**Appendix A. Supplementary Information**

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| **Table SI 1: Description of CAST model parameters indicating soil initial conditions** | |
| **CAST model parameters** | **Description** |
| clay | Soil clay content |
| silt-clay | Soil silt-clay content |
| BD | Initial soil Bulk Density |
| DPM to RPM ratio | Apportionment of plant litter input to RPM and DPMc (suggested values: use 1.44 for cropland and improved grassland, 0.67 for shrubland and unimproved grassland, 0.25 for forest/or calibrate) |
| AC1 | Aggregate type 1 (<53μm) |
| AC2 | Aggregate type 2 – micro-aggregates (< 250 μm) |
| AC3 | Aggregate type 3 - macro-aggregates (> 250 μm) |

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| **Table SI 2: Calibrated rate constants of CAST model for the natural ecosystems** | | | | | | | | | | |
| **Parameters** | **Heilongjiang Mollisols NatF** | **Heilongjiang Mollisols Alfa** | **Koiliaris CZO Natural** | **Clear Creek Natural** | **Slavkov Forest CZO** | **Damma Glacier CZO Young Soils** | **Damma Glacier CZO Intermediate Soils** | **Damma Glacier CZO Old Soils** | **Marchfeld CZO Forest** | **Marchfeld CZO Grassland** |
| **Fragmentation** |  |  |  |  |  |  |  |  |  |  |
| RPM to RPMc | 1.0000 | 1.0000 | 15.0000 | 20.0000 | 5.0000 | 1.0000 | 20.0000 | 17.0000 | 15.0000 | 15.0000 |
| RPMc to RPMf | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.1000 | 0.0001 | 0.0010 | 0.0010 | 3.0000 | 0.0000 |
| RPMc(AC3) to RPMf(AC3) | 0.0100 | 0.0100 | 0.1000 | 0.8000 | 0.1000 | 0.0100 | 0.1000 | 0.1000 | 0.1000 | 0.0010 |
| DPMc(AC3) to DPMf(AC3) | 0.0100 | 0.0100 | 0.5000 | 1.0000 | 0.5000 | 0.0100 | 0.5000 | 0.5000 | 0.1000 | 0.1000 |
| **Macroaggregation** |  |  |  |  |  |  |  |  |  |  |
| RPMc | 0.0060 | 0.0060 | 0.6000 | 0.6500 | 2.0000 | 0.1000 | 0.1000 | 0.1000 | 5.0000 | 1.0000 |
| DPMc | 0.0047 | 0.0047 | 0.4700 | 0.6500 | 2.0000 | 0.1000 | 0.1000 | 0.5000 | 5.0000 | 1.0000 |
| **Microaggregation** |  |  |  |  |  |  |  |  |  |  |
| RPMf(AC2inAC3) | 0.0050 | 0.0050 | 0.2000 | 0.3000 | 0.2000 | 0.2000 | 0.2000 | 0.2000 | 1.0000 | 1.0000 |
| DPMf(AC2inAC3) | 0.0050 | 0.0050 | 0.2000 | 0.3000 | 0.2000 | 0.2000 | 0.2000 | 0.2000 | 1.0000 | 1.0000 |
| **Decomposition** |  |  |  |  |  |  |  |  |  |  |
| fresh plant input(DPM) | 0.5000 | 0.5000 | 10.4500 | 10.0000 | 7.0000 | 3.0000 | 7.0000 | 20.0000 | 9.0000 | 2.0000 |
| HUM(AC1) within AC3 | 0.0100 | 0.0100 | 0.0031 | 0.1500 | 0.0003 | 0.0100 | 0.0100 | 0.1000 | 0.0003 | 0.0001 |
