First order lateral volume | DynamicRoots | mm |
| Root distribution | Convex hull volume of root system | GiA3D | mm3 |
|  | Solidity of root system | GiA3D | ratio |
|  | Bushiness of root system | GiA3D | ratio |
|  | Density first order laterals | DynamicRoots | TL |
|  | Density first order laterals | DynamicRoots | BRTL |
|  | Average interbranch distance | DynamicRoots | mm |
|  | Maximum width of root system | GiA3D | mm |
|  | Maximum depth of root system | GiA3D | mm |
|  | Width:Depth ratio of root system | GiA3D | ratio |
|  | Depth of all roots | DynamicRoots | mm |
|  | Depth of all lateral roots | DynamicRoots | mm |
|  | Length distribution of root system | Gia3D | mm |
|  | Average tortuosity of all roots | DynamicRoots | ratio |
|  | Average tortuosity of primary root | DynamicRoots | ratio |
|  | Average tortuosity of lateral roots | DynamicRoots | ratio |
|  | Average soil angle of all roots | DynamicRoots | degrees |
|  | Primary root soil angle | DynamicRoots | degrees |
|  | Average soil angle of lateral roots | DynamicRoots | degrees |
|  | Average branching angle from parent | DynamicRoots | degrees |
|  | Average branching angle of laterals | DynamicRoots | degrees |
|  | Specific root length | Root length / Root dry mass (derived) |  m g-1 |
| Root lateral:axial fraction | Lateral + secondary lateral root length / total root length (derived) | - |
| Root Growth | Lateral root growth rate | Change in lateral root length / hours (derived) | mm hour-1 |
|  | Total root growth rate | Change in total root length / hours (derived) | mm hour-1 |
| Root anatomy | Root maximum diameter |  | mm |
| Average radius of all roots | DynamicRoots | mm |
| Radius of primary root | DynamicRoots | mm |
|  | Average radius lateral roots | DynamicRoots | mm |
| Shoot size | Shoot dry mass total | Measured after 3 days at 60℃ | g |
| Rosette size | PlantCV | cm |
| Leaf count | PlantCV | cm |
| Biomass distribution | Plant dry mass total | Root + Shoot dry mass (derived) | g |
|  | Root mass fraction | Root dry mass / total dry mass (derived) | g g1 |

*Supplementary Table 2. Day x N condition ANOVA for plant traits in Spring32 in four nitrate conditions*

|  |  |
| --- | --- |
| Trait | Source of variation |
|  | Day | NTreatment | Day:NTreatment |
| InterbranchMeanDistance\_mm | 95.35 \*\*\* | 5.88 \*\* | 2.46 \* |
| InterbranchMedianDistance\_mm | 170.64 \*\*\* | 3.64 \* | 1.84 ns |
| RootBushiness3D | 40.14 \*\*\* | 1.26 ns | 1.68 ns |
| RootConvexHullVolume3D\_mm3 | 91.91 \*\*\* | 7.39 \*\*\* | 3.58 \*\*\* |
| RootCountFirstOrderLateral | 211.66 \*\*\* | 2.72 ns | 0.80 ns |
