

## Glyphosate Leaching Through a Sandy Loam Soil Amended with Cattle Dung or Rice Husk Ash: A Laboratory Column Study

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### ABSTRACT

This study investigated the influence of added organic materials on glyphosate mobility through sandy loam soil. An equivalent rate of 10 t ha<sup>-1</sup> of either cattle dung or rice husk ash were mixed with the soil and inserted into leaching tubes. Both soil mixture and controls were spiked with 20 mL of 200 mg L<sup>-1</sup> glyphosate. This was followed by an addition 100 mL of stimulated rainfall and the leachate collected at time intervals (0,3,10,22,32,40,50 and 65 days) for glyphosate analysis. After 65 days, soils were cut into three, dried and determined for its glyphosate residual concentration. The data obtained was analysed and results revealed no significance difference ( $p > 0.05$ ) in glyphosate concentration between the treatments, at time intervals (0,3,10,22,32,40,50 and 65 days) and from residual concentration in soil after leaching. Nonetheless, an increased concentration was obtained from both cattle dung (10%) and rice husk (9%) compared with control, indicating potential influence of these wastes on glyphosate mobility. The order of cumulative glyphosate concentration from post-leaching soils was as follows: control with 17.798  $\mu\text{g g}^{-1}$ ; > soil + rice husk ash with 15.484  $\mu\text{g g}^{-1}$ ; and > soil + cattle dung with 14.918  $\mu\text{g g}^{-1}$ . Meanwhile, irrespective of the treatments applied, the concentration of glyphosate in the soil layers were of the following order: top layer with 17.020  $\mu\text{g g}^{-1}$ ; > middle with 16.745  $\mu\text{g g}^{-1}$ ; and > lower layer with 14.436  $\mu\text{g g}^{-1}$ . The length of each layer was about 3.3 cm, suggesting low glyphosate mobility.

**Key words:** sorption, soil organic matter, mobility, sandy loam, herbicide

### INTRODUCTION

Glyphosate [*N*-(phosphonomethyl)glycine] is often applied to agricultural land for weed control. Though it is a foliage applied herbicide, glyphosate enters the soil through spray drift or direct surface application. Even though, glyphosate is largely regarded as relatively immobile in weathered tropical soils, previous studies indicate that its transport from application sites to the surrounding environment is significant (Battaglin *et al.* 2014; Ronco *et al.* 2016; Poiger *et al.* 2017; Masiol *et al.* 2018; Padilla and Selim 2018). These results coupled with concern about the environmental and health effects of glyphosate (Torretta *et al.* 2018; Van Bruggen *et al.* 2018) necessitate continuous investigation into its mobility in soils and thorough risk assessment concerning the food chain contamination impact and adverse health effects of glyphosate.

Soil types and properties generally affect glyphosate profile mobility. Al-Rajab *et al.* (2008) reported high glyphosate leaching in clay loam compared to silty clay loam and sandy loam

soils of the Lorraine region in eastern France. Similarly, glyphosate was not detected in the sandy soil of Lilla site but was detected in the leachate collected from the clay soil of Lanna site, both in southwest Sweden (Aronsson *et al.* 2011). Glyphosate leaching is therefore, governed by macro porous soil structure which supports preferential flow of water and solute. Meanwhile, in non-structured soils with no or less macro pores, glyphosate leaching is minimal. Glyphosate leaching is largely controlled by the sorption capacity of soil (Berzins *et al.* 2019). Thus, soil with amorphous oxides, high content of clay and organic matter, and high CEC strongly adsorb glyphosate and render it immobile.

Application of organic waste as manure is a common practice among our farmers and its benefits includes improving soil structure, porosity and water holding capacity of the soils, improving soil aggregation and water retention and reducing leaching of contaminants (Aldana *et al.* 2020). Cattle dung and rice husk ash are abundantly found in Malaysia and largely incorporated into the soil as a supplementary source of nutrient but their potential as amendments in soil remediation still remains largely undocumented. It was hypothesised that application of these wastes will increase the content of soil organic matter to a significant level (20 to 50%) which in turns will increase the adsorption capacity of soil, hence decreasing glyphosate leaching. The present study therefore aims to investigate the influence of adding cattle dung or rice husk ash on leaching of glyphosate through a Malaysian sandy loam soil in a laboratory column study.

## **MATERIALS AND METHODS**

### **Soil Sampling, Collection of Cattle Dung and Rice Husk Ash**

Benta series is a sandy loam that was collected from Sementa Hulu (Latitude. 38<sup>o</sup>41'66.3"N, Longitude. 101<sup>o</sup> 94' 72.5"E), Raub district, Pahang Malaysia. Surface soils (0-20 cm) were sampled from different locations in the sample area and later bulked to one composite sample. Cattle dung was collected from the animal section of the experimental farm, Faculty of Agriculture, Universiti Putra Malaysia. (Latitude. 29<sup>o</sup> 86' 46.0"N, Longitude. 101<sup>o</sup> 73'31.3"E). Rice husk ash was obtained from BERNAS rice mill Selangor, Malaysia. (Latitude. 3<sup>o</sup>40'32.4"N, Longitude. 100<sup>o</sup>59'42.5"E).

