# Dynamics of Soil $N_2O$ and $CO_2$ Emissions in Response to Freeze–Thaw Intensity and Moisture Variations: A Laboratory Experiment

**Yuhua Kong [1,†], Shanshan Gong [1,†], Longfei Zhu [1,2], Haohao Wu [2,3], Keji Duan [1], Weiguo Cheng [4], Dmitriy Khoroshaev [5], Yong Lai [1,*] and Xingkai Xu [2,6,*]**

[1] College of Forestry, Henan Agricultural University, Zhengzhou 450046, China; y.kong@henau.edu.cn (Y.K.); gss16181618@163.com (S.G.); zhucl727@163.com (L.Z.); 13069302032@163.com (K.D.)
[2] State Key Laboratory of Atmospheric Environment and Extreme Meteorology, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China; hhwu@niglas.ac.cn
[3] Key Laboratory of Lake and Watershed Science for Water Security, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
[4] Faculty of Agriculture, Yamagata University, Tsuruoka 997-8555, Japan; cheng@tds1.tr.yamagata-u.ac.jp
[5] Institute of Physicochemical and Biological Problems in Soil Science of the Russian Academy of Sciences, Pushchino 142290, Russia; d.khoroshaev@pbcras.ru
[6] Department of Atmospheric Chemistry and Environmental Science, College of Earth and Planetary Sciences, University of Chinese Academy of Sciences, Beijing 100049, China
* Correspondence: yonglai@henau.edu.cn (Y.L.); xingkai_xu@mail.iap.ac.cn (X.X.)
† These authors contributed equally to this work.

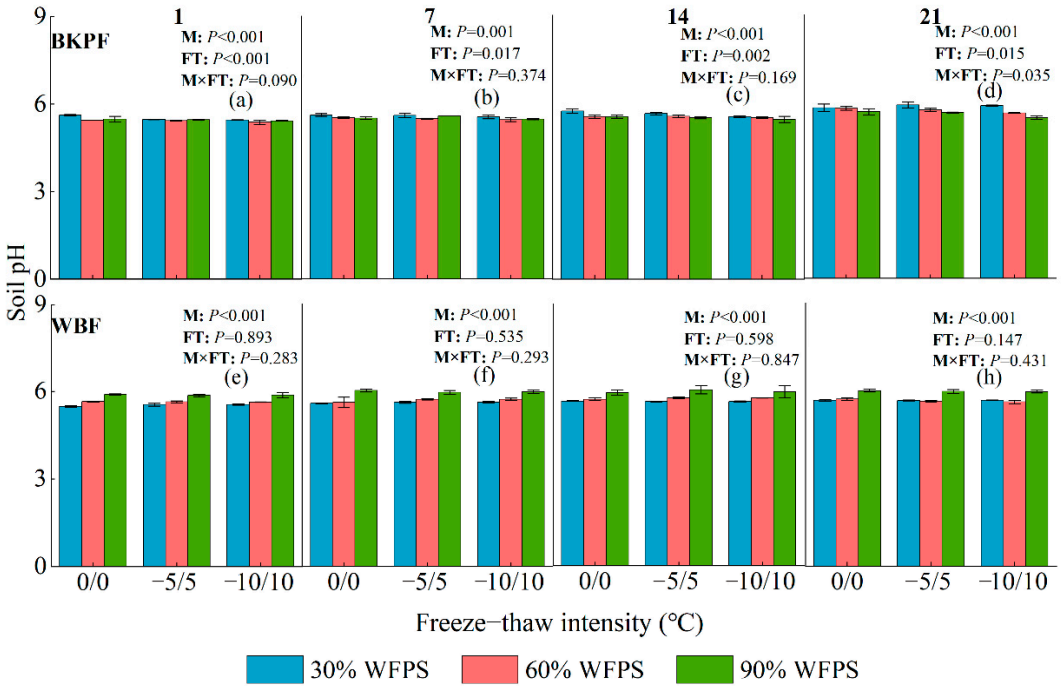


**Figure S1** Effects of freeze–thaw intensity and freeze–thaw frequency on pH in two forest soils with different initial soil moisture. M, initial soil moisture; FT, freeze–thaw intensity; 1, 7, 14 and 21 indicated 1 (a,e), 7 (b,f), 14 (c,g), and 21 (d,h) freeze–thaw cycles, respectively.