| HUM(AC2) within AC3 | 0.0100 | 0.0100 | 0.0021 | 0.0500 | 0.0021 | 0.0100 | 0.0100 | 0.1000 | 0.0001 | 0.0001 |
| HUM(AC2) | 0.0005 | 0.0005 | 0.0051 | 0.3000 | 0.0005 | 0.0051 | 0.0005 | 0.1000 | 0.0005 | 0.0001 |
| HUM(AC1) | 0.0010 | 0.0001 | 0.0051 | 0.4500 | 0.0005 | 0.0010 | 0.0100 | 0.3975 | 0.0005 | 0.0001 |
| **Contirbution in macroaggregation** |  |  |  |  |  |  |  |  |  |  |
| RPMc | 0.3000 | 0.2000 | 0.2000 | 0.3000 | 0.1000 | 0.3000 | 0.3500 | 0.3500 | 0.2000 | 0.3000 |
| DPMc | 0.2500 | 0.1000 | 0.2000 | 0.3000 | 0.1000 | 0.5500 | 0.5000 | 0.5000 | 0.2300 | 0.4000 |
| AC1 | 0.3000 | 0.6000 | 0.3000 | 0.3500 | 0.4000 | 0.1000 | 0.1000 | 0.1000 | 0.5200 | 0.2000 |
| AC2 | 0.1500 | 0.1000 | 0.3000 | 0.0500 | 0.4000 | 0.0500 | 0.0500 | 0.0500 | 0.0500 | 0.1000 |
| **Contribution in microaggregation** |  |  |  |  |  |  |  |  |  |  |
| RPMfwithin AC3 | 0.1340 | 0.1340 | 0.2340 | 0.1800 | 0.2340 | 0.2000 | 0.2000 | 0.2000 | 0.1000 | 0.8000 |
| DPMfwithinAC3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.7000 | 0.7000 | 0.7000 | 0.0000 | 0.0000 |
| AC1within AC3 | 0.8660 | 0.8660 | 0.7660 | 0.8200 | 0.7660 | 0.1000 | 0.1000 | 0.1000 | 0.9000 | 0.2000 |
| **Disruption** |  |  |  |  |  |  |  |  |  |  |
| fDPM+cDPM within AC3 | 0.00001 | 0.00001 | 0.00150 | 0.01500 | 0.00100 | 0.00001 | 0.00001 | 0.00001 | 0.02200 | 0.01000 |
| fDPM+cDPM AC2 within AC3 | 0.00001 | 0.00001 | 0.00150 | 0.15000 | 0.00100 | 0.00001 | 0.00001 | 0.00001 | 0.20000 | 0.01000 |
| fDPM+cDPM within AC2 | 0.00001 | 0.00001 | 0.00150 | 0.15000 | 0.00100 | 0.00001 | 0.00001 | 0.00001 | 0.30000 | 0.01000 |

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| **Table SI 3: Calibrated rate constants of CAST model for the agricultural sites** | | | | | | | | | | |
| **Parameters** | **Heilongjiang Mollisols F0C0** | **Heilongjiang Mollisols F1C0** | **Heilongjiang Mollisols F1C1** | **Heilongjiang Mollisols F1C2** | **Koiliaris CZO Agricultural** | **Clear Creek Agricultural** | **Milia 1** | **Milia 2** | **Milia 3** | **Marchfeld CZO Cropland** |
|
| ***Fragmentation*** |  |  |  |  |  |  |  |  |  |  |
| RPM to RPMc | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 15.0000 | 10.0000 | 50.0000 | 50.0000 | 50.0000 | 15.0000 |
| RPMc to RPMf | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 3.0000 | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| RPMc(AC3) to RPMf(AC3) | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0500 | 1.0000 | 0.1000 | 0.1000 | 0.1000 | 0.1000 |