All the samples were dried at the drying room, Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia. The soils and cattle dung were ground using laboratory pestle and mortar followed by sieving of the soils with 2-mm sieve while a 1-mm sieve was used for cattle dung and rice husk ash. The sieved soils, cattle dung and rice husk were all stored in a clean container for analysis and further studies.

### **Column Leaching Experiment**

This study was performed according to Ismail *et al.* (2002) with some modification. One hundred grams of sampled soil in triplicate was weighed into a plastic container, and added with 0.5 g of either cattle dung or rice husk ash to obtain an equivalent rate of 10 tons ha<sup>-1</sup>. The soils and added residues were weighed into three different containers as replicates and controls were also included. Then, the soils containing either cattle dung or rice husk ash were thoroughly mixed and homogenised by repeated stirring with a stainless steel rod. Meanwhile, leaching tubes, 20 cm in length by 2.5 cm in diameter, were placed on a rake in the laboratory with the bottom sealed with cotton and covered by filter paper to support bedding. The controls and soil mixture were placed into the column tubes with the top 10 cm space for addition of water. The water was later added to settle the soils into the column. Thereafter, 20 mL of 200 mg L<sup>-1</sup> glyphosate solution was evenly spiked into each column by using a needle syringe. This was followed by the addition of 100 mL of stimulated rainfall (pH 4.5) and leachate was collected at 0, 3, 10, 22, 32, 40, 50 and 65 days for glyphosate analysis. Though 20-cm leaching

tubes were chosen to mimic rooting depth, only 10 cm of its length was filled with soil due to rapid inactivation of glyphosate in soil (Sprankle *et al.* 1975), Therefore, it was assumed that the spiked glyphosate will as usual remain on the first 10 cm of the soil surface. The pH of the water used was adjusted to 4.5 to mimic the pH of natural rainwater. The leachate was collected at day zero to mimic an immediate rain event after glyphosate application which is reported to cause mobility of the herbicide (Vereecken 2005), and then collected at the remaining days earlier mentioned (3, 10, 22, 32, 40, 50 and 65 days). It is to be noted that at each day of leachate collection, 100 mL of water was freshly added and flow rate adjusted such that the water eluted was collected after 24 h. All the samples were arranged in a completely randomized design (CRD) and maintained at 23°C on a bench in the laboratory. At the end of this experiment, the soil in each column was divided into three layers, dried and analysed for glyphosate residue.

### **Glyphosate Residues Analysis**

Glyphosate residue in both leachate and divided soil layers was analysed by high performance liquid chromatography (HPLC) using the method described in Garba *et al.* (2018). Briefly, 1 mL of leachate or extracted solution containing glyphosate from the divided soil layers was mixed with 2 mL 0.05 M borate buffer (pH 9) solution and 1 mL 0.02 M 9-flourenylmethylchloroformate chloride (FMOC-Cl) and poured into a 25- mL centrifuge tube. The mixture was shaken with end-to-end shaker at 180 rpm for 1 h. This was followed by a washing with the addition of 2 mL diethyl ether and vortex mixed for 2 min. The organic layer from the mixture was removed and the aqueous solution containing glyphosate-FMOC was transferred to HPLC vials for analysis. The instrument used was HPLC Agilent 1100 series (Agilent Santa Clara, USA) equipped with a G 1315B ultraviolet detector. The analysis of glyphosate was carried out using a stationary phase of Agilent® Zorbax Eclipse plus C<sub>18</sub> (4.6 x 150 mm, 5 µm) column. The mobile phase solvent was acetonitrile and 0.05 M KH<sub>2</sub>PO<sub>4</sub> mixture (30:70 v/v) using isocratic mode. The flow rate was 0.7 mL min<sup>-1</sup> with a column temperature of 40°C and 20 µl injection volume with the wave lengths being 206 and 210 nm. This method had the lowest limit of detection and quantification of 0.024 mg L<sup>-1</sup> and 0.076 mg L<sup>-1</sup> respectively.

### **Statistical Analysis**

All the data obtained was subjected to analysis of variance (ANOVA) using SAS 9.4 (Cary, North Caroline) statistical software to determine the significant difference between the treatment means at 95% confidence level with the significant means separated using student's Tukey range test.

