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Soil CO_2 Uptake in Deserts and Its Implications to the Groundwater Environment

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Abstract: Recent studies of soil carbon cycle in arid and semi-arid ecosystems demonstrated that there exists an abiotic CO_2 absorption by saline-alkali soils (A_a) at desert ecosystems and suggested potential contributions of CO_2 dissolution beneath deserts to the terrestrial ecosystems carbon balance. However, the overall importance of such soil CO_2 uptake is still undetermined and its implications to the groundwater environment remain unaddressed. In this manuscript, a simple method is proposed for the direct computation of A_a from the total soil CO_2 flux (F_a) as well as for the evaluation of A_a importance to F_a. An artificial soil-groundwater system was employed to investigate the implications to groundwater environment and it was found that soil CO_2 uptake in deserts can contribute a possible influence on the evolution of the groundwater environment, providing that the absorbed CO_2 largely remained in the soil-groundwater system.

Keywords: abiotic CO_2 absorption; soil CO_2 flux; the soil-groundwater system

1. Introduction

Global soil CO_2 releases account for 20%–38% of the annual input of CO_2 from terrestrial and marine sources to the atmosphere [1–11]. Therefore, soil CO_2 flux (F_a) is a significant determinant of the ecosystem carbon balance. Among the components of F_a, the biotic processes (including the root and microbial respiratory components) were thought to be significantly contributing to it [2–6], while the abiotic processes were always neglected [12–20]. However, a series of recent studies of deserts ecosystems have highlighted that the abiotic processes (including subterranean CO_2 dissolution and other abiotic carbon sink beneath deserts) must be taken into account in the budget of F_a [7–10].

Some recent studies attributed the abiotic processes to the effects of the soil water dynamics on subterranean carbon cycle and presented theoretical and experimental analyses based on the biogeochemical reactive transport modeling [21,22]. This not only developed the methodology of the partition of F_a into the biotic and abiotic components across some special environments, but also highlighted that the subterranean dissolution of CO_2 has been involved in the ecosystem carbon balance in deserts, and can even temporally dominate [7–11]. However, soil CO_2 dissolution and effusion, as abiotic processes in deserts, are different from the considered processes in these previous studies. Especially in some experimental contrast, only the top few cm of the soil was considered. It became much more impressive after the abiotic CO_2 absorption (A_a) by the soil collected from a saline desert was directly observed after a minimizing-disturbance sterilization treatment on the soil [8]. This demonstrated that there exists an abiotic CO_2 uptake by saline-alkali soils (A_a) at desert ecosystems and suggested a potential contribution of such soil CO_2 uptake to the ecosystem carbon balance in deserts [8,10].

There is strong evidence suggesting that A_a can contribute significantly to F_a and the net ecosystem carbon balance, but the overall importance of the soil CO_2 uptake to F_a is still undetermined. Presently, both the field observations and the laboratory experiments are still limited on site scales. Because of the lack of large-scale experiments, the magnitude of such CO_2 uptake is still a matter of controversy. Some recent publications have further presented the laboratory data on the soil abiotic CO_2 absorption and the field data on the net CO_2 exchange in desert ecosystems [23,24], whereas it is still imperative to have a simple method for a direct computation of the abiotic soil CO_2 uptake from the total soil CO_2 flux and for quantifying its overall importance to F_a.

The minimizing-disturbance sterilization treatment on soils has been widely recognized as an experimental method for separating A_a [10]. Since the significance of CO_2 dissolution and effusion as the abiotic processes has become much more impressive after the soil CO_2 uptake was directly observed after such a sterilization treatment on the soil [8,10], another subsequent unresolved issue is whether the beneath CO_2 dissolution has a non-negligible implication to the groundwater environment beneath deserts, providing that the dissolved and absorbed CO_2 largely remained in the soil-groundwater system. This certainly desires a further investigation but remains unaddressed.

This manuscript aims to design a simple method for a direct computation of the abiotic soil CO_2 uptake from the total soil CO_2 flux and proposed a simple approach to quantify its overall importance to F_a. After a special treatment, F_a is reconciled as a simple function of A_a, which is implemented in two different approaches. In the experimental approach, all A_a data are collected after the minimizing-disturbance sterilization treatment on the soils, while in the other semi-experimental approach, most of the A_a data are directly calculated from a simple regressive model. The potential implications of A_a and the beneath CO_2 dissolution to the groundwater environment are also preliminarily discussed.

2. Materials and Methods

2.1. Data Sources

Sampling data of soil CO_2 fluxes were collected from Xie et al. [8]. The measurements were conducted in the Gurbantunggut Desert, which is located at hinterland of the Eurasian Continent (87°56′ E, 44°17′ N; elevation: 461 m), with an arid, windy climate (sunshine: 3079 h; precipitation: 144.7 mm; evapotranspiration: 2020 mm; radiation: 5439 MJ/m^2; velocity: 2.6 m/s). Note that two LI-8100s (LI-COR, Lincoln, Nebraska, NE, USA) have been employed for the valid comparison between the flux data measured at the sterilized and unsterilized samples. It should be noted that the soil was smashed, roots-sieved, air-dried and the many sinks and sources of CO_2 in the subsurface environment have been excluded. After sterilization, the net soil CO_2 fluxes were negative and the CO_2 exchange was abiotic. In order to highlight the soil CO_2 uptake, such abiotic exchange is hence defined as "soil abiotic CO_2 absorption" throughout this manuscript (Figure 1). Consequently, the variations of F_a were largely determined by A_a and the soil microbial respiration (R_m).

With the purpose of a preliminary discussion on the potential implications of the beneath CO_2 dissolution to the groundwater environment, an artificial soil-groundwater system was employed and the groundwater were sampled with six replications (Figure 2). The groundwater pH and the concentration of dissolved inorganic carbon (DIC) in the artificial soil-groundwater system were measured, where the concentration of DIC (symbolized as (DIC) was defined as the sum of the concentration of the dissolved carbonate ion and bicarbonate ion.

