**TABLE 1** Selected soil physicochemical properties along an elevational gradient in the Helan Mountains.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Parameters | 1380 m | 1650 m | 2139 m | 2249 m | 2438 m | *F* | *P*-value |
| Clay (%) | 4.702±0.230a | 2.682±0.268b | 2.812±0.392b | 2.792±0.246b | 1.626±0.195c | 16.671 | *P*<0.001 |
| Silt (%) | 55.498±0.615a | 43.632±3.629b | 54.840±3.893a | 50.446±1.942a | 39.066±1.925b | 8.191 | *P*<0.001 |
| Sand (%) | 39.798±0.541b | 53.690±3.864ab | 42.348±4.281b | 46.764±2.167ab | 59.308±2.072a | 8.770 | *P*<0.001 |
| SWC (%) | 3.947±0.068e | 5.520±0.140d | 8.995±0.041c | 13.810±0.648b | 15.096±0.325a | 223.771 | *P*<0.001 |
| BD (g cm-3) | 1.276±0.025a | 1.162±0.016ab | 1.105±0.059ab | 1.059±0.067ab | 0.881±0.130b | 4.457 | *P*<0.001 |
| pH | 8.436±0.051a | 8.412±0.046a | 7.825±0.061b | 7.695±0.010c | 7.580±0.022c | 107.679 | *P*<0.001 |
| SOC (g kg-1) | 11.445±0.767c | 16.247±1.878c | 31.711±4.337b | 34.092±5.565b | 46.376±5.083a | 17.083 | *P*<0.001 |
| TN (g kg-1) | 1.184±0.068c | 1.431±0.151c | 2.266±0.297b | 2.789±0.413b | 3.892±0.461a | 17.024 | *P*<0.001 |
| TP (g kg-1) | 0.431±0.039b | 0.588±0.007a | 0.422±0.068b | 0.460±0.033b | 0.702±0.035a | 11.554 | *P*<0.001 |
| C:N  | 9.672±0.305c | 11.374±0.491b | 14.022±0.475a | 12.082±0.484b | 12.016±0.670b | 10.295 | *P*<0.001 |
| C:P  | 27.607±3.398b | 27.716±3.340b | 80.080±10.543a | 72.120±8.120a | 66.134±6.573a | 16.128 | *P*<0.001 |
| N:P  | 2.873±0.378b | 2.437±0.261b | 5.722±0.772a | 5.921±0.532a | 5.507±0.501a | 14.349 | *P*<0.001 |

Notes: Different letters in the same row indicate significant differences (*P*<0.05) among the different altitudes based on one-way ANOVA and the LSD test. The results are shown as the mean ± standard errors (n=6). The same below. SWC, soil water content; BD, bulk density; SOC, soil organic carbon; TN, total nitrogen; TP, total phosphorus; C:N, the mass ratio of SOC to TN; C:P, the mass ratio of SOC to TP; N: P, the mass ratio of TN to TP.

**TABLE 2** Soil enzymes and corresponding abbreviations, substrates, and Enzyme Commission (EC) numbers.

|  |  |  |  |
| --- | --- | --- | --- |
| **Enzyme** | **Abbreviation** | **Substrate** | **EC** |
| β-Glucosidase | BG | 4-MUB-β-D-glucopyranoside | 3.2.1.21 |
| Cellobiohydrolase | CBH | 4-MUB-β-D-cellobioside | 3.2.1.91 |
| N-Acetyl- β-D-glucosaminidase | NAG | 4-MUB-N-acetyl-β-Dglucosaminide | 3.2.1.52 |
| Leucine- α-aminopeptidase | LAP | L-Leucine-7-amido-4-methylcoumarin hydrochloride | 3.4.11.1 |