| RootCountLateral | 93.25 \*\*\* | 4.34 \*\* | 2.63 \* |
| RootDensityFirstOrderLateral\_BRTL | 167.02 \*\*\* | 4.48 \*\* | 1.22 ns |
| RootDensityFirstOrderLateral\_TL | 114.65 \*\*\* | 5.09 \*\* | 0.91 ns |
| RootDepth3D\_mm | 100.41 \*\*\* | 3.91 \* | 0.41 ns |
| RootDepthPrimary\_mm | 65.25 \*\*\* | 3.04 \* | 0.45 ns |
| RootLateralGrowthRate\_mm.h | 164.01 \*\*\* | 11.36 \*\*\* | 5.18 \*\*\* |
| RootLengthDistribution3D\_mm | 1041.93 \*\*\* | 11.18 \*\*\* | 1.33 ns |
| RootLengthFirstOrderLateral\_mm | 199.83 \*\*\* | 14.82 \*\*\* | 5.90 \*\*\* |
| RootLengthLateral\_mm | 164.01 \*\*\* | 11.36 \*\*\* | 5.18 \*\*\* |
| RootLengthPrimary\_mm | 121.67 \*\*\* | 2.95 \* | 0.66 ns |
| RootLengthSecondOrderLateral\_mm | 19.86 \*\*\* | 0.87 ns | 1.45 ns |
| RootMaximumNetworkWidth3D\_mm | 226.28 \*\*\* | 12.98 \*\*\* | 3.64 \*\*\* |
| RootMeanBranchingAngle\_degrees | 124.42 \*\*\* | 0.68 ns | 1.20 ns |
| RootMeanBranchingAngleFirstOrderLateral\_degrees | 808.80 \*\*\* | 4.83 \*\* | 2.39 \* |
| RootMeanBranchingAngleLateral\_degrees | 1000.69 \*\*\* | 2.84 \* | 3.29 \*\* |
| RootMeanDepth\_mm | 19.79 \*\*\* | 1.53 ns | 1.17 ns |
| RootMeanDepthFirstOrderLateral\_mm | 144.16 \*\*\* | 0.73 ns | 1.18 ns |
| RootMeanDepthLateral\_mm | 107.52 \*\*\* | 0.90 ns | 1.57 ns |
| RootMeanLength\_mm | 22.56 \*\*\* | 5.16 \*\* | 0.78 ns |
| RootMeanLengthFirstOrderLateral\_mm | 284.10 \*\*\* | 18.45 \*\*\* | 6.34 \*\*\* |
| RootMeanLengthLateral\_mm | 191.45 \*\*\* | 8.45 \*\*\* | 2.63 \* |
| RootMeanRadius\_mm | 35.03 \*\*\* | 9.77 \*\*\* | 1.60 ns |
| RootMeanRadiusFirstOrderLateral\_mm | 1967.11 \*\*\* | 11.17 \*\*\* | 1.51 ns |
| RootMeanRadiusLateral\_mm | 1546.97 \*\*\* | 6.86 \*\*\* | 1.16 ns |
| RootMeanSoilAngle\_degrees | 95.21 \*\*\* | 2.37 ns | 0.57 ns |
| RootMeanSoilAngleFirstOrderLateral\_degrees | 458.29 \*\*\* | 8.68 \*\*\* | 3.12 \*\* |
| RootMeanSoilAngleLateral\_degrees | 308.70 \*\*\* | 6.08 \*\*\* | 1.96 ns |
| RootMeanTortuosity | 34.95 \*\*\* | 4.32 \*\* | 2.07 \* |
| RootMeanTortuosityFirstOrderLateral | 15423.97 \*\*\* | 2.96 \* | 1.12 ns |
| RootMeanTortuosityLateral | 21286.41 \*\*\* | 1.42 ns | 1.09 ns |
| RootMeanVolume\_mm3 | 25.46 \*\*\* | 7.91 \*\*\* | 1.29 ns |
| RootMeanVolumeFirstOrderLateral\_mm3 | 256.51 \*\*\* | 28.47 \*\*\* | 7.75 \*\*\* |
| RootMeanVolumeLateral\_mm3 | 190.03 \*\*\* | 12.08 \*\*\* | 2.82 \*\* |
| RootMedianBranchingAngle\_degrees | 138.13 \*\*\* | 0.67 ns | 1.49 ns |
| RootMedianBranchingAngleFirstOrderLateral\_degrees | 1073.06 \*\*\* | 8.15 \*\*\* | 3.16 \*\* |
| RootMedianBranchingAngleLateral\_degrees | 1377.15 \*\*\* | 8.10 \*\*\* | 3.69 \*\*\* |