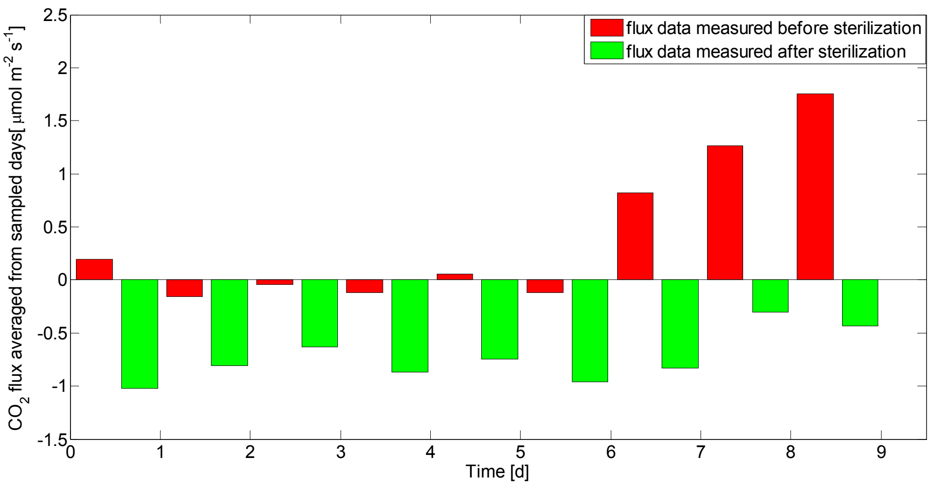

Figure 1. Contrast of mean CO_2 flux before/after sterilization.

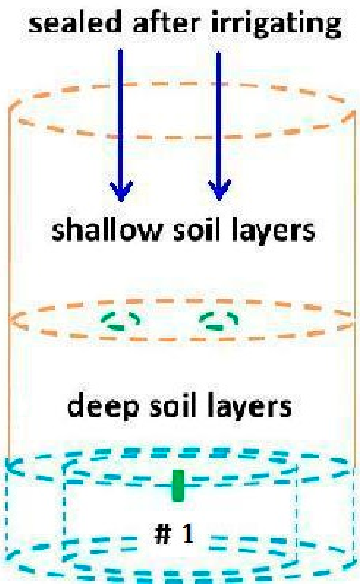

Figure 2. A diagram of the artificial soil-groundwater system. The samples were collected from #1, with 6 replications.

2.2. Modeling Approach

Neglecting A_a, it is well-known that F_a can be formulated as an exponential function of the soil surface temperature or the ambient air temperature [19]:

$$F_a = F_{a20} \times Q_{10}{}^{(T_S-20)/10} \tag{1}$$

where F_{a20} is measured F_a at 20 °C, T_S is the soil temperature (here it is measured at 0–10 cm), and Q_{10} is the relative change in F_a with 10 °C increases.

R_m is formulated as in [20]:

$$R_m = R_{m20} \cdot Q_{10}{}^{(T_S-20)/10} \tag{2}$$

where R_{m20} is the measured value of R_m at 20 °C.

Taking into account A_a, F_a is reconciled as,

$$F_a = R_m + A_a \tag{3}$$

The experimental method separates A_a by the sterilization treatment on the soils and hence R_{m20} can be estimated as follows:

$$R_{m20} = F_{a20} - A_{a20} \quad (4)$$

where A_{a20} are measured A_a at 20 °C.

Substituting Equation (2) into Equation (4), R_m is reconciled as:

$$R_m = (F_{a20} - A_{20}) \cdot Q_{10}{}^{(T_S - 20)/10} \quad (5)$$

Correspondingly, F_a can be finally reconciled as:

$$F_a = (F_{a20} - A_{20}) \cdot Q_{10}{}^{(T_S - 20)/10} + A_a \quad (6)$$

Unfortunately, extensive time is required during the minimizing-disturbance sterilization treatment on the soil. At large scales, it is necessary to couple with other methodologies. Development of a semi-experimental method for the rough partition of A_a is thus necessary.

Similar to semi-experimental approaches for the partition of the biotic components of F_a [12], the relationship between A_a and F_a could be assumed to be represented by a simple linear regressive model and written as:

$$A_a = \beta_0 F_a + \beta_1 \quad (7)$$

where β_0 and β_1 are determined by the contributions of A_a to F_a.

Under this assumption, R_m is reconciled as:

$$R_m = (1 - \beta_0) F_a - \beta_1 \quad (8)$$

and correspondingly

$$R_{m10} = (1 - \beta_0) F_{a10} - \beta_1 \quad (9)$$

By Equation (2), the Q_{10} value for R_m can be estimated by

$$R_m = [(1 - \beta_0) F_{a10} - \beta_1] \cdot Q_{10}{}^{(T_S - 10)/10} \quad (10)$$

Combining Equations (8) and (10), the soil CO_2 flux could be finally reconciled as

$$F_a = [F_{a10} - \frac{\beta_1}{1 - \beta_0}] \cdot Q_{10}{}^{(T_S - 10)/10} + \frac{\beta_1}{1 - \beta_0} \quad (11)$$

The parameters β_0 and β_1 can be estimated by Equation (7) after a few experiments and a large magnitude of time will be saved in the partition of A_a.

Regarding the first approach, the relationship between the groundwater pH and (DIC) are analyzed by utilizing an exponentially regressive model:

$$pH = \lambda_0 e^{\lambda_1 (DIC)} \quad (12)$$

where λ_0 and λ_1 are determined by the contributions of (DIC) to the groundwater pH.

3. Results and Discussion

3.1. Separated Biotic and Abiotic Components of Soil CO_2 Fluxes

The aforementioned parameters of β_0 and β_1 are estimated using the measured values of A_a and F_a on two clear days in two typical desert ecosystems, saline desert and oasis farmland (Figure 3).

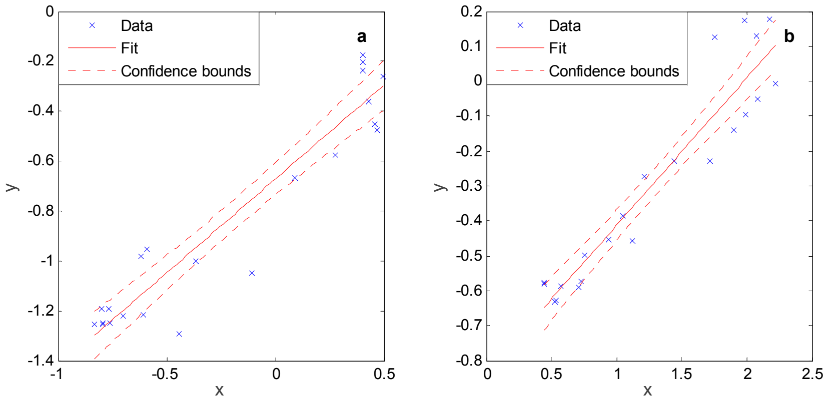

Figure 3. Parameters β_0 and β_1 estimated at desert ecosystems (**a**) and oasis farmland (**b**).