**TABLE 3** Soil microbial community diversity indices at different elevations.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Parameters | 1380 m | 1650 m | 2139 m | 2249 m | 2438 m | *F* | *P*-value |
| Shannon-Wiener | 1.281±0.029a | 1.264±0.024a | 1.273±0.022a | 1.309±0.021a | 1.267±0.011a | 0.665 | 0.622 |
| Brillouin | 1.278±0.009a | 1.282±0.013a | 1.291±0.007a | 1.300±0.009a | 1.285±0.011a | 0.759 | 0.562 |
| Pielou | 0.588±0.009a | 0.596±0.007a | 0.584±0.007a | 0.602±0.006a | 0.593±0.005a | 0.923 | 0.466 |
| Simpson | 0.545±0.011a | 0.548±0.008a | 0.542±0.008a | 0.560±0.006a | 0.547±0.004a | 0.733 | 0.578 |
| Mcintosh | 0.381±0.009a | 0.382±0.006a | 0.377±0.008a | 0.392±0.006a | 0.381±0.004a | 0.655 | 0.629 |
| GMM | 0.725±0.004a | 0.727±0.023a | 0.722±0.017a | 0.742±0.015a | 0.726±0.020a | 0.825 | 0.734 |

**TABLE 4** Pearson correlation analysis showing the relationships between soil properties, soil enzyme activities, and enzymatic stoichiometry.

|  |  |  |
| --- | --- | --- |
| Variable | Enzyme activity | Enzymatic stoichiometry |
| BG | CBH | NAG | LAP | AP | (BG + CBH)/(NAG + LAP) | (BG + CBH)/AP | (NAG + LAP)/AP |
| Clay | -0.225 | **-0.584\*\*** | -0.119 | **-0.394\*** | **-0.579\*\*** | -0.283 | -0.079 | 0.233 |
| Silt | 0.206 | -0.190 | 0.222 | -0.242 | -0.132 | 0.037 | 0.196 | 0.100 |
| Sand | -0.158 | 0.244 | -0.186 | 0.267 | 0.191 | 0.001 | -0.168 | -0.119 |
| SWC | **0.483\*\*** | **0.848\*\*** | 0.296 | 0.009 | **0.727\*\*** | **0.697\*\*** | 0.352 | **-0.469\*\*** |
| BD | -0.070 | **-0.483\*\*** | -0.201 | -0.165 | **-0.459\*\*** | -0.121 | 0.037 | 0.182 |
| pH | **-0.592\*\*** | **-0.837\*\*** | **-0.393\*** | -0.095 | **-0.785\*\*** | **-0.697\*\*** | **-0.415\*** | 0.416\* |
| SOC | 0.318 | **0.702\*\*** | 0.241 | 0.136 | **0.710\*\*** | **0.453\*** | 0.125  | **-0.405\*** |
| TN | 0.222 | **0.667\*\*** | 0.186 | 0.056 | **0.625\*\*** | **0.418\*** | 0.083 | -0.401 |
| TP | -0.261 | 0.129 | **-0.399\*** | 0.022 | 0.108 | 0.095 | -0.246 | -0.294 |
| C/N | **0.532\*\*** | **0.498\*\*** | **0.367\*** | **0.475\*\*** | **0.674\*\*** | 0.324 | 0.264 | -0.134 |
| C/P | **0.528\*\*** | **0.719\*\*** | **0.565\*\*** | 0.233 | **0.745\*\*** | **0.419\*** | 0.310 | -0.216 |
| N/P | **0.471\*\*** | **0.728\*\*** | **0.557\*\*** | 0.147 | **0.683\*\*** | **0.409\*** | 0.307 | -0.210 |
| Total  | 0.030 | -0.283 | -0.051 | 0.100 | -0.064 | -0.126 | -0.112 | 0.042 |
| Bact | 0.037 | -0.278 | -0.048 | -0.116 | -0.062 | -0.126 | -0.102 | 0.051 |
| Fun | 0.094 | -0.220 | 0.014 | 0.188 | 0.008 | -0.107 | -0.059 | 0.065 |
| Act | -0.199 | **-0.441\*** | -0.215 | -0.116 | -0.252 | -0.219 | -0.270 | 0.007 |
| AMF | 0.073 | -0.269 | 0.012 | 0.048 | -0.044 | -0.105 | -0.092 | 0.022 |
| Pro | -0.062 | -0.324 | -0.212 | 0.257 | -0.235 | -0.231 | -0.093 | 0.198 |
| GP | -0.006 | -0.347 | -0.084 | 0.089 | -0.111 | -0.171 | -0.157 | 0.058 |
| GN | 0.081 | -0.195 | -0.004 | 0.072 | 0.010 | -0.048 | -0.067 | -0.009 |
| GP/GN | -0.234 | -0.160 | -0.161 | 0.006 | -0.210 | -0.205 | -0.149 | 0.113 |
| F/B | 0.295 | 0.142 | 0.253 | 0.330 | 0.299 | 0.069 | 0.149 | 0.044 |