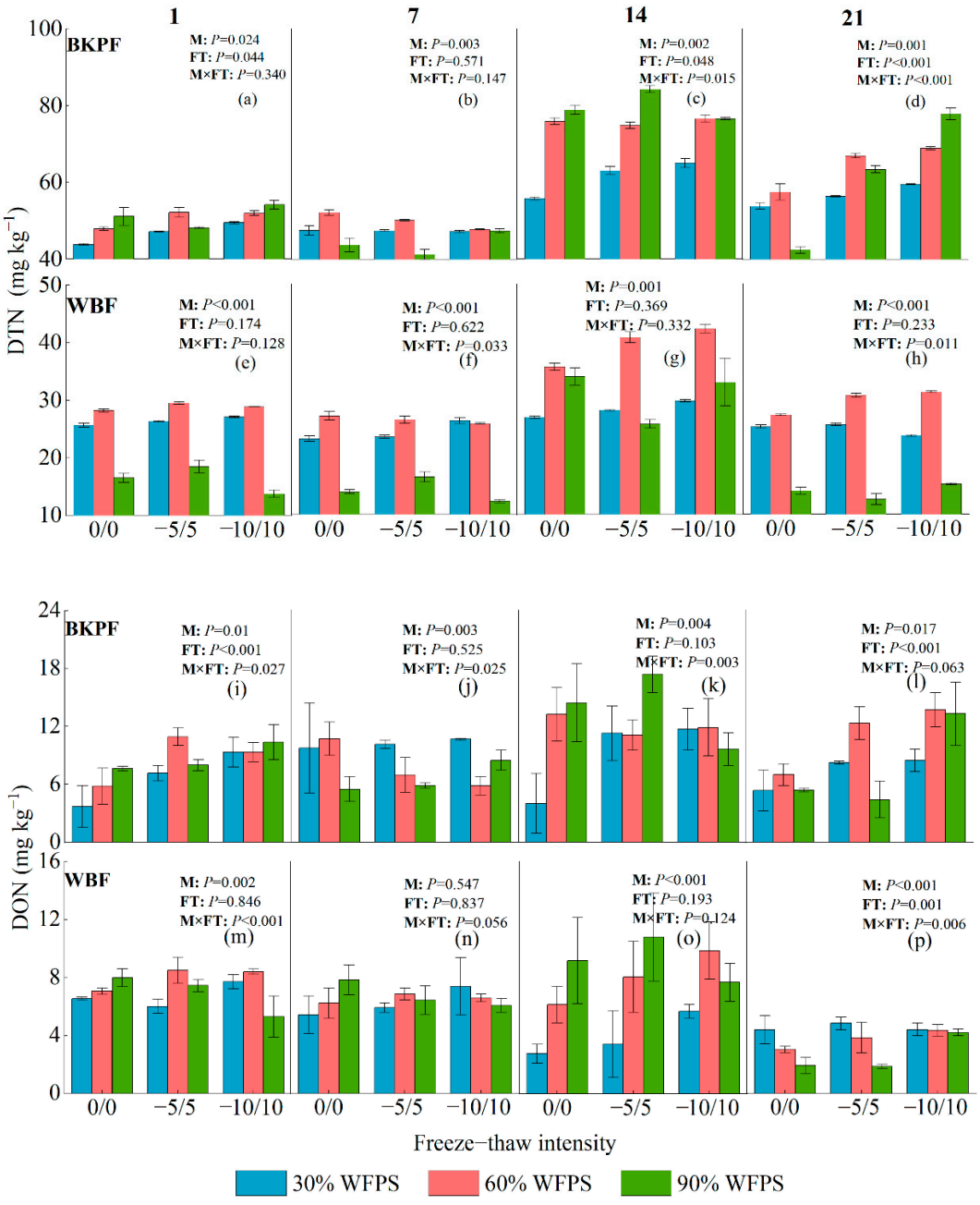


**Figure S2** Effects of freeze–thaw intensity and freeze–thaw frequency on DTN (a–h) and DON (i–p) in two forest soils with different initial soil moisture. M, initial soil moisture; FT, freeze–thaw intensity; 1, 7, 14 and 21 indicated 1 (a,e,i,m), 7 (b,f,j,n), 14 (c,g,k,o), and 21 (d,h,l,p) freeze–thaw cycles, respectively.