## **RESULTS AND DISCUSSION**

Analysis of variance revealed no significant difference ( $p > 0.05$ ) between glyphosate residual concentration in the leachate of control and amended soils. The difference in glyphosate residual content between control and amended soils across the leaching period was also not significant ( $p > 0.05$ ). Similarly, post-leaching glyphosate residue contents between the soil layers of all treatments was not statistically different ( $p > 0.05$ ). Table 1 shows the cumulative values of glyphosate residual concentration from different treatments in the studied soils. Though the residual contents were statistically similar, application of cattle dung or rice husk ash showed an increase in glyphosate residue compared to control. The soil applied with cattle dung had a glyphosate residue of 36.064 µg mL<sup>-1</sup> followed by soil with rice husk ash with 34.571 µg mL<sup>-1</sup> and control had 26.125 µg mL<sup>-1</sup>, representing 37%, 36% and 27% of the total residue, respectively. The increase in glyphosate mobility from cattle dung or rice husk ash applied soil compared to control can be attributed to their effect on soil properties and glyphosate molecule itself. Results of the chemical analyses (Table 2) showed cattle dung and rice husk ash to have

an alkaline condition with their P contents being 0.216 and 0.173% respectively. Our previous study (Garba *et al.* 2019) revealed that both cattle dung and rice husk ash contain oxygen acidic functional groups with the former containing more carboxylic and lactones than the latter with cattle dung having an additional amines group. Therefore, incorporation of either of these into the soil might result in ionization or protonation of these functional groups and increasing soil negative charges (Novak *et al.* 2010; Song and Guo 2012; Zhang *et al.* 2014) which lead to increasing glyphosate repulsion and mobility. Similarly, decomposition of these added residues can increase the soil pH, which increases soil negative charges resulting in greater repulsion and mobility of glyphosate. Application of cattle dung or rice husk ash improves soil structure thereby increasing preferential flow and glyphosate mobility (Landry *et al.* 2005).

TABLE 1  
Cumulative values of glyphosate concentration in the leachate of the treated soils

Treatments	Concentration in the leachate ( $\mu\text{g mL}^{-1}$ )
Control	26.125 $\pm$ 0.59
Soil + cattle dung	36.064 $\pm$ 1.45
Soil + rice husk ash	34.571 $\pm$ 1.06

Note:  $p > 0.05$  (n= 24,  $\pm$  SE)

Mobility of glyphosate in soil occurs in solution or in suspension through preferential pathways such as macro pores and cracks between the soil aggregates ( De Jonge *et al.* 2000; Borggaard and Gimsing 2008), and depends on the hydraulic conductivity of soils. The amount of water (100 mL) applied at each day of leachate collection mimic heavy rainfall and the 24 h flow rate adjustments stimulate normal water flow within the soils. This flow increases soil solution and moves along with colloidal particles. In either case, glyphosate in solution or bounded to soil colloids will be transported by this water flow. As glyphosate strongly adsorbs soil mineral and organic colloids (Sprankle *et al.* 1975; Piccolo *et al.* 1994), it is therefore less mobile in soil. However, increasing pH and soil negative charges results in greater desorption leading to its mobility. The present study is in agreements with Cheah *et al.* (1997) who reported low glyphosate mobility in Malaysian muck and sandy loam soils. In a laboratory soil column study involving sandy and sandy loam soils of Malaysia, Ismail *et al.* (2002) reported glyphosate mobility from the soils with higher amounts of glyphosate detected at 0-10 cm suggesting its low mobility.

TABLE 2  
Selected properties of soil, cattle dung and rice husk ash

Parameter	Soil	Cattle dung	Rice husk ash
pH	6.7	8.14	9.95
Ec ( $\mu\text{s/cm}$ )	24	2183	3320
C (%)	1.67	31	1.80
N (%)	0.16	2.53	Nd
P (g/kg)	0.007	2.16	1.73
K (g/kg)	0.13	9.16	1.93
CEC ( $\text{cmol}_{(+)}/\text{kg}$ )	12.67	34.50	10.20

Note: nd, not detected

The interaction of treatments and time on glyphosate mobility during the study period is shown in Figure 1. The control column had low residual glyphosate concentration compared to

amended column and out of the total leached from this column, 20% was at day 50 followed by 19%, 17%, 16% and 11% for days 40, 10, 65 and 3, respectively. The amount leached at day 0 was 7% while 5% and 4% were for days 32 and 22. The cattle dung-applied soil column had more glyphosate leachate than that with rice husk ash. Out of the total glyphosate leached from this column, 37% was at day 10 while 19% 13% 12% and 7% leached at days 65, 40, 50 and 3, respectively. Moreover, the percent glyphosate leached at day 0 was 6% while 3% and 4% leached at days 32 and 22, respectively. Similarly, out of the total glyphosate leached from rice husk ash applied column, 30% was at day 10. This was followed by 17% at day 50, 16% at day 65 and 14% at day 40. The remaining day intervals of 3, 0, 33 and 22 had glyphosate leached of 9%, 6%, 4% and 3%, respectively.

