Open Access Journal of Environmental and Soil Sciences

DOI: 10.32474/OAJESS.2020.04.000190

ISSN: 2641-6794

Mini Review

Applications of Diffusive Gradients in Thin Films (DGT) in Soil studies

Dong-Xing Guan and Henry Teng H*

Institute of Surface-Earth System Science, Tianjin University, China

***Corresponding author:** Dong-Xing Guan, H. Henry Teng, Institute of Surface-Earth System Science, Tianjin University, China

Received: January 16, 2020 **Published:** January 24, 2019

Mini Review

Soil is the key component in surface-Earth system providing food, fiber and other ecosystem services, and controlling element biogeochemical cycles. Reliable and easy-to-use techniques play critical roles in understanding environmental processes such as soil conservation and land reclamation that directly affect soil function and agricultural productivity. Diffusive gradients in thin-films (DGT) technique is one of such tools and has become increasingly powerful in soil science research. DGT was developed in 1993 by Davison and Zhang at Lancaster University, UK [1] for measuring trace elements in natural waters, but was soon extended to sediments [2,3] and soils [4,5]. Conceptually, the key components of a DGT device are the well-defined diffusive layer/gel where ions diffuse following Fick's first diffusion law and diffusion gradients are formed, and the binding layer/gel for efficiently binding the diffused ions. In last two decades, DGT measurements and DGT-derived information have contributed greatly to elucidating biogeochemical mechanisms and dynamics in soils.

Similar to measurements in waters and sediments, DGT is useful in soil studies through acquiring mobile or labile concentrations and fluxes of nutrients, metal/metalloids, radionuclides, organics, and others (e.g. rare earth elements, nano ZnO) in soils [6]. For example, Kalkhajeh et al. [7] examined P availability in 75 topsoil samples from five representative Chinese PGVPs (plastic-covered greenhouse vegetable production systems) covering a wide range of physiochemical soil properties and cultivation history using several soil P tests, and found that DGT-measure P concentration correlated well with soil solution P demonstrating that DGT P is a versatile measure of P mobility regardless of soil type. More recently, some attempts have been made to use DGT for selective determination of chemical species. By controlling the binding specificity in DGT, selectively measurement of methylmercury [8], Se(IV) [9] and Sb(III) [10] is fulfilled in paddy soils growing with rice plants. Furthermore, if complexes of a metal dissociate rapidly (fully labile) during the diffusion process in the diffusive layer, they can be captured by DGT [11]. These studies reveal that DGT measurement not only provide a concentration or flux information of a chemical or species in soils, but also reflect the kinetic information of metal complexes.

DGT has great potential in bioavailability study in soils. In a broad sense, DGT provides a better prediction of the uptake of nutrients and metal/metalloids (e.g., P, Cd, Cu, Pb, As, Se, Zn, and Ni) by plants (e.g. wheat, lettuce, and lupin) and soil organisms (e.g. earthworms) in comparison to conventional chemical extraction methods, such as CaCl2 and EDTA extractions. For example, Tandy et al. [12] found that the concentrations of Cu, Zn and P in the youngest leaf of barley in a pot trail with fourteen agricultural soils can be best predicted by DGT, compared to other tests, such as EDTA and DTPA extraction for Cu and Zn, NaHCO3 extraction for P and soil solution concentrations. Relative to other soil tests, DGT method best mimicked bioavailability of Cd to earthworm (Eisenia fetida) [13], although the same quality observation was not made for uranium uptake by plants [14]. Recently, DGT has been extended to study the bioavailability of organic contaminants to terrestrial plants, but progress remains to be seen. It should be pointed out that these studies only focus on contaminants of herbicides (glyphosate, atrazine and its metabolites) and methylmercury without thoroughly investigating the underlying uptake mechanisms. In addition, compared to some conventional soil tests, the database for soil monitoring using DGT is still small so far, indicating that more studies are needed to expand the application. When a DGT device is deployed in wetted soil, chemical concentration in the solution phase of the thin soil layer (~ 1 mm) contiguous to the DGT sampling window gets depleted quickly. To respond, there will be a resupply or desorption of chemical from the soil phase to the solution phase. As such, DGT measurement not only captures the solution phase concentration, but can provide information concerning the desorption kinetics from soil solid to solution phase as well. Based on DGT data, models such as DIFS (DGT-Induced Fluxes in Soils) [15] can be used to derive parameters of desorption kinetics of nutrients and contaminants, including labile distribution coefficient (Kdl) between solid phase and soil solution, soil response time (Tc, time needed to bring the DGT-soil interfacial concentration from 0 to 63% of its pseudo steady state value) to depletion, and the desorption rate constant (k-1). Such studies were initially carried out for cationic metals (e.g. Cd, Ni, Zn), and later extended to include anions (e.g. As and P). Ernstberger et al. [16] used DGT devices containing a Chelex binding gel to acquire a series of time-dependent DGT results (R(t), the ratio of DGT-measured to soil solution concentration at time t) in five different soils, and modelled these nonlinear R(t)~t relationships using DIFS. As reflected by the derived Tc values, desorption of Zn and Cd from soil solids was quick, whereas desorption of Ni was slow [16]. The result indicates that the mobilities of metals are strongly related to their element characteristics, such as chalcophile (S-loving, e.g. Zn and Cd) and siderophile (Fe-loving, e.g. Ni), which may be further effected by edaphic factors (e.g. pH, organic matter). Menezes-Blackburn et al. [17] adopted a holistic approach based on DGT, DET (Diffusive Equilibration in Thin-films, similar to DGT but without the binding gel) and DIFS to evaluate the desorption kinetics of phosphorus in 32 soils. Results showed that DGT-measured inorganic P flux responses in the first hour was mainly a function of soil water retention and organic carbon, at longer times it became a function of the P resupply from the soil solid phase. Quite recently, DGT has been further used to study the desorption kinetics of organic contaminants, i.e. antibiotics and bisphenols, in soils [18-20]. Modelling of the time-dependent DGT results using DIFS revealed that the supply of three bisphenols in five spiked soils to DGT was limited by their desorption rate, but soils with more binding sites (e.g. higher organic mater and iron oxides) could resupply BPs more quickly, highlighting the danger of just considering partition effects [19].