| RootMedianDepth\_mm | 23.26 \*\*\* | 1.67 ns | 1.04 ns |
| RootMedianDepthFirstOrderLateral\_mm | 150.38 \*\*\* | 1.10 ns | 1.14 ns |
| RootMedianDepthLateral\_mm | 113.86 \*\*\* | 1.20 ns | 1.48 ns |
| RootMedianLength\_mm | 29.42 \*\*\* | 4.69 \*\* | 1.08 ns |
| RootMedianLengthFirstOrderLateral\_mm | 148.55 \*\*\* | 12.41 \*\*\* | 4.30 \*\*\* |
| RootMedianLengthLateral\_mm | 69.33 \*\*\* | 5.11 \*\* | 2.26 \* |
| RootMedianRadius\_mm | 47.29 \*\*\* | 11.37 \*\*\* | 1.54 ns |
| RootMedianRadiusFirstOrderLateral\_mm | 2325.58 \*\*\* | 16.29 \*\*\* | 2.06 \* |
| RootMedianRadiusLateral\_mm | 2221.19 \*\*\* | 13.63 \*\*\* | 1.82 ns |
| RootMedianSoilAngle\_degrees | 99.72 \*\*\* | 2.02 ns | 0.63 ns |
| RootMedianSoilAngleFirstOrderLateral\_degrees | 881.29 \*\*\* | 19.39 \*\*\* | 5.49 \*\*\* |
| RootMedianSoilAngleLateral\_degrees | 486.69 \*\*\* | 7.53 \*\*\* | 2.38 \* |
| RootMedianTortuosity | 30.32 \*\*\* | 0.08 ns | 2.57 \* |
| RootMedianTortuosityFirstOrderLateral | 24962.16 \*\*\* | 8.38 \*\*\* | 3.13 \*\* |
| RootMedianTortuosityLateral | 17496.68 \*\*\* | 1.16 ns | 1.28 ns |
| RootMedianVolume\_mm3 | 53.49 \*\*\* | 5.42 \*\* | 1.79 ns |
| RootMedianVolumeFirstOrderLateral\_mm | 116.82 \*\*\* | 14.35 \*\*\* | 4.58 \*\*\* |
| RootMedianVolumeLateral\_mm3 | 63.01 \*\*\* | 3.58 \* | 2.07 \* |
| RootRadiusPrimary | 2.88 \* | 31.56 \*\*\* | 1.15 ns |
| RootSoilAnglePrimary\_degrees | 12.91 \*\*\* | 9.09 \*\*\* | 1.54 ns |
| RootSolidity3D | 334.40 \*\*\* | 1.82 ns | 1.80 ns |
| RootTortuosityPrimary | 0.91 ns | 0.85 ns | 0.92 ns |
| RootTotalCount | 98.25 \*\*\* | 4.78 \*\* | 2.58 \* |
| RootTotalDepth\_mm | 88.75 \*\*\* | 1.50 ns | 1.53 ns |
| RootTotalDepthFirstOrderLateral\_mm | 92.81 \*\*\* | 1.23 ns | 1.14 ns |
| RootTotalDepthLateral\_mm | 76.52 \*\*\* | 1.39 ns | 1.56 ns |
| RootTotalGrowthRate\_mm.h | 211.79 \*\*\* | 11.81 \*\*\* | 5.19 \*\*\* |
| RootTotalLength\_mm | 209.60 \*\*\* | 11.88 \*\*\* | 5.17 \*\*\* |
| RootTotalVolume\_mm3 | 191.80 \*\*\* | 21.29 \*\*\* | 5.50 \*\*\* |
| RootVolumeFirstOrderLateral\_mm3 | 201.32 \*\*\* | 26.84 \*\*\* | 9.01 \*\*\* |
| RootVolumeLateral\_mm3 | 145.47 \*\*\* | 16.43 \*\*\* | 6.12 \*\*\* |
| RootVolumePrimary\_mm3 | 120.26 \*\*\* | 11.76 \*\*\* | 0.43 ns |
| RootWidthDepth3D\_Ratio | 56.15 \*\*\* | 5.48 \*\* | 1.71 ns |

\*\*\* P < 0.001; \*\* P < 0.01; \* P < 0.05; ns not significant

*Supplementary Table 3. Genotype x N condition ANOVA for plant traits at day 17 in Spring32, MN106, and ISU89, in high N and trace N conditions*

|  |  |
| --- | --- |
| Trait | Source of variation |