| DPMc(AC3) to DPMf(AC3) | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0500 | 1.0000 | 0.5000 | 0.5000 | 0.5000 | 0.1000 |
| ***Macroaggregation*** |  |  |  |  |  |  |  |  |  |  |
| RPMc | 0.0060 | 0.0060 | 0.0250 | 0.0300 | 1.1000 | 0.6000 | 1.2000 | 1.2000 | 1.2000 | 0.3500 |
| DPMc | 0.0047 | 0.0047 | 0.0250 | 0.0300 | 1.1000 | 0.3000 | 0.8000 | 0.8000 | 0.8000 | 0.3500 |
| ***Microaggregation*** |  |  |  |  |  |  |  |  |  |  |
| RPMf(AC2inAC3) | 0.0050 | 0.0050 | 0.0050 | 0.0050 | 0.1000 | 0.5000 | 2.0000 | 2.0000 | 2.0000 | 1.0000 |
| DPMf(AC2inAC3) | 0.0050 | 0.0050 | 0.0050 | 0.0050 | 0.1000 | 0.5000 | 2.0000 | 2.0000 | 2.0000 | 1.0000 |
| ***Decomposition*** |  |  |  |  |  |  |  |  |  |  |
| fresh plant input(DPM) | 0.5000 | 1.0000 | 1.0000 | 0.5000 | 15.0000 | 20.0000 | 0.4000 | 0.4000 | 0.4000 | 20.0000 |
| HUM(AC1) within AC3 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0003 | 0.0510 | 0.0030 | 0.0030 | 0.0030 | 0.0001 |
| HUM(AC2) within AC3 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0500 | 0.0020 | 0.0020 | 0.0020 | 0.0001 |
| HUM(AC2) | 0.0005 | 0.0005 | 0.0005 | 0.0005 | 0.0200 | 0.0300 | 0.0020 | 0.0020 | 0.0020 | 0.0200 |
| HUM(AC1) | 0.0010 | 0.0010 | 0.0010 | 0.0010 | 0.0800 | 0.9000 | 0.0020 | 0.0020 | 0.0020 | 0.0000 |
| ***Contirbution in macroaggregation*** |  |  |  |  |  |  |  |  |  |  |
| RPMc | 0.1000 | 0.1000 | 0.1500 | 0.1000 | 0.2000 | 0.1200 | 0.4500 | 0.4500 | 0.4500 | 0.1500 |
| DPMc | 0.1500 | 0.1500 | 0.2000 | 0.2000 | 0.2000 | 0.1200 | 0.3800 | 0.3800 | 0.3800 | 0.2400 |
| AC1 | 0.6000 | 0.6000 | 0.6000 | 0.6000 | 0.3000 | 0.3800 | 0.0700 | 0.0700 | 0.0700 | 0.6000 |
| AC2 | 0.1500 | 0.1500 | 0.0500 | 0.1000 | 0.3000 | 0.3800 | 0.1000 | 0.1000 | 0.1000 | 0.0100 |
| ***Contribution in microaggregation*** |  |  |  |  |  |  |  |  |  |  |
| RPMfwithin AC3 | 0.1340 | 0.1340 | 0.1340 | 0.1340 | 0.8000 | 0.0500 | 0.8000 | 0.8000 | 0.8000 | 0.8000 |
| DPMfwithinAC3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| AC1within AC3 | 0.8660 | 0.8660 | 0.8660 | 0.8660 | 0.2000 | 0.9000 | 0.2000 | 0.2000 | 0.2000 | 0.2000 |
| ***Disruption*** |  |  |  |  |  |  |  |  |  |  |
| fDPM+cDPM within AC3 | 0.00100 | 0.00100 | 0.00100 | 0.00100 | 0.01000 | 0.08000 | 0.03000 | 0.03000 | 0.03000 | 0.00150 |
| fDPM+cDPM AC2 within AC3 | 0.00100 | 0.00100 | 0.00100 | 0.00100 | 0.01000 | 0.80000 | 0.03000 | 0.03000 | 0.03000 | 0.00150 |
| fDPM+cDPM within AC2 | 0.00100 | 0.00100 | 0.00100 | 0.00100 | 0.00100 | 0.60000 | 0.03000 | 0.03000 | 0.03000 | 0.00150 |