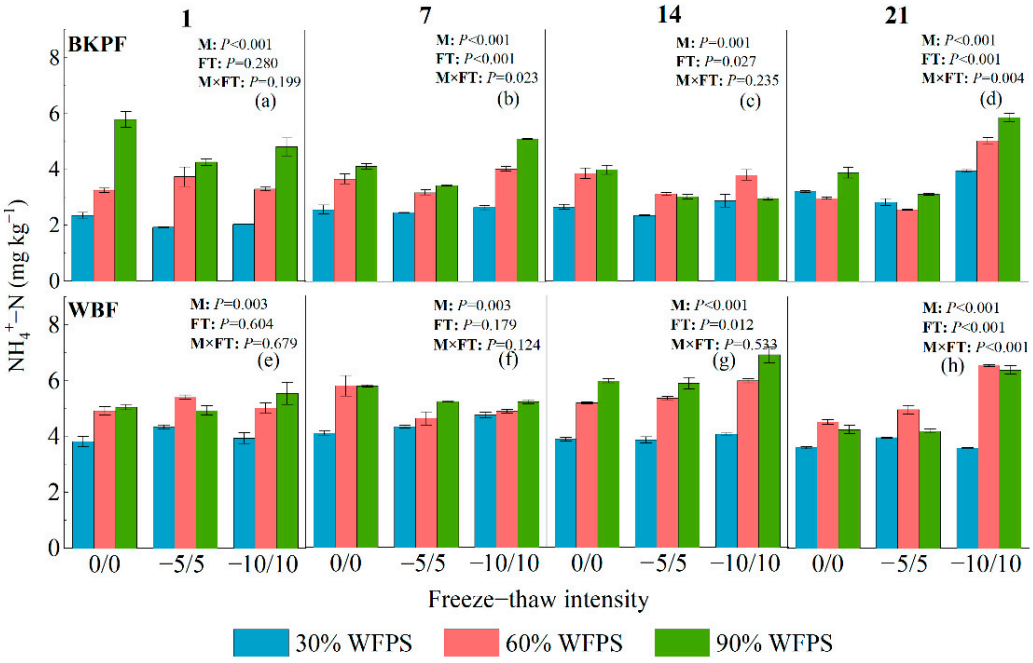


**Figure S3** Effects of freeze–thaw intensity and freeze–thaw frequency on $NH_4^+$-N in two forest soils with different initial soil moisture. M, initial soil moisture; FT, freeze–thaw intensity; 1, 7, 14 and 21 indicated 1 (a,e), 7 (b,f), 14 (c,g), and 21 (d,h) freeze–thaw cycles, respectively.