|  | Geno | NTreatment | Geno:NTreatment |
| InterbranchMeanDistance\_mm | 0.84 ns | 5.92 \* | 0.59 ns |
| InterbranchMedianDistance\_mm | 2.83 ns | 1.29 ns | 0.63 ns |
| RootBushiness3D | 1.82 ns | 2.24 ns | 0.12 ns |
| RootConvexHullVolume3D\_mm3 | 12.23 \*\*\* | 13.35 \*\* | 3.31 ns |
| RootCountFirstOrderLateral | 0.92 ns | 0.07 ns | 2.70 ns |
| RootCountLateral | 2.17 ns | 1.88 ns | 0.64 ns |
| RootDensityFirstOrderLateral\_BRTL | 1.41 ns | 5.95 \* | 1.08 ns |
| RootDensityFirstOrderLateral\_TL | 0.81 ns | 0.06 ns | 1.65 ns |
| RootDepth3D\_mm | 2.31 ns | 13.44 \*\* | 0.48 ns |
| RootDepthPrimary\_mm | 1.80 ns | 13.11 \*\* | 0.45 ns |
| RootDW\_g | 0.91 ns | 0.22 ns | 1.38 ns |
| RootLateralGrowthRate\_mm.h | 2.52 ns | 21.16 \*\*\* | 0.07 ns |
| RootLengthDistribution3D\_mm | 1.49 ns | 2.54 ns | 1.83 ns |
| RootLengthFirstOrderLateral\_mm | 0.89 ns | 4.10 ns | 1.09 ns |
| RootLengthLateral\_mm | 0.25 ns | 1.27 ns | 0.21 ns |
| RootLengthPrimary\_mm | 0.65 ns | 4.69 \* | 0.60 ns |
| RootLengthSecondOrderLateral\_mm | 0.96 ns | 0.00 ns | 1.20 ns |
| RootMaximumNetworkWidth3D\_mm | 19.82 \*\*\* | 28.85 \*\*\* | 4.17 \* |
| RootMeanBranchingAngle\_degrees | 6.75 \*\* | 0.26 ns | 0.01 ns |
| RootMeanBranchingAngleFirstOrderLateral\_degrees | 11.54 \*\*\* | 1.53 ns | 0.53 ns |
| RootMeanBranchingAngleLateral\_degrees | 6.86 \*\* | 0.32 ns | 0.01 ns |
| RootMeanDepth\_mm | 0.37 ns | 0.24 ns | 1.00 ns |
| RootMeanDepthFirstOrderLateral\_mm | 0.82 ns | 0.01 ns | 1.28 ns |
| RootMeanDepthLateral\_mm | 0.34 ns | 0.05 ns | 1.14 ns |
| RootMeanLength\_mm | 22.53 \*\*\* | 2.00 ns | 1.19 ns |
| RootMeanLengthFirstOrderLateral\_mm | 12.06 \*\*\* | 9.96 \*\* | 1.38 ns |
| RootMeanLengthLateral\_mm | 18.89 \*\*\* | 3.06 ns | 1.81 ns |
| RootMeanRadius\_mm | 0.36 ns | 2.14 ns | 0.73 ns |
| RootMeanRadiusFirstOrderLateral\_mm | 0.20 ns | 1.64 ns | 0.40 ns |
| RootMeanRadiusLateral\_mm | 0.34 ns | 1.95 ns | 0.87 ns |
| RootMeanSoilAngle\_degrees | 7.74 \*\* | 10.83 \*\* | 0.23 ns |
| RootMeanSoilAngleFirstOrderLateral\_degrees | 34.86 \*\*\* | 16.52 \*\*\* | 0.40 ns |
| RootMeanSoilAngleLateral\_degrees | 9.02 \*\* | 11.73 \*\* | 0.26 ns |
| RootMeanTortuosity | 0.89 ns | 0.00 ns | 0.90 ns |
| RootMeanTortuosityFirstOrderLateral | 7.44 \*\* | 0.13 ns | 1.62 ns |
| RootMeanTortuosityLateral | 3.21 ns | 0.89 ns | 0.79 ns |
| RootMeanVolume\_mm3 | 12.82 \*\*\* | 0.04 ns | 0.21 ns |
| RootMeanVolumeFirstOrderLateral\_mm3 | 13.08 \*\*\* | 8.58 \*\* | 0.78 ns |
| RootMeanVolumeLateral\_mm3 | 17.34 \*\*\* | 2.11 ns | 0.85 ns |
| RootMedianBranchingAngle\_degrees | 9.99 \*\*\* | 0.00 ns | 0.06 ns |