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| **Table SI 4: Rate constants used to calibrate WSA distribution and SOC stocks distribution - A range of values** | | | | | | | | |
|  | *All sites* | | | | *Agricultural sites* | | *Natural sites* | |
| Calibration Parameters | min | max | average | stdev | average | stdev | average | stdev |
| ***Fragmentation*** | | | | | | | | |
| *RPM to RPMc, 1/year* | 1.00000 | 50.00000 | 15.20000 | 16.58344 | 19.40000 | 21.83372 | 11.00000 | 8.04156 |
| *RPMc to RPMf, 1/year* | 0.00000 | 3.00000 | 0.35514 | 0.93154 | 0.40004 | 0.96607 | 0.31023 | 0.94561 |
| *RPMc(AC3) to RPMf(AC3) , 1/year* | 0.00100 | 1.00000 | 0.14105 | 0.26510 | 0.14900 | 0.30201 | 0.13310 | 0.23878 |
| *DPMc(AC3) to DPMf(AC3) , 1/year* | 0.01000 | 1.00000 | 0.29600 | 0.32694 | 0.26900 | 0.33982 | 0.32300 | 0.32948 |
| ***Macroaggregation*** | | | | | | | | |
| *RPMc, 1/year* | 0.00600 | 5.00000 | 0.76395 | 1.15061 | 0.57170 | 0.55234 | 0.95620 | 1.55168 |
| *DPMc, 1/year* | 0.00470 | 5.00000 | 0.70219 | 1.13314 | 0.42144 | 0.41739 | 0.98294 | 1.53665 |
| ***Microaggregation*** | | | | | | | | |
| *RPMf(AC2inAC3, 1/year)* | 0.00500 | 2.00000 | 0.54650 | 0.70996 | 0.76200 | 0.91005 | 0.33100 | 0.36430 |
| *DPMf(AC2inAC3) , 1/year* | 0.00500 | 2.00000 | 0.54650 | 0.70996 | 0.76200 | 0.91005 | 0.33100 | 0.36430 |
| ***Decomposition*** | | | | | | | | |
| *Fresh plant input(DPM) , 1/year* | 0.40000 | 20.00000 | 6.43250 | 7.26253 | 5.92000 | 8.67638 | 6.94500 | 5.95700 |
| *BIO(AC1) within AC3, 1/year* | 0.00100 | 0.66000 | 0.12355 | 0.22459 | 0.09500 | 0.20007 | 0.15210 | 0.25427 |
| *HUM(AC1) within AC3, 1/year* | 0.00010 | 0.15000 | 0.01971 | 0.03850 | 0.01004 | 0.01498 | 0.02938 | 0.05194 |
| *BIO(AC2) within AC3, 1/year* | 0.00100 | 0.80000 | 0.18755 | 0.28590 | 0.16900 | 0.29838 | 0.20610 | 0.28768 |
| *HUM(AC2) within AC3, 1/year* | 0.00010 | 0.10000 | 0.01503 | 0.02450 | 0.01061 | 0.01448 | 0.01944 | 0.03185 |
| *BIO(AC2), 1/year* | 0.00010 | 0.66000 | 0.15891 | 0.25138 | 0.17440 | 0.25653 | 0.14341 | 0.25898 |
| *HUM(AC2), 1/year* | 0.00010 | 0.30000 | 0.02454 | 0.06872 | 0.00780 | 0.01108 | 0.04128 | 0.09604 |
| *BIO(AC1) , 1/year* | 0.00010 | 9.00000 | 0.64641 | 2.01381 | 1.09841 | 2.83207 | 0.19440 | 0.29467 |
| *HUM(AC1, 1/year)* | 0.00000 | 0.90000 | 0.09279 | 0.22997 | 0.09900 | 0.28253 | 0.08658 | 0.17816 |
| ***Contirbution in macroaggregation*** | | | | | | | | |
| *RPMc, %* | 0.10000 | 0.45000 | 0.24350 | 0.12270 | 0.22700 | 0.15692 | 0.26000 | 0.08097 |
| *DPMc, %* | 0.10000 | 0.55000 | 0.27650 | 0.13937 | 0.24000 | 0.10231 | 0.31300 | 0.16607 |