Soils are generally of high heterogeneity, especially at the interfaces with water and biota (e.g. plant roots) [21]. DGT has greatly facilitated the understating of solute heterogeneous distribution and dynamic mobility across key environmental interfaces, such as plant rhizosphere [22,23]. With easy-to-access equipment of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) and easy-to-operate method of colorimetry, high-resolution information of inorganic solutes, such as phosphorus [24], metals [25], and sulfide [26], at sub-millimeter scale is acquired through mapping the binding layer after retrieval. At the root tips of rice (RIL 46) where was characterized by O_2 enrichment and low pH, a new geochemical niche of greatly enhanced As, Pb, and Fe(II) mobilization into solution was clearly captured by DGT gels [27]. Using DGT, increase of Fe and as fluxes in root vicinity of lupin (*Lupinus albus L.*) was also captured, and As and Fe (II) co-solubilization by root exudates was found, which was likely as a response to P deficiency [28]. Under P-limited conditions, plant root activities and related processes of P mobilization, as reflected by DGT measurement, are typically localized around root apices, but also expand towards the extension/root hair zone, reflecting the complex interaction of plant P acquisition strategies with rhizosphere soils [24].

Collectively, DGT has promising applications in concentration/flux and speciation measurements, bioavailability studies, desorption kinetics explorations and interfacial process investigations in soils. More work should be done to relate kinetic parameters from solid desorption or diffusion process with element/compound properties, soil properties, and ultimately with biota uptake or response. To provide a holistic view in element/chemical mobility and availability related to processes of oxidation-reduction, adsorption-desorption, biota (e.g. plant roots, benthic fauna, and microbiology) activity at millimeter or even higher resolution, researchers can combine DGT with other diffusion-based techniques, such as planar optodes for solutes (e.g. pH, O_2, pCO_2) and soil zymography for enzymes.

Acknowledgement

This work was funded by the National Natural Science Foundation of China (41807353), and Key Laboratory of Original Agro-Environmental Pollution Prevention and Control, Ministry of Agriculture and Rural Affairs/Tianjin Key Laboratory of Agro-Environment and Agro-Product Safety (19cdhj-1). of iron-based soil amendments. Chemosphere 182: 373-381.

References

1. Davison W, Zhang H (1994) In situ speciation measurements of trace components in natural waters using thin-film gels. Nature 367: 546-548.
2. Zhang H, Davison W, Miller S, Tych W (1995) In situ high resolution measurements of fluxes of Ni, Cu, Fe, and Mn and concentrations of Zn and Cd in porewaters by DGT. Geochimica et Cosmochimica Acta 59: 4181-4192.
3. Davison W, Fones GR, Grime GW (1997) Dissolved metals in surface sediment and a microbial mat at 100-µm resolution. Nature 387: 885-888.
4. Harper MP, Davison W, Zhang H, Tych W (1998) Kinetics of metal exchange between solids and solutions in sediments and soils interpreted from DGT measured fluxes. 62: 2757-2770.
5. Zhang H, Davison W, Knight B, McGrath S (1998) In situ measurements of solution concentrations and fluxes of trace metals in soils using DGT. Environmental Science & Technology 32: 704-710.
6. Guan DX (2019) Diffusive gradients in thin films (DGT): An effective and simple tool for assessing contaminant bioavailability in waters, soils and sediments. In: Nriagu J (Editor), Encyclopedia of Environmental Health (Second Edition), Elsevier, Oxford, UK, pp. 111-124.
7. Kalkhajeh YK (2018) DGT technique to assess P mobilization from greenhouse vegetable soils in China: A novel approach. Science of the Total Environment 630: 331-339.
8. Liu J, Feng X, Qiu G, Anderson CW, Yao H, et al. (2012) Prediction of methyl mercury uptake by rice plants (Oryza sativa L.) using the diffusive

gradient in thin films technique. Environmental Science & Technology 46(20): 11013-11020.