| RootMedianBranchingAngleFirstOrderLateral\_degrees | 10.99 \*\*\* | 1.25 ns | 0.23 ns |
| RootMedianBranchingAngleLateral\_degrees | 9.57 \*\*\* | 0.01 ns | 0.05 ns |
| RootMedianDepth\_mm | 0.13 ns | 0.05 ns | 0.21 ns |
| RootMedianDepthFirstOrderLateral\_mm | 0.42 ns | 0.60 ns | 0.56 ns |
| RootMedianDepthLateral\_mm | 0.14 ns | 0.03 ns | 0.19 ns |
| RootMedianLength\_mm | 9.06 \*\* | 0.36 ns | 2.01 ns |
| RootMedianLengthFirstOrderLateral\_mm | 9.37 \*\* | 7.81 \* | 1.95 ns |
| RootMedianLengthLateral\_mm | 9.05 \*\* | 0.10 ns | 2.27 ns |
| RootMedianRadius\_mm | 0.81 ns | 2.55 ns | 0.32 ns |
| RootMedianRadiusFirstOrderLateral\_mm | 0.91 ns | 2.78 ns | 0.09 ns |
| RootMedianRadiusLateral\_mm | 0.49 ns | 2.86 ns | 0.69 ns |
| RootMedianSoilAngle\_degrees | 12.53 \*\*\* | 9.95 \*\* | 0.89 ns |
| RootMedianSoilAngleFirstOrderLateral\_degrees | 32.04 \*\*\* | 13.41 \*\* | 0.10 ns |
| RootMedianSoilAngleLateral\_degrees | 11.06 \*\*\* | 10.52 \*\* | 0.91 ns |
| RootMedianTortuosity | 3.59 \* | 2.05 ns | 0.18 ns |
| RootMedianTortuosityFirstOrderLateral | 7.24 \*\* | 0.34 ns | 0.10 ns |
| RootMedianTortuosityLateral | 3.72 \* | 2.82 ns | 0.09 ns |
| RootMedianVolume\_mm3 | 8.58 \*\* | 0.51 ns | 0.59 ns |
| RootMedianVolumeFirstOrderLateral\_mm | 7.79 \*\* | 4.53 \* | 0.25 ns |
| RootMedianVolumeLateral\_mm3 | 9.06 \*\* | 0.16 ns | 0.94 ns |
| RootRadiusPrimary | 1.38 ns | 0.09 ns | 0.32 ns |
| RootSoilAnglePrimary\_degrees | 1.08 ns | 6.85 \* | 0.76 ns |
| RootSolidity3D | 20.98 \*\*\* | 6.81 \* | 0.09 ns |
| RootTortuosityPrimary | 1.03 ns | 2.29 ns | 0.78 ns |
| RootTotalCount | 1.93 ns | 2.24 ns | 0.57 ns |
| RootTotalDepth\_mm | 1.78 ns | 0.38 ns | 1.45 ns |
| RootTotalDepthFirstOrderLateral\_mm | 1.35 ns | 0.09 ns | 1.88 ns |
| RootTotalDepthLateral\_mm | 1.59 ns | 0.34 ns | 1.35 ns |
| RootTotalGrowthRate\_mm.h | 1.12 ns | 4.78 \* | 1.10 ns |
| RootTotalLength\_mm | 1.24 ns | 4.40 \* | 0.64 ns |
| RootTotalVolume\_mm3 | 2.32 ns | 2.82 ns | 1.56 ns |
| RootVolumeFirstOrderLateral\_mm3 | 1.49 ns | 4.78 \* | 0.77 ns |
| RootVolumeLateral\_mm3 | 1.03 ns | 0.82 ns | 0.23 ns |
| RootVolumePrimary\_mm3 | 20.87 \*\*\* | 43.39 \*\*\* | 5.98 \*\* |
| RootWidthDepth3D\_Ratio | 1.14 ns | 0.41 ns | 0.13 ns |
| ShootDW\_g | 1.77 ns | 1.15 ns | 1.74 ns |
| SpecRootLength\_m.g | 0.86 ns | 0.49 ns | 0.22 ns |
| TotalMass\_g | 0.84 ns | 5.92 \* | 0.59 ns |

\*\*\* P < 0.001; \*\* P < 0.01; \* P < 0.05; ns not significant

*Supplementary Table 4. Day x Genotype ANOVA for plant traits across the 24 diverse pennycress accession lines [missing shoot traits]*

|  |  |
| --- | --- |
