**Crop** **conversion from** **annual to perennials: An effective strategy to increase soil multifunctionality**

Panpan Liua, b, Dong Wanga, \*, Yue Lic, Ji Liub, Yongxing Cuid, Guopeng Liange, Chaoquan Wangf, g, Chao Wangh, Daryl L Moorheadi, Ji Chenb,j, \*

*a International Joint Research Laboratory of Global Change Ecology, School of Life Sciences, Henan University, Kaifeng, Henan 475004, PR China*

*b State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences,* *Xi'an, China*

*c Faculty of Modern Agricultural Engineering, Kunming University of Science and Technology, Kunming, 650500, China*

*d Institute of Biology, Freie Universität Berlin, Berlin, Germany*

*e Department of Forest Resources, University of Minnesota, Saint Paul, MN 55108, USA*

*f Biogeochemistry of Agroecosystems, University of Göttingen, 37077 Göttingen, Germany*

*g Faculty of Land and Food Systems, University of British Columbia, V6S0K4 Vancouver, Canada*

*h School of Ecology and Environment, Northwestern Polytechnical University, Xi'an 710072, China*

*i Department of Environmental Sciences, University of Toledo, Toledo, OH, 43606, USA*

*j Department of Agroecology, Aarhus University, Tjele, Denmark*

*⁎ Corresponding authors.*

*E-mail addresses:* *wangdong19882005@163.com,* *ji.chen@agro.au.dk*

**Supplementary Tables S1 to S3**

Table S1

Linear mixed-effects model of crop type, soil depth and their interactive effects on soil physical, chemical, and microbial properties.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Data | Treatment | | numDF | denDF | F-value | | | p-value |
|
| Soil water content | | Intercept | 1 | 21 |  | 824.04 | **< 0.01** | |
|  | | Crop type | 3 | 21 |  | 6.01 | **< 0.01** | |
|  | | Soil depth | 1 | 21 |  | 1.54 | 0.23 | |
|  | | Crop type × Soil depth | 3 | 21 |  | 0.92 | 0.45 | |
| Bulk density | | Intercept | 1 | 21 |  | 3750.62 | **< 0.01** | |
|  | | Crop type | 3 | 21 |  | 5.13 | **< 0.01** | |
|  | | Soil depth | 1 | 21 |  | 11.26 | **< 0.01** | |
|  | | Crop type × Soil depth | 3 | 21 |  | 0.08 | 0.97 | |
| Soil pH | | Intercept | 1 | 21 |  | 32141.97 | **< 0.01** | |
|  | | Crop type | 3 | 21 |  | 16.45 | **< 0.01** | |
|  | | Soil depth | 1 | 21 |  | 0.01 | 0.93 | |
|  | | Crop type × Soil depth | 3 | 21 |  | 0.28 | 0.84 | |
| Dissolved organic carbon content | | Intercept | 1 | 21 |  | 560.38 | **< 0.01** | |
|  | | Crop type | 3 | 21 |  | 26.69 | **< 0.01** | |
|  | | Soil depth | 1 | 21 |  | 0.29 | 0.60 | |
|  | | Crop type × Soil depth | 3 | 21 |  | 3.19 | **0.04** | |
| Microbial biomass carbon | | Intercept | 1 | 21 |  | 719.94 | **< 0.01** | |
|  | | Crop type | 3 | 21 |  | 24.57 | **< 0.01** | |
|  | | Soil depth | 1 | 21 |  | 0.29 | 0.60 | |
|  | | Crop type × Soil depth | 3 | 21 |  | 4.71 | **0.01** | |
| Microbial biomass nitrogen | | Intercept | 1 | 21 |  | 467.23 | **< 0.01** | |
|  | | Crop type | 3 | 21 |  | 8.02 | **< 0.01** | |
|  | | Soil depth | 1 | 21 |  | 0.25 | 0.62 | |
|  | | Crop type × Soil depth | 3 | 21 |  | 4.55 | **0.01** | |

numDF, numerator degree of freedom. denDF, denominator degree of freedom. Linear mixed-effects models were conducted, crop type, soil depth and their interaction (crop type × soil depth) were considered as fixed factors, while plots nested within blocks were considered as random factors.

Table S2

Linear mixed-effects model of crop type, soil depth and their interactive effects on soil extracellular enzymatic activities.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Data | Treatment | numDF | denDF |  | F-value | p-value |
| Carbon acquisition extracellular enzymatic activities | Intercept | 1 | 21 |  | 1627.29 | **< 0.01** |
| Crop type | 3 | 21 |  | 69.85 | **< 0.01** |
|  | Soil depth | 1 | 21 |  | 193.14 | **< 0.01** |
|  | Crop type × Soil depth | 3 | 21 |  | 47.79 | **< 0.01** |
| Nitrogen acquisition extracellular enzymatic activities | Intercept | 1 | 21 |  | 1996.14 | **< 0.01** |
| Crop type | 3 | 21 |  | 97.99 | **< 0.01** |
|  | Soil depth | 1 | 21 |  | 3.62 | 0.07 |
|  | Crop type × Soil depth | 3 | 21 |  | 56.99 | **< 0.01** |
| Phosphorus acquisition extracellular enzymatic activities | Intercept | 1 | 21 |  | 757.58 | **< 0.01** |
| Crop type | 3 | 21 |  | 72.67 | **< 0.01** |
|  | Soil depth | 1 | 21 |  | 559.36 | **< 0.01** |
|  | Crop type × Soil depth | 3 | 21 |  | 52.23 | **< 0.01** |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Data | Treatment | numDF | denDF |  | F-value | p-value |
| Soil multifunctionality | Intercept | 1 | 21 |  | 0.00 | 1.00 |
|  | Crop type | 3 | 21 |  | 26.12 | **< 0.01** |
|  | Soil depth | 1 | 21 |  | 112.08 | **< 0.01** |
|  | Crop type × Soil depth | 3 | 21 |  | 6.45 | **< 0.01** |
| Water regulation | Intercept | 1 | 21 |  | 0.27 | 0.61 |
|  | Crop type | 3 | 21 |  | 0.71 | 0.56 |
|  | Soil depth | 1 | 21 |  | 6.86 | **0.02** |
|  | Crop type × Soil depth | 3 | 21 |  | 4.36 | **0.02** |
| Carbon cycle multifunctionality | Intercept | 1 | 21 |  | 0.00 | 1.00 |
|  | Crop type | 3 | 21 |  | 165.29 | **< 0.01** |
|  | Soil depth | 1 | 21 |  | 458.14 | **< 0.01** |
|  | Crop type × Soil depth | 3 | 21 |  | 104.34 | **< 0.01** |
| Nitrogen cycle multifunctionality | Intercept | 1 | 21 |  | 0.00 | 1.00 |
|  | Crop type | 3 | 21 |  | 33.38 | **< 0.01** |
|  | Soil depth | 1 | 21 |  | 0.90 | 0.35 |
|  | Crop type × Soil depth | 3 | 21 |  | 18.55 | **< 0.01** |
| Phosphorus cycle multifunctionality | Intercept | 1 | 21 |  | 0.00 | 1.0000 |
|  | Crop type | 3 | 21 |  | 64.17 | **< 0.01** |
|  | Soil depth | 1 | 21 |  | 493.94 | **< 0.01** |
|  | Crop type × Soil depth | 3 | 21 |  | 46.12 | **< 0.01** |

Table S3

Linear mixed-effects model of crop type, soil depth and their interactive effects on soil multifunctionality.