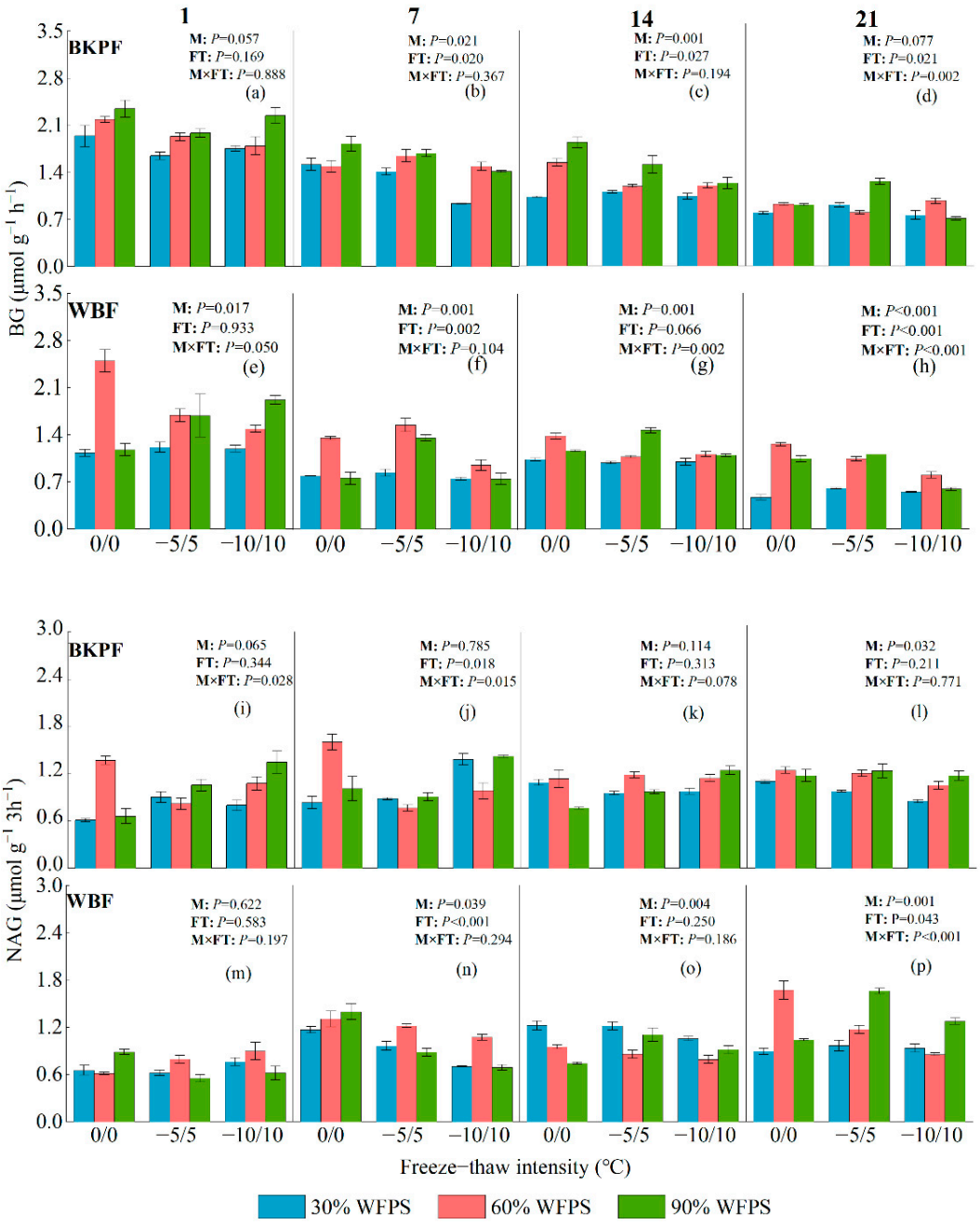


**Figure S4** Effects of freeze–thaw intensity and freeze–thaw frequency on BG (a–h) and NAG (i–p) in two forest soils with different initial soil moisture. M, initial soil moisture; FT, freeze–thaw intensity; 1, 7, 14 and 21 indicated 1 (a,e,i,m), 7 (b,f,j,n), 14 (c,g,k,o), and 21 (d,h,l,p) freeze–thaw cycles, respectively.