The estimated parameters of β_0 and β_1 are then applied to the semi-experimental separation of A_a at the corresponding ecosystems in a drought period of one growing season in 2006, taking into account their difference for different ecosystems (the estimated β_0 and β_1 from saline desert are also applied to its neighbor abandoned farmland, as provided in Table 1).

Table 1. Suitable parameters for the isolation of A_a.

Study Sites	Parameters Applied in Semi-Experimental Method	
Saline desert	β_0 = 0.5284	β_1 = −0.8975
Abandoned farmland	β_0 = 0.5284	β_1 = −0.8975
Oasis farmland	β_0 = 0.4266	β_1 = −0.8330

It is obvious that A_a separated in both the experimental and semi-experimental approaches acts as a CO_2 sink. A_a separated into two approaches varies in a similar pattern during the considered drought period. Through comparison with the total soil CO_2 flux F_a, it was found that most F_a data are positive. This implies that the other flux component of F_a, the microbial soil respiration R_m, plays a dominant role within this period (Figure 4)

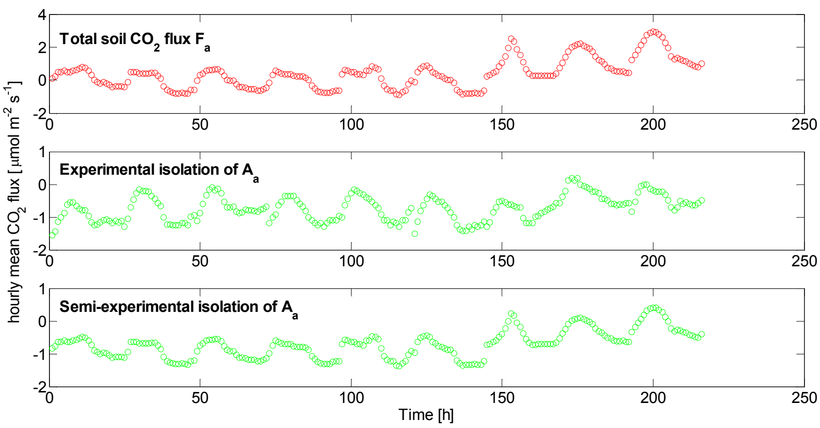

Figure 4. Isolated A_a by experimental/semi-experimental method.

Considering that β_0 and β_1 are determined by the contributions of A_a to F_a, they might be very different in various ecosystems (A_a is not very different, but F_a can be very different). Choosing soil sites for the few sampled experiments should be done cautiously.

The values of Q_{10} for the microbial soil respiration R_m might also be different in various ecosystems. From the visualization of the separated R_m in considered drought period by a continuous curve, the gradient of R_m in some sites and sampling days might not be evident. For to this reason, only the separated results of R_m on nine sampled days are presented here and three kinds of ecosystems are selected for the comparison, the saline desert, abandoned farmland and oasis farmland. It could also facilitate the valid and explicit comparison between the separated results of R_m from the experimental method and the semi-experimental method. Obviously, the separated R_m in the semi-experimental and experimental approaches show similar patterns. The diurnal dynamics on nine sampled days also reveal a duplicated variability (Figures 5 and 6).

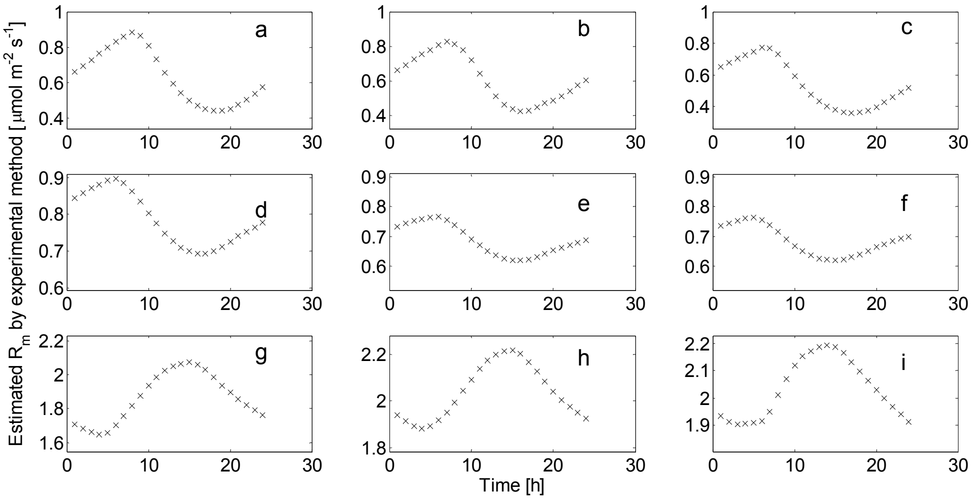

Figure 5. Isolated R_m by experimental method (**a**–**c**: saline desert; **d**–**f**: abandoned farmland; **g**–**i**: oasis farmland).