9. Shi X (2018) In situ selective measurement of Se^{IV} in waters and soils: Diffusive gradients in thin-films with bi-functionalized silica nanoparticles. Environmental Science & Technology 52(24): 14140-14148.
10. Fang W (2020) In situ selective measurement based on Diffusive Gradients in Thin-Films technique with mercapto-functionalized mesoporous silica for high-resolution imaging of Sb^{III} in soil. Anal Chem.
11. Davison W, Zhang H (2012) Progress in understanding the use of diffusive gradients in thin films (DGT) - back to basics. Environmental Chemistry 9: 1-13.
12. Tandy S, Mundus S, Yngvesson J, de Bang TC, Lombi E, et al. (2011) The use of DGT for prediction of plant available copper, zinc and phosphorus in agricultural soils. Plant and Soil 346(1): 167-180.
13. Gu X (2017) Coupling biological assays with diffusive gradients in thin-films technique to study the biological responses of Eisenia fetida to cadmium in soil. Journal of Hazardous Materials 339: 340-346.
14. Duquène L, Vandenhove H, Tack F, Van Hees M, Wannijn J (2010) Diffusive gradient in thin FILMS (DGT) compared with soil solution and labile uranium fraction for predicting uranium bioavailability to ryegrass. Journal of Environmental Radioactivity 101(2): 140-147.
15. Sochaczewski Ł, Tych W, Davison B, Zhang H (2007) 2D DGT induced fluxes in sediments and soils (2D DIFS). Environ Modell Softw 22(1): 14-23.
16. Ernstberger H, Zhang H, Tye A, Young S, Davison W (2005) Desorption kinetics of Cd, Zn, and Ni measured in soils by DGT. Environmental Science & Technology 39(6): 1591-1597.
17. Menezes-Blackburn D (2016) A holistic approach to understanding the desorption of phosphorus in soils. Environmental Science & Technology 50(7): 3371-3381.
18. Chen CE, Jones KC, Ying GG, Zhang H (2014) Desorption kinetics of sulfonamide and trimethoprim antibiotics in soils assessed with diffusive gradients in thin films. Environmental Science & Technology 48(10): 5530-5536.
19. Guan DX, Zheng JL, Luo J, Zhang H, Davison W, et al. (2017) A diffusive gradients in thin-films technique for the assessment of bisphenols desorption from soils. Journal of Hazardous Materials 331: 321-328.
20. Ren S, Wang Y, Cui Y, Wang Y, Wang X, et al. (2020) Desorption kinetics of tetracyclines in soils assessed by diffusive gradients in thin films. Environmental Pollution 256: 113394.
21. Antoniadis V (2017) Trace elements in the soil-plant interface: Phytoavailability, translocation, and phytoremediation–A review. Earth-Science Reviews 171: 621-645.
22. Santner J, Larsen M, Kreuzeder A, Glud RN (2015) Two decades of chemical imaging of solutes in sediments and soils--a review. Analytica Chimica Acta 878: 9-42.
23. Oburger E, Schmidt H (2016) New methods to unravel rhizosphere processes. Trends in Plant Science 21(3): 243-255.
24. Kreuzeder A, Santner J, Scharsching V, Oburger E, Hoefer C, et al. (2018) In situ observation of localized, sub-mm scale changes of phosphorus biogeochemistry in the rhizosphere. Plant and Soil 424(1): 573-589.
25. Guan DX, Williams PN, Luo J, Zheng JL, Xu HC, et al. (2015) Novel precipitated zirconia-based DGT technique for high-resolution imaging of oxyanions in waters and sediments. Environmental Science & Technology 49(6): 3653-3661.
26. Gao Y, van de Velde S, Williams PN, Baeyens W, Zhang H (2015) Two-dimensional images of dissolved sulfide and metals in anoxic sediments by a novel diffusive gradients in thin film probe and optical scanning techniques. TrAC Trends in Analytical Chemistry 66: 63-71.
27. Paul N. Williams, Jakob Santner, Hao Zhang (2014) Localized flux maxima of arsenic, lead, and iron around root apices in flooded lowland rice. Environmental Science & Technology 48(15): 8498-8506.
28. Fresno T, Peñalosa JM, Santner J, Puschenreiter M, Moreno-Jiménez E (2017) Effect of *Lupinus albus L.* root activities on As and Cu mobility after addition of iron-based soil amendments. J chemosphere182:373-381.

DOI: 10.32474/OAJESS.2020.04.000190