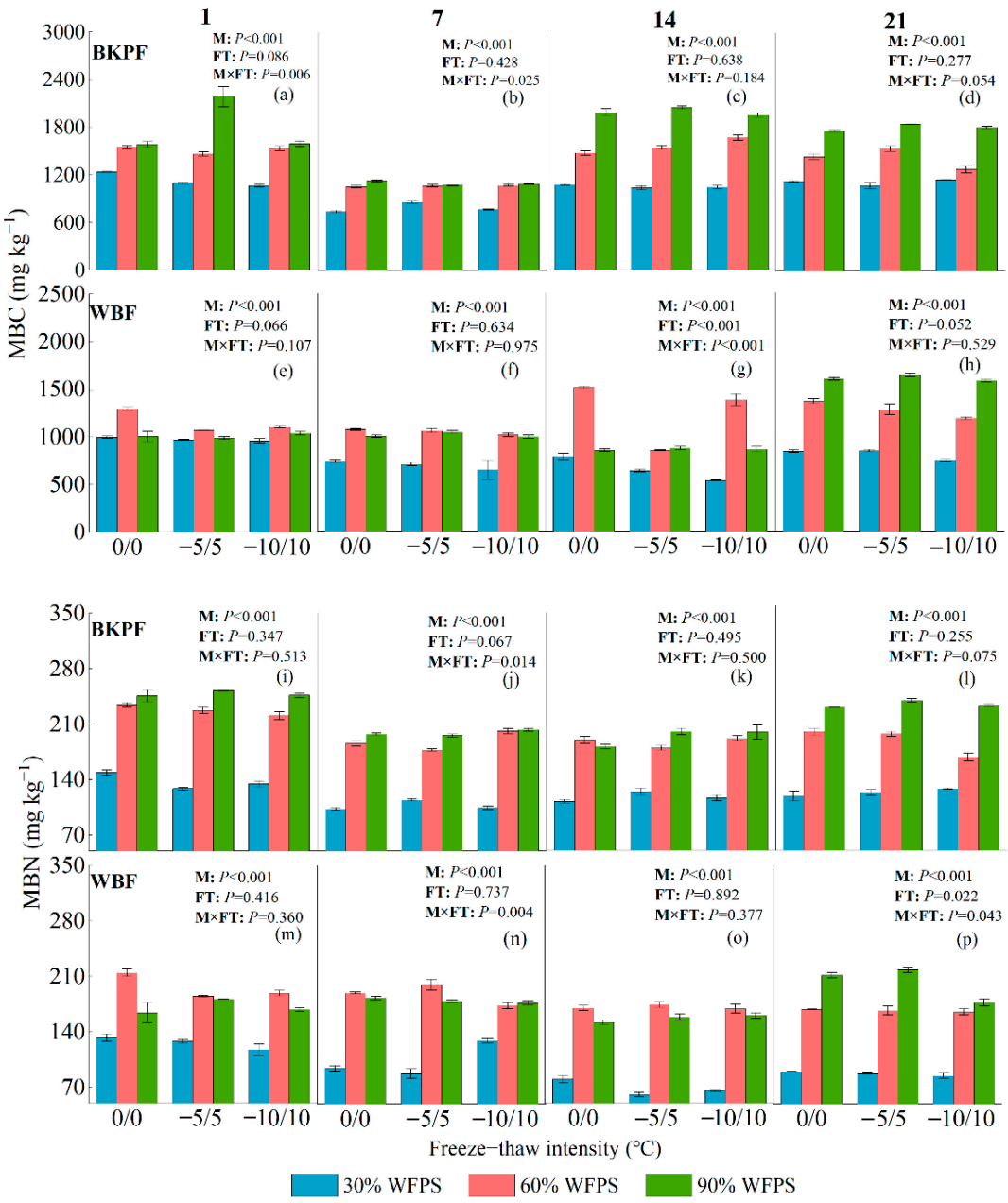


**Figure S5** Effects of freeze–thaw intensity and freeze–thaw frequency on MBC (a–h) and MBN (i–p) in two forest soils with different initial soil moisture. M, initial soil moisture; FT, freeze–thaw intensity; 1, 7, 14 and 21 indicated 1 (a,e,i,m), 7 (b,f,j,n), 14 (c,g,k,o), and 21 (d,h,l,p) freeze–thaw cycles, respectively.