| *AC1, %* | 0.07000 | 0.60000 | 0.34300 | 0.21263 | 0.38900 | 0.24402 | 0.29700 | 0.17664 |
| *AC2, %* | 0.01000 | 0.40000 | 0.13700 | 0.11508 | 0.14400 | 0.11286 | 0.13000 | 0.12293 |
| ***Contribution in microaggregation*** | | | | | | | | |
| *RPMfwithin AC3, %* | 0.05000 | 0.80000 | 0.35010 | 0.30528 | 0.45860 | 0.36074 | 0.24160 | 0.20114 |
| *DPMfwithinAC3, %* | 0.00000 | 0.70000 | 0.10750 | 0.25561 | 0.00500 | 0.01581 | 0.21000 | 0.33813 |
| *AC1within AC3, %* | 0.10000 | 0.90000 | 0.54240 | 0.35181 | 0.53640 | 0.35474 | 0.54840 | 0.36794 |
| ***Disruption*** | | | | | | | | |
| *fDPM+cDPM within AC3,%* | 0.00001 | 0.08000 | 0.01175 | 0.01954 | 0.01855 | 0.02531 | 0.00496 | 0.00794 |
| *fDPM+cDPM AC2 within AC3, %* | 0.00001 | 0.80000 | 0.06340 | 0.18137 | 0.09055 | 0.24962 | 0.03626 | 0.07413 |
| *fDPM+cDPM within AC2, %* | 0.00001 | 0.60000 | 0.05795 | 0.14656 | 0.06965 | 0.18684 | 004626 | 0.10067 |

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| **Table SI 5: Parameters used for the Principal Components Analysis and the components values** | | |
| Variable | PC1 | PC2 |
| Bulk Density | -0.249 | 0.060 |
| SiltClay | -0.169 | 0.158 |
| Clay | -0.174 | 0.179 |
| Dpm to Rpm ratio | 0.029 | 0.176 |
| Temperature | 0.251 | -0.092 |
| Precipitation | 0.064 | -0.216 |
| Evapotranspiration | 0.226 | 0.019 |
| SOC/silt+clay initial | 0.270 | -0.091 |
| SOC/silt+clay final | 0.202 | -0.136 |
| Carbon Input | 0.165 | 0.063 |
| SOC/silt+clay % turnover | -0.114 | -0.093 |
| AC3 initial | 0.275 | 0.056 |
| AC3 final | 0.214 | 0.064 |
| AC3 turnover (%) | -0.129 | 0.087 |
| Inintial SOC | 0.224 | 0.010 |
| Final SOC | 0.156 | -0.054 |
| Carbon Storage (%) | -0.175 | -0.039 |
| CO2 flux (%) | 0.181 | 0.038 |
| Bacterial Stock (%) | -0.105 | -0.125 |
| RPM to RPMc (fragmentation) | 0.212 | -0.255 |
| RPMc (for AC3 formation) | 0.100 | -0.049 |
| k\_RPMf\_AC2\_in\_AC3\_ag\_ini (for AC2) | 0.182 | -0.244 |
| DPM (plant litter decomposition | 0.127 | 0.166 |
| RPM (plant litter decomposition) | 0.120 | 0.190 |
| BIO(AC2) within AC3 | 0.177 | 0.216 |
| HUM(AC2) within AC3 | 0.083 | 0.281 |
| BIO(AC2) | 0.172 | 0.231 |
| HUM(AC2) | 0.097 | 0.145 |
| BIO(AC1) | 0.143 | 0.249 |
| HUM(AC1) | 0.149 | 0.273 |
| plant litter contribution in AC3 | 0.050 | -0.307 |
| RPMf within AC3 (contribution in AC2) | 0.152 | -0.218 |
| DPMf within AC3 (contribution in AC2) | -0.083 | -0.135 |
| AC1 within AC3 (contribution in AC2) | -0.072 | 0.287 |
| Disruption | 0.208 | 0.091 |