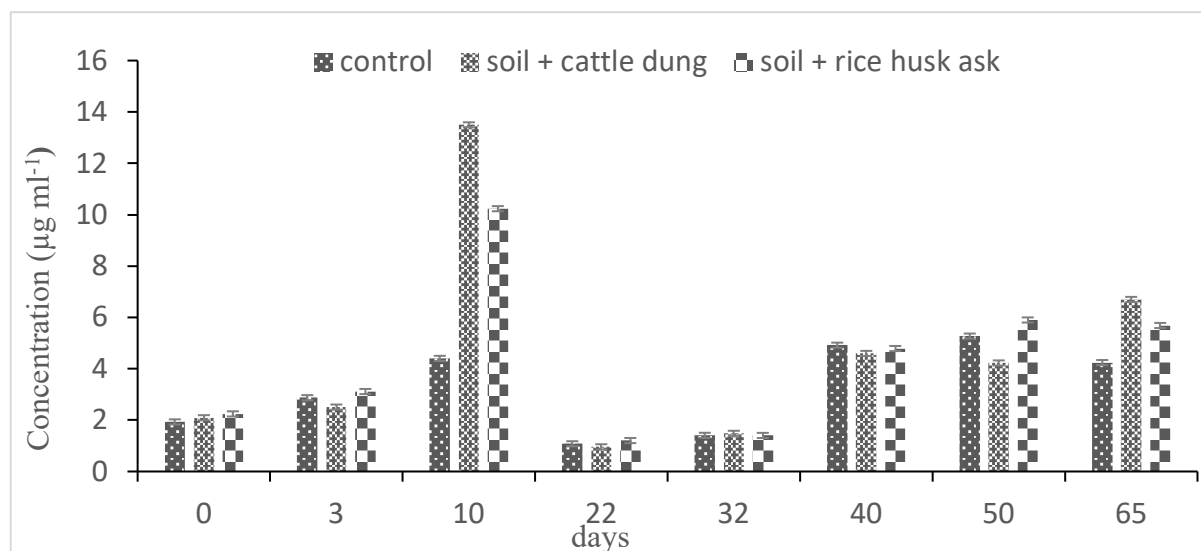


Figure 1. Residual glyphosate concentration among the treatments in the leachate of the studied soil over time ( $p > 0.05$ ).

The length of each soil column was 10 cm which is within the rooting zone and region of high microbial function. Therefore, available glyphosate in soil solution can rapidly be broken down, resulting in no or less leaching. A strong binding of glyphosate to soil colloids and its immediate and complete breakdown by soil microorganisms makes for unlikely contamination of underground water (Solomon *et al.* 2007), unless in the event of a substantial spill or an abnormal amount used. Results of P mineralisation (Garba *et al.* 2017) showed that cattle dung and rice husk ash significantly ( $p < 0.05$ ) increased extractable P from these soils. Result of chemical analysis (Table 2) indicates that cattle dung contains more P than rice husk ash thus, suggesting an increase in the amount of extractable P in soils applied with cattle dung compared to rice husk ash. Application of these residues therefore, resulted in increasing soil inorganic P which competes with glyphosate for adsorption (Borggaard and Gimsing 2008). Furthermore, inorganic P had a higher affinity (De Jonge *et al.* 2000; Gimsing *et al.* 2007; Kjær *et al.* 2011) for adsorption surface than glyphosate, resulting in a greater amount of glyphosate in soil solution and consequently its mobility.

Results of the post-leaching glyphosate residue analysis (Table 3) showed more glyphosate content in control ( $17.798 \mu\text{g g}^{-1}$ ) followed by the column with rice husk ash ( $15.484 \mu\text{g g}^{-1}$ ) and cattle dung ( $14.918 \mu\text{g g}^{-1}$ ). This difference in readings obtained is attributed to increased leaching of glyphosate from the soils due to cattle dung or rice husk ash application. Therefore, the residue left was inversely related to the rate of glyphosate mobility from each treatment. From the glyphosate residual concentration in the soil layers, it is found that middle layers of control and column amended with cattle dung had more glyphosate residue compared to their

respective top and lower layers. Meanwhile, top layer of the column amended with rice husk ash had more glyphosate residue than its middle and lower layers. The length of each soil layer was about 3.3 cm. The present study showed a high glyphosate residue in the top 5cm of both soils suggesting its low mobility due to adsorption by soil mineral and organic surfaces. This is in agreement with Okada *et al.* (2016) who reported a higher glyphosate residue(67.53% of initial applied doses) on the top layer (0-5 cm) of undisturbed columns of Mollisols.

TABLE 3

Post-leaching glyphosate residual concentration ( $\mu\text{g g}^{-1}$ ) among the treatments at different layers of the studied soils

Treatments