| Trait | Source of variation |
|  | Day | Geno | Geno:Day |
| Extended\_Root | 18.38 \*\*\* | 0.90 ns | 0.84 ns |
| InterbranchMeanDistance\_mm | 96.33 \*\*\* | 2.01 \*\* | 1.05 ns |
| InterbranchMedianDistance\_mm | 69.85 \*\*\* | 1.32 ns | 1.02 ns |
| RootBushiness3D | 107.98 \*\*\* | 4.72 \*\*\* | 1.57 \*\* |
| RootConvexHullVolume3D\_mm3 | 164.11 \*\*\* | 7.72 \*\*\* | 2.64 \*\*\* |
| RootCountFirstOrderLateral | 243.43 \*\*\* | 3.60 \*\*\* | 1.22 ns |
| RootCountLateral | 343.20 \*\*\* | 4.57 \*\*\* | 1.20 ns |
| RootDensityFirstOrderLateral\_BRTL | 78.63 \*\*\* | 1.74 \* | 1.13 ns |
| RootDensityFirstOrderLateral\_TL | 126.18 \*\*\* | 3.07 \*\*\* | 1.42 \* |
| RootDepth3D\_mm | 448.05 \*\*\* | 2.82 \*\*\* | 0.57 ns |
| RootDepthPrimary\_mm | 419.96 \*\*\* | 2.70 \*\*\* | 0.57 ns |
| RootLateralGrowthRate\_mm.h | 91.04 \*\*\* | 2.71 \*\*\* | 1.05 ns |
| RootLengthDistribution3D\_mm | 223.94 \*\*\* | 2.15 \*\* | 1.59 \*\* |
| RootLengthFirstOrderLateral\_mm | 156.78 \*\*\* | 3.90 \*\*\* | 1.07 ns |
| RootLengthLateral\_mm | 179.60 \*\*\* | 4.41 \*\*\* | 1.10 ns |
| RootLengthPrimary\_mm | 459.43 \*\*\* | 2.79 \*\*\* | 0.52 ns |
| RootLengthSecondOrderLateral\_mm | 7.39 \*\*\* | 1.11 ns | 0.89 ns |
| RootMaximumNetworkWidth3D\_mm | 210.88 \*\*\* | 9.12 \*\*\* | 1.70 \*\* |
| RootMeanBranchingAngle\_degrees | 222.42 \*\*\* | 1.43 ns | 1.52 \*\* |
| RootMeanBranchingAngleFirstOrderLateral\_degrees | 137.35 \*\*\* | 1.20 ns | 1.42 \* |
| RootMeanBranchingAngleLateral\_degrees | 169.08 \*\*\* | 1.27 ns | 1.65 \*\* |
| RootMeanDepth\_mm | 58.11 \*\*\* | 2.16 \*\* | 1.35 \* |
| RootMeanDepthFirstOrderLateral\_mm | 288.52 \*\*\* | 3.23 \*\*\* | 1.03 ns |
| RootMeanDepthLateral\_mm | 280.66 \*\*\* | 2.78 \*\*\* | 0.97 ns |
| RootMeanLength\_mm | 11.99 \*\*\* | 2.43 \*\*\* | 1.87 \*\*\* |
| RootMeanLengthFirstOrderLateral\_mm | 156.16 \*\*\* | 4.42 \*\*\* | 1.21 ns |
| RootMeanLengthLateral\_mm | 185.57 \*\*\* | 5.48 \*\*\* | 1.46 \* |
| RootMeanRadius\_mm | 159.34 \*\*\* | 1.72 \* | 1.16 ns |
| RootMeanRadiusFirstOrderLateral\_mm | 104.08 \*\*\* | 1.09 ns | 1.24 ns |
| RootMeanRadiusLateral\_mm | 124.20 \*\*\* | 1.29 ns | 1.44 \* |
| RootMeanSoilAngle\_degrees | 170.13 \*\*\* | 1.81 \* | 1.69 \*\* |
| RootMeanSoilAngleFirstOrderLateral\_degrees | 387.11 \*\*\* | 3.34 \*\*\* | 0.99 ns |
| RootMeanSoilAngleLateral\_degrees | 468.39 \*\*\* | 4.27 \*\*\* | 1.07 ns |
| RootMeanTortuosity | 12.40 \*\*\* | 2.47 \*\*\* | 1.17 ns |
| RootMeanTortuosityFirstOrderLateral | 395.47 \*\*\* | 1.70 \* | 1.43 \* |
| RootMeanTortuosityLateral | 552.82 \*\*\* | 2.58 \*\*\* | 1.81 \*\*\* |