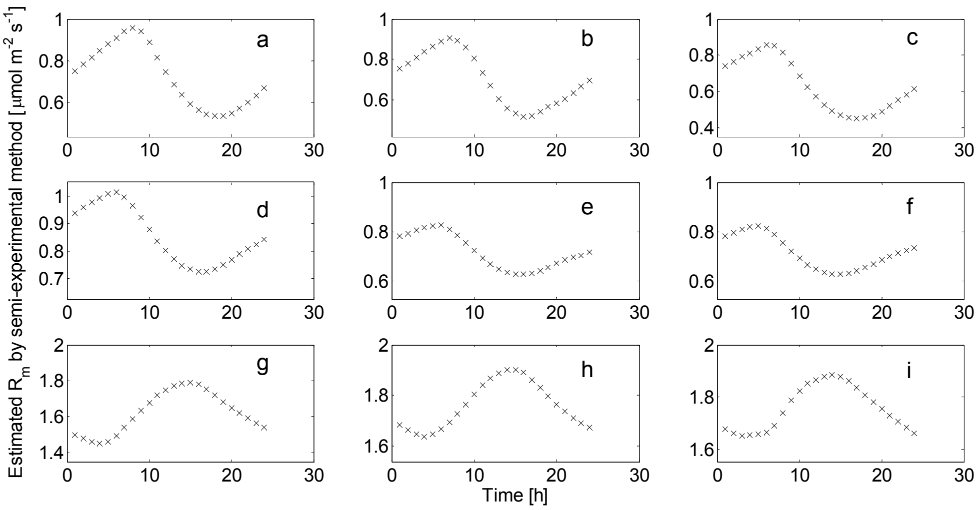

Figure 6. Isolated R_m by semi-experimental method (**a**–**c**: saline desert; **d**–**f**: abandoned farmland; **g**–**i**: oasis farmland).

The separated results of R_m in the former two ecosystems are almost the same (Table 2), which are all different with the oasis farmland. This might be the reason that the soil microbial activity in the saline desert is very different to that in oasis farmland.

The separated A_a from the semi-experimental approach represents about 80% of that from the experimental approach, which indicates a reliable cross validation (Figure 7). In fact, the experimental method should still be used with much caution since it indicates a large magnitude of carbon sink in the most barren ecosystems [10,14]. Thus, the cross validations between these two methods are necessary.

Table 2. Q_{10} values for isolated R_m by two methods.

Study Sites	Semi-Experimental Method	Experimental Method
Saline desert	0.53200	0.58711
Abandoned farmland	0.81835	0.77012
Oasis farmland	1.21009	1.19123

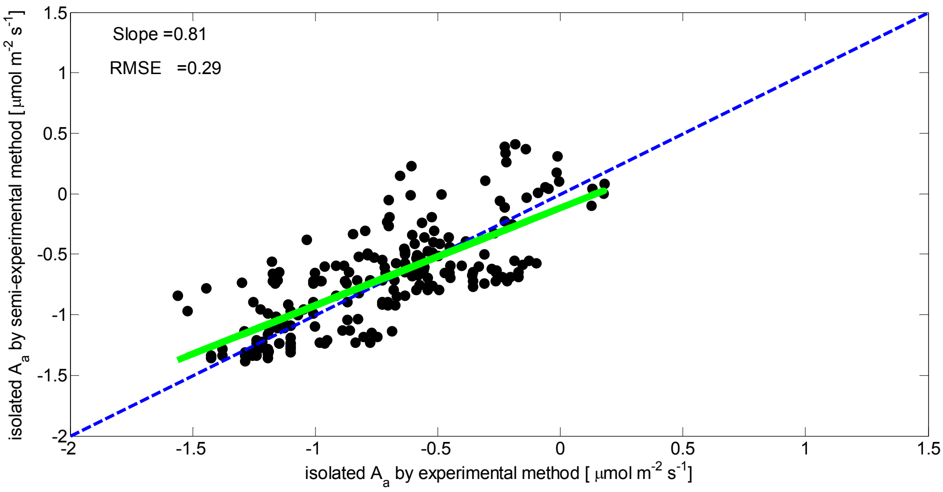

Figure 7. Reliability of semi-experimental partition method (the green line is the linear regression line determined by the observed values and the simulated values) utilizing a linear regression curve (the green line). The diagonal blue line is taken as a reference.

Employing the estimated β_0 and β_1 in Equation (10) and fitted Q_{10} provided in Table 2, the separated R_m by the semi-experimental method explain well the variability of separated R_m by the experimental method (Figure 8). Both semi-experimental and experimental methods reconcile F_a as a direct sum of A_a and R_m, rendering the cross validation of reconciled F_a using these two methods necessary. In Figure 9, it is also found that F_a reconciled by Equation (11) using the semi-experimental approach almost coincides with that reconciled by Equation (6) in the experimental approach. The aforementioned results of cross validation also show that the semi-experimental separations of R_m and A_a proposed in Section 2 are both feasible and reliable (Table 3).

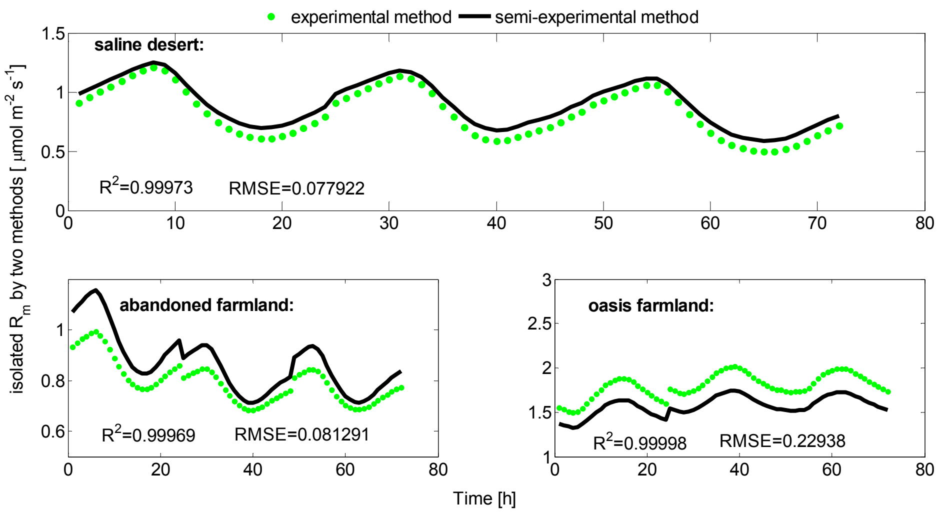

Figure 8. Cross validation of isolated R_m by two methods.