SWC, soil water content; BD, bulk density; SOC, soil organic carbon; TN, total nitrogen; TP, total phosphorus; C/N, the ratio of SOC to TN; C/P, the ratio of SOC to TP; N/P, the ratio of TN to TP; Total: total PLFAs; Bact: bacteria; Fun: fungi; Act: actinomycetes; AMF: arbuscular mycorrhizal fungi; Pro: protozoa; GP: gram-positive bacteria; GN: gram-negative bacteria; F/B: the ratio of fungi to bacteria; GP/GN: the ratio of gram-positive bacteria to gram-negative bacteria; BG: β-1,4-glucosidase; CBH: Cellobiohydrolase; NAG: β-1,4-N-acetylglucosaminidase; LAP: leucine aminopeptidase; AP: alkaline phosphatase. Note: Bold values indicate significant effects at *P* < 0.05. The asterisks “\*\*” show significant correlations at the 0.01 level, while “\*” show significant correlations at the 0.05 level.

**TABLE S1** Basic information of sample plots.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Elevation (m) | Slope (°) | Aspect | MAT (◦) | MAP (mm) | DBH (cm) | Shrub diversity | Herbdiversity | Vegetation cover (%) | Litter layer thickness (cm) | Dominant species |
| 1380 | 12 | North west  | 9.2 | 145.0 | — | 3.67 | 3.33 | 29.00 | 0.57 | *Convolvulus tragacanthoide, Stipa capillata*, *Caragana roborovskyi* |
| 1650 | 10 | North west | 6.9 | 224.0 | — | 8.00 | 6.33 | 41.00 | 0.97 | *Amygdalus mongolica*, *Potentilla fruticose, Caragana roborovskyi* |
| 2139 | 34 | North west | 4.9 | 280.4 | 12.59 | 5.00 | 9.00 | 66.67 | 11.16 | *Pinus tabuliformis*, *Spiraea salicifolia L.*, *Berberis dubia Schneid* |
| 2249 | 15 | North west | 3.7 | 315.8 | 10.36 | 3.33 | 10.67 | 71.00 | 10.51 | *Picea crassifolia*, *Populus davidiana*, *Berberis dubia Schneid* |
| 2438 | 24 | North west | 2.6 | 342.2 | 11.51 | 4.33 | 5.00 | 92.00 | 11.23 | *Picea crassifolia*, *Berberis dubia Schneid*, *Carex spp* |

Note: MAT: mean annual temperature; MAP: mean annual precipitation; DBH: diameter at breast height.

**TABLE S2** Species diversity of plants at different altitudes.

|  |  |  |  |
| --- | --- | --- | --- |
| Elevation (m) | Diversity of herb layer  | Diversity of shrub layer | Litter layer (cm) |
| Margalef  | Shannon-Wiener | Simpson | Pielou | Margalef | Shannon-Wiener | Simpson  | Pielou |
| 1380 | 0.851±0.220b | 0.992±0.185b | 0.562±0.106b | 0.765±0.054b | 0.390±0.011c | 0.617±0.019b | 0.426±0.018ab | 0.891±0.028a | 0.57±0.21c |
| 1650 | 1.418±0.262a | 1.706±0.241a | 0.767±0.074a | 0.792±0.050b | 0.824±0.225b | 0.925±0.361ab | 0.510±0.188a | 0.632±0.037bc | 0.97±0.28b |
| 2139 | 1.304±0.240a | 0.896±0.181b | 0.565±0.063b | 0.939±0.065a | 0.380±0.021c | 0.483±0.171c | 0.281±0.115b | 0.590±0.202bc | 11.16±3.17a |
| 2249 | 1.194±0.169a | 1.145±0.249b | 0.620±0.065b | 0.808±0.051ab | 0.746±0.166b | 1.063±0.257a | 0.600±0.102a | 0.774±0.078ab | 10.51±2.45a |
| 2438 | — | — | — | — | 0.365±0.119c | 0.771±0.256b | 0.518±0.183a | 0.611±0.175bc | 11.23±1.71a |

Note: different letters in the same row indicate significant differences at the different altitudes based on one-way ANOVA at 0.05 level. The same below. The results are shown as the mean ± standard errors (n=6).