| RootMeanVolume\_mm3 | 48.40 \*\*\* | 1.76 \* | 1.71 \*\*\* |
| RootMeanVolumeFirstOrderLateral\_mm3 | 76.05 \*\*\* | 3.27 \*\*\* | 0.86 ns |
| RootMeanVolumeLateral\_mm3 | 87.91 \*\*\* | 3.90 \*\*\* | 0.92 ns |
| RootMedianBranchingAngle\_degrees | 216.96 \*\*\* | 1.44 ns | 1.58 \*\* |
| RootMedianBranchingAngleFirstOrderLateral\_degrees | 133.94 \*\*\* | 1.17 ns | 1.50 \*\* |
| RootMedianBranchingAngleLateral\_degrees | 169.25 \*\*\* | 1.28 ns | 1.81 \*\*\* |
| RootMedianDepth\_mm | 24.90 \*\*\* | 2.31 \*\*\* | 1.21 ns |
| RootMedianDepthFirstOrderLateral\_mm | 243.42 \*\*\* | 3.12 \*\*\* | 1.05 ns |
| RootMedianDepthLateral\_mm | 233.29 \*\*\* | 2.65 \*\*\* | 0.99 ns |
| RootMedianLength\_mm | 38.94 \*\*\* | 2.14 \*\* | 1.78 \*\*\* |
| RootMedianLengthFirstOrderLateral\_mm | 124.50 \*\*\* | 3.88 \*\*\* | 1.19 ns |
| RootMedianLengthLateral\_mm | 148.14 \*\*\* | 4.70 \*\*\* | 1.54 \*\* |
| RootMedianRadius\_mm | 219.46 \*\*\* | 1.61 \* | 1.42 \* |
| RootMedianRadiusFirstOrderLateral\_mm | 104.24 \*\*\* | 1.10 ns | 1.30 ns |
| RootMedianRadiusLateral\_mm | 124.06 \*\*\* | 1.33 ns | 1.52 \*\* |
| RootMedianSoilAngle\_degrees | 164.46 \*\*\* | 1.83 \* | 1.75 \*\*\* |
| RootMedianSoilAngleFirstOrderLateral\_degrees | 390.10 \*\*\* | 3.00 \*\*\* | 1.00 ns |
| RootMedianSoilAngleLateral\_degrees | 488.34 \*\*\* | 4.18 \*\*\* | 1.12 ns |
| RootMedianTortuosity | 17.34 \*\*\* | 1.63 \* | 1.43 \* |
| RootMedianTortuosityFirstOrderLateral | 398.32 \*\*\* | 1.75 \* | 1.44 \* |
| RootMedianTortuosityLateral | 559.47 \*\*\* | 2.61 \*\*\* | 1.79 \*\*\* |
| RootMedianVolume\_mm3 | 108.72 \*\*\* | 1.72 \* | 1.86 \*\*\* |
| RootMedianVolumeFirstOrderLateral\_mm | 64.10 \*\*\* | 3.10 \*\*\* | 0.92 ns |
| RootMedianVolumeLateral\_mm3 | 84.65 \*\*\* | 4.13 \*\*\* | 1.11 ns |
| RootRadiusPrimary | 2.60 ns | 2.39 \*\*\* | 0.76 ns |
| RootSoilAnglePrimary\_degrees | 34.44 \*\*\* | 1.26 ns | 1.50 \*\* |
| RootSolidity3D | 186.13 \*\*\* | 1.88 \*\* | 0.91 ns |
| RootTortuosityPrimary | 1.84 ns | 2.39 \*\*\* | 0.76 ns |
| RootTotalCount | 353.14 \*\*\* | 4.67 \*\*\* | 1.09 ns |
| RootTotalDepth\_mm | 216.47 \*\*\* | 2.89 \*\*\* | 0.89 ns |
| RootTotalDepthFirstOrderLateral\_mm | 146.80 \*\*\* | 3.06 \*\*\* | 1.01 ns |
| RootTotalDepthLateral\_mm | 160.05 \*\*\* | 2.88 \*\*\* | 0.93 ns |
| RootTotalGrowthRate\_mm.h | 94.02 \*\*\* | 2.60 \*\*\* | 1.08 ns |
| RootTotalLength\_mm | 361.66 \*\*\* | 5.26 \*\*\* | 1.10 ns |
| RootTotalVolume\_mm3 | 211.07 \*\*\* | 3.95 \*\*\* | 0.62 ns |
| RootVolumeFirstOrderLateral\_mm3 | 112.09 \*\*\* | 4.14 \*\*\* | 1.03 ns |

\*\*\* P < 0.001; \*\* P < 0.01; \* P < 0.05; ns not significant