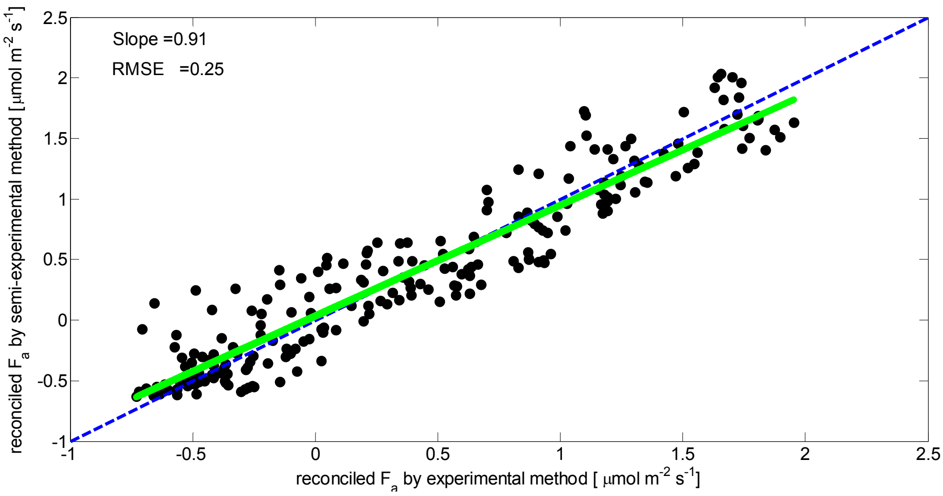

Figure 9. Cross validation of reconciled F_a by two methods, utilizing a linear regression curve (the green line). The diagonal blue line is taken as a reference.

Table 3. Fitted relationships between isolated components by two methods.

Flux Components	Slope	RMSE
Alkaline absorption	0.80630	0.29089
Microbial respiration	0.71842	0.14753
Reconciled soil CO_2 flux	0.91428	0.25061

3.2. Implications of Soil CO_2 Uptake to the Groundwater Environment

Although soil CO_2 uptake in deserts has been investigated in many previous studies, its potential influences on the groundwater environment remain unaddressed [25–39]. This is partially due to the lack of a simple method for the separation and quantification of such CO_2 uptake. This study presents a simple yet efficient method for partitioning CO_2 influxes to and efflux from bare saline-alkali soils, implying a time to consider the implications of such CO_2 uptake beneath deserts to the groundwater environment. An unresolved issue, where the absorbed CO_2 has gone, still remains. Most studies assumed that these absorbed CO_2 are partially dissolved in the soil-groundwater system. However, the magnitude of the beneath CO_2 dissolution remains undetermined [25–30].

Furthermore, the experimental partition method is still desired for further improvement. Based on some recent studies, there exists little difference between abiotic soil CO_2 influx and efflux when excluding the role of groundwater and soil is left to absorb/release CO_2 naturally [28]. The difference might be attributed to the extent of the sterilization treatment on the soil and the existence of some soil microbial respiration (R_m), or the interaction between the existing R_m and A_a. Future studies must keep a most cautious mind in extending the results from the laboratory experiments to field research. In reality, the conditions are much more complex and the additional confounding factors for many flux components exist and might interact with each other.

It has been widely recognized that the overall magnitude of CO_2 dissolution beneath deserts and its contributions to the ecosystem carbon balance can be huge [30–39], but its effect on the local environment are seldom reported. As a first attempt to analyze the implications of the soil CO_2 uptake to the groundwater environment, the present study simply assumes that the absorbed CO_2 has been largely dissolved in the soil-groundwater system beneath the deserts. Under this assumption, an artificial soil-groundwater system has been incubated for a long period in the laboratory. Collected data at the first stage confirm that the implications to the water environment should be taken into account (Figure 10).

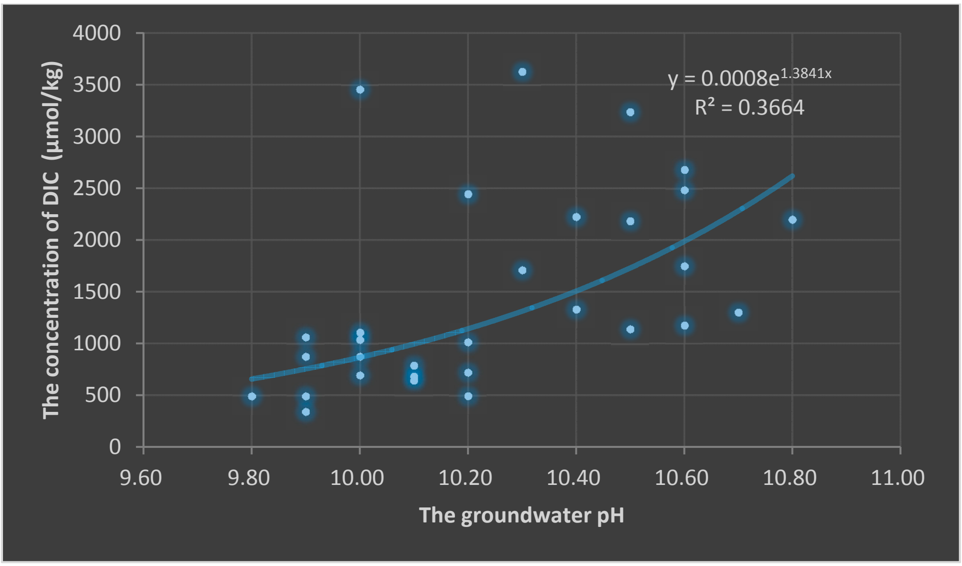

Figure 10. The relationship between the groundwater pH and the concentration of dissolved inorganic carbon (DIC) in the artificial soil-groundwater system.

Since the potential contributions of these abiotic components to the total soil CO_2 fluxes were non-negligible, the implication of the biotic CO_2 effluxes and abiotic CO_2 influxes to the soil-groundwater environment cycle is a subsequent problem. Despite the recent studies of soil carbon cycle in the desert ecosystems and the biogeochemical investigations in the arid ecosystems [40–49], the dynamics of beneath CO_2 dissolution [7,10] is still not well-understood. Furthermore, even the mechanisms of subterranean abiotic processes are still not wholly known. It is worth noting that the groundwater pH is essentially significant for the local water environment and has attracted a wide attention [50–60]. Attaining a reliable quantification for the contributions of soil CO_2 uptake to the groundwater environment remains one major challenge and hence should be a research priority.

Because the mechanisms for the abiotic CO_2 absorption and the overall magnitude of the soil CO_2 uptake are still not well-understood, there are still considerable uncertainties in more explicit analyses of the contributions of such soil CO_2 uptake to the groundwater environment [8,10,14]. Additionally, the data required by the present experimental method can only be collected from the top few cm of the soil. The whole atmospheric exchange of CO_2 requires some further investigations towards better and more suitable experimental and non-experimental methodologies.

4. Conclusions

This study presented a simple yet efficient method to work out the magnitude of soil abiotic CO_2 absorption in deserts from the data set of soil CO_2 fluxes, along with a first approach to illustrate its potential role in influencing environments in an artificial soil-groundwater system. The first approach highlighted significant events where an evident variation of the groundwater pH, provided that the absorbed CO_2 largely remained in the soil-groundwater system. Considering the CO_2 sink size across different environments remains unknown, there are still considerable uncertainties and further investigations are necessary.

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Author Contributions: Xi Chen and Wenfeng Wang conceived and designed the experiments; Wenfeng Wang performed the experiments; Xi Chen, Wenfeng Wang and Jing Qian analyzed the data; Hongwei Zheng, Ruide Yu, Yifan Zhang and Jianjun Yu contributed analysis tools; and Wenfeng Wang wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Raich, J.W.; Schlesinger, W.H. The global carbon dioxide flux insoil respiration and its relationship to vegetation and climate. *Tellus* **1992**, *44*, 81–99. [CrossRef]
2. Hőgberg, P.; Nordgren, A.; Buchmann, N.; Taylor, A.F.; Ekblad, A.; Högberg, M.N.; Nyberg, G.; Ottosson-Löfvenius, M.; Read, D.J. Large-scale forest girdling shows that current photosynthesis drives soil respiration. *Nature* **2001**, *411*, 789–792. [CrossRef] [PubMed]
3. Bowling, D.R.; Pataki, D.E.; Randerson, J.T. Carbon isotopes in terrestrial ecosystem pools and CO_2 fluxes. *New Phytol.* **2008**, *178*, 24–40. [CrossRef] [PubMed]
4. Grace, J. Understanding and managing the global carbon cycle. *J. Ecol.* **2004**, *92*, 189–202. [CrossRef]
5. Gregory, P.J. Roots, rhizosphere and soil: The route to a better understanding of soil science. *Eur. J. Soil Sci.* **2006**, *57*, 2–12. [CrossRef]
6. Hendricks, J.J.; Nadelhoffer, K.J.; Aber, J.D. Assessing the role of fine roots in carbon and nutrient cycling. *Trends Ecol. Evol.* **1993**, *8*, 174–178. [CrossRef]
7. Kowalski, A.S.; Serrano-Ortiz, P.; Janssens, I.A.; Sánchez-Moral, S.; Cuezva, S.; Domingo, F.; Were, A.; Alados-Arboledas, L. Can flux tower research neglect geochemical CO_2 exchange? *Agric. For. Meteorol.* **2008**, *148*, 1045–1054. [CrossRef]
8. Xie, J.X.; Li, Y.; Zhai, C.X.; Li, C.H.; Lan, Z.D. CO_2 absorption by alkaline soils and its implication to the global carbon cycle. *Environ. Geol.* **2009**, *56*, 953–961. [CrossRef]
9. Serrano-Ortiz, P.; Roland, M.; Sanchez-Moral, S.; Janssens, I.A.; Domingo, F.; Goddérise, Y.; Kowalski, A.S. Hidden, abiotic CO_2 flows and gaseous reservoirs in the terrestrial carbon cycle: Review andperspectives. *Agric. For. Meteorol.* **2010**, *150*, 321–329. [CrossRef]
10. Stone, R. Have desert researchers discovered a hidden loop inthe carbon cycle? *Science* **2008**, *320*, 1409–1410. [CrossRef] [PubMed]
11. Inglima, I.; Alberti, G.; Bertolini, T.; Vaccari, F.P.; Gioli, B.; Miglietta, F.; Cotrufo, M.F.; Peressotti, A. Precipitation pulses enhance respiration of mediterranean ecosystems: The balance between organic and inorganic components of increased soil CO_2 efflux. *Glob. Chang. Biol.* **2009**, *15*, 1289–1301. [CrossRef]
12. Baggs, E.M. Partitioning the components of soil respiration: A research challenge. *Plant Soil* **2006**, *284*, 1–5. [CrossRef]
13. Chen, X.; Wang, W.F.; Luo, G.P.; Li, L.H.; Li, Y. Time lag between carbon dioxide influx to and efflux from bare saline-alkali soil detected by the explicit partitioning and reconciling of soil CO_2, flux. *Stoch. Environ. Res. Risk Assess.* **2013**, *27*, 737–745. [CrossRef]
14. Schlesinger, W.H.; Belnap, J.; Marion, G. On carbon sequestration in desert ecosystems. *Glob. Chang. Biol.* **2009**, *15*, 1488–1490. [CrossRef]
15. Davidson, E.A.; Verchot, L.V.; Cattanio, J.H.; Ackerman, I.L.; Carvalho, J.E.M. Effects of soil water content on soil respiration in forest and cattle pastures of eastern Amazonia. *Biochemistry* **2000**, *48*, 53–69.
16. Hanson, P.J.; Edwards, N.T.; Garten, C.T.; Andrews, J.A. Separating root and soil microbial contributions to soil respiration: A review of methods and observations. *Biogeochemistry* **2000**, *48*, 115–146. [CrossRef]
17. Kuzyakov, Y. Sources of CO_2 efflux from soil and review of partitioning methods. *Soil Biol. Biochem.* **2006**, *38*, 425–448. [CrossRef]
18. Kuzyakov, Y.; Gavrichkova, O. Time lag between photosynthesis and carbon dioxide efflux from soil: A review of mechanisms and controls. *Glob. Chang. Biol.* **2010**, *16*, 3386–3406. [CrossRef]
19. Wang, X.H.; Piao, S.L.; Ciais, P.; Janssens, I.A.; Reichstein, M.; Peng, S.; Wang, T. Are ecological gradients in seasonal Q_{10} of soil respiration explained by climate or by vegetation seasonality? *Soil Biol. Biochem.* **2010**, *42*, 1728–1734. [CrossRef]
20. Yuste, J.C.; Baldocchi, D.D.; Gershenson, A.; Goldstein, A.; Misson, L.; Wong, S. Microbial soil respiration and its dependency oncarbon inputs, soil temperature and moisture. *Glob. Chang. Biol.* **2007**, *13*, 2018–2035. [CrossRef]

21. Arora, B.; Spycher, N.F.; Steefel, C.I.; Molins, S.; Bill, M.; Conrad, M.E.; Dong, W.; Faybishenko, B.; Tokunaga, T.K.; Wan, J.; et al. Influence of hydrological, biogeochemical and temperature transients on subsurface carbon fluxes in a flood plain environment. *Biogeochemistry* **2016**, *127*, 367–396. [CrossRef]
22. Kim, D.G.; Vargas, R.; Bond-Lamberty, B.; Turetsky, M.R. Effects of soil rewetting and thawing on soil gas fluxes: A review of current literature and suggestions for future research. *Biogeosciences* **2012**, *9*, 2459–2483. [CrossRef]
23. Chen, X.; Wang, W.F. On the apparent CO_2 absorption by alkaline soils. *Biogeosci. Discuss.* **2014**, *11*, 2665–2683. [CrossRef]
24. Li, L.; Chen, X.; Tol, C.; Luo, G.; Su, Z. Growing season net ecosystem CO_2 exchange of two desert ecosystems with alkaline soils in Kazakhstan. *Ecol. Evol.* **2014**, *4*, 14–26. [CrossRef] [PubMed]
25. Jin, Z.; Dong, Y.S.; Wang, Y.Q.; Wei, X.R.; Wang, Y.F.; Cui, B.L.; Zhou, W.J. Natural vegetation restoration is more beneficial to soil surface organic and inorganic carbon sequestration than tree plantation on the Loess Plateau of China. *Sci. Total Environ.* **2014**, *485–486*, 615–623. [CrossRef] [PubMed]
26. Wang, W.F.; Chen, X.; Luo, G.P.; Li, L.H. Modeling the contribution of abiotic exchange to CO_2 flux in alkaline soils of arid areas. *J. Arid Land* **2014**, *6*, 27–36. [CrossRef]
27. Raggio, J.; Pintado, A.; Vivas, M.; Sancho, L.G.; Büdel, B.; Colesie, C.; Weber, B.; Schroeter, B.; Lázaro, R.; Green, T.G.A. Continuous chlorophyll fluorescence, gas exchange and microclimate monitoring in a natural soil crust habitat in Tabernas badlands, Almería, Spain: Progressing towards a model to understand productivity. *Biodivers. Conserv.* **2014**, *23*, 1809–1826. [CrossRef]
28. Ma, J.; Liu, R.; Tang, L.S.; Lan, Z.D.; Li, Y. A downward CO_2 flux seems to have nowhere to go. *Biogeoscience* **2014**, *11*, 6251–6262. [CrossRef]
29. Laudicina, V.A.; Novara, A.; Gristina, L.; Badalucco, L. Soil carbon dynamics as affected by long-term contrasting cropping systems and tillages under semiarid Mediterranean climate. *Appl. Soil Ecol.* **2014**, *73*, 140–147. [CrossRef]
30. Liu, J.; Feng, W.; Zhang, Y.; Jia, X.; Wu, B.; Qin, S.G.; Fa, K.Y.; Lai, Z.R. Abiotic CO_2, Exchange between soil and atmosphere and its response to temperature. *Environ. Earth Sci.* **2015**, *73*, 2463–2471. [CrossRef]
31. Lu, N.; Liu, X.R.; Du, Z.L.; Wang, Y.D.; Zhang, Q.Z. Effect of biochar on soil respiration in the maize growing season after 5 years of consecutive application. *Soil Res.* **2014**, *52*, 505–512. [CrossRef]
32. Wang, X.J.; Xu, M.G.; Wang, J.P.; Zhang, W.J.; Yang, X.Y.; Huang, S.M.; Liu, H. Fertilization enhancing carbon sequestration as carbonate in arid cropland: Assessments of long-term experiments in northern China. *Plant Soil* **2014**, *380*, 89–100. [CrossRef]
33. Fa, K.Y.; Liu, J.B.; Zhang, Y.Q.; Wu, B.; Qin, S.G.; Feng, W.; Lai, Z.R. CO_2, absorption of sandy soil induced by rainfall pulses in a desert ecosystem. *Hydrol. Process.* **2014**, *29*, 2043–2051. [CrossRef]
34. Wang, J.P.; Wang, X.J.; Zhang, J.; Zhao, C.Y. Soil organic and inorganic carbon and stable carbon isotopes in the Yanqi Basin of northwestern China. *Eur. J. Soil Sci.* **2015**, *66*, 95–103. [CrossRef]
35. Zhang, J.; Wang, X.J.; Wang, J.P.; Wang, W.X. Carbon and Nitrogen Contents in Typical Plants and Soil Profiles in Yanqi Basin of Northwest China. *J. Integr. Agric.* **2014**, *13*, 648–656. [CrossRef]
36. Li, Y.; Wang, Y.; Houghton, R.A.; Tang, L.S. Hidden carbon sink beneath desert. *Geophys. Res. Lett.* **2015**, *42*, 5880–5887. [CrossRef]
37. Verburg, P.S.J.; Kapitzke, S.E.; Stevenson, B.A.; Bisiaux, M. Carbon allocation in Larrea tridentata plant-soil systems as affected by elevated soil moisture and N availability. *Plant Soil* **2014**, *378*, 227–238. [CrossRef]
38. Prazeres, A.R.; Rivas, J.; Paulo, Ú.; Ruas, F.; Carvalho, F. Sustainable treatment of different high-strength cheese whey wastewaters: An innovative approach for atmospheric CO_2, mitigation and fertilizer production. *Environ. Sci. Pollut.* **2016**, *23*, 13062–13075. [CrossRef] [PubMed]
39. Ma, J.; Li, Y.; Liu, R. The abiotic contribution to total CO_2 flux for soils in arid zone. *Biogeosci. Discuss.* **2015**, *12*, 11217–11244. [CrossRef]
40. Liu, B.; Jin, H.; Sun, Z.; Zhao, S. Geochemical weathering of aeolian sand and its palaeoclimatic implications in the Mu Us Desert, northern China, since the Late Holocene. *J. Arid Land* **2016**, *8*, 647–659. [CrossRef]
41. Wen, Q.; Dong, Z. Geomorphologic patterns of dune networks in the Tengger Desert, China. *J. Arid Land* **2016**, *8*, 660–669. [CrossRef]
42. Li, J.Y.; Dong, Z.B.; Qian, G.Q.; Zhang, Z.C.; Luo, W.Y.; Lu, J.F.; Wang, M. Pattern analysis of a linear dune field on the northern margin of Qarhan Salt Lake, northwestern China. *J. Arid Land* **2016**, *8*, 670–680. [CrossRef]

43. Zhang, F.; Bai, L.; Li, L.H.; Wang, Q. Sensitivity of runoff to climatic variability in the northern and southern slopes of the Middle Tianshan Mountains, China. *J. Arid Land* **2016**, *8*, 681–693. [CrossRef]
44. Gong, Y.; Wang, X.; Hu, B.X.; Zhou, Y.X.; Hao, C.B.; Wan, L. Groundwater contributions in water-salt balances of the lakes in the Badain Jaran Desert, China. *J. Arid Land* **2016**, *8*, 694–706. [CrossRef]
45. Jia, W.R.; Zhang, C.L.; Li, S.Y.; Wang, H.F.; Ma, X.X.; Wang, N.B. Grain size distribution at four developmental stages of crescent dunes in the hinterland of the Taklimakan Desert, China. *J. Arid Land* **2016**, *8*, 722–733. [CrossRef]
46. Song, X.D.; Zhang, G.L.; Liu, F.; Li, D.C.; Zhao, Y.G.; Yang, J.L. Modeling spatio-temporal distribution of soil moisture by deep learning-based cellular automata model. *J. Arid Land* **2016**, *8*, 734–748. [CrossRef]
47. Wang, P.Y.; Li, Z.Q.; Huai, B.J.; Wang, W.B.; Li, H.L.; Wang, L. Spatial variability of glacial changes and their effects on water resources in the Chinese Tianshan Mountains during the last five decades. *J. Arid Land* **2015**, *7*, 717–727. [CrossRef]
48. Yahiaoui, I.; Douaoui, A.; Zhang, Q.; Ziane, A. Soil salinity prediction in the Lower Cheliff plain(Algeria) based on remote sensing and topographic feature analysis. *J. Arid Land* **2015**, *7*, 794–805. [CrossRef]
49. Zhou, Z.; Zhang, X.; Gan, Z. Changes in soil organic carbon and nitrogen after 26 years of farmland management on the Loess Plateau of China. *J. Arid Land* **2015**, *7*, 806–813. [CrossRef]
50. Lundberg, A. Surface water-groundwater interaction. *Theriogenology* **2016**, *85*, 543–546.
51. Baram, S.; Couvreur, V.; Harter, T.; Read, M.; Brown, P.H.; Hopmans, J.W.; Smart, D.R. Assessment of orchard N losses to groundwater with a vadose zone monitoring network. *Agric. Water Manag.* **2016**, *172*, 83–95. [CrossRef]
52. Kurunc, A.; Ersahin, S.; Sonmez, N.K.; Kaman, H.; Uz, I.; Uz, B.Y.; Aslan, G.E. Seasonal changes of spatial variation of some groundwater quality variables in a large irrigated coastal Mediterranean region of Turkey. *Sci. Total Environ.* **2016**, *554–555*, 53–63. [CrossRef] [PubMed]
53. Masoud, A.A.; Koike, K.; Mashaly, H.A.; Gergis, F. Spatio-temporal trends and change factors of groundwater quality in an arid area with peat rich aquifers: Emergence of water environmental problems in Tanta District, Egypt. *J. Arid Environ.* **2016**, *124*, 360–376. [CrossRef]
54. Pawar, R.J.; Bromhal, G.S.; Chu, S.; Dilmore, R.M.; Oldenburg, C.M.; Stauffer, P.H.; Zhang, Y.Q.; Guthrie, G.D. The National Risk Assessment Partnership's integrated assessment model for carbon storage: A tool to support decision making amidst uncertainty. *Int. J. Greenh. Gas Control* **2016**, *52*, 175–189. [CrossRef]
55. Liu, F.; Huang, G.; Sun, J.; Jing, J.H.; Zhang, Y. A New Evaluation Method for Groundwater Quality Applied in Guangzhou Region, China: Using Fuzzy Method Combining Toxicity Index. *Water Environ. Res.* **2016**, *88*, 99–106. [CrossRef] [PubMed]
56. Herczeg, A.L.; Barnes, C.J.; Macumber, P.G.; Olley, J.M. A stable isotope investigation of groundwater-surface water interactions at Lake Tyrrell, Victoria, Australia. *Chem. Geol.* **2016**, *96*, 19–32. [CrossRef]
57. Rawling, G.C.; Newton, B.T. Quantity and location of groundwater recharge in the Sacramento Mountains, south-central New Mexico (USA), and their relation to the adjacent Roswell Artesian Basin. *Hydrogeol. J.* **2016**, *24*, 1–30. [CrossRef]
58. Jayalath, N.; Mosley, L.M.; Fitzpatrick, R.W.; Marschner, P. Addition of organic matter influences pH changes in reduced and oxidised acid sulfate soils. *Geoderma* **2016**, *262*, 125–132. [CrossRef]
59. Chen, X.; Wang, W.F.; Luo, G.P.; Ye, H. Can soil respiration estimate neglect the contribution of abiotic exchange? *J. Arid Land* **2014**, *6*, 129–135. [CrossRef]
60. Hildenbrand, Z.L.; Carlton, D.D.; Fontenot, B.E.; Meik, J.M.; Walton, J.L.; Thacker, J.B.; Korlie, S.; Shelor, C.P.; Kadjo, A.F.; Clark, A.; et al. Temporal variation in groundwater quality in the Permian Basin of Texas, a region of increasing unconventional oil and gas development. *Sci. Total Environ.* **2016**, *562*, 906–913. [CrossRef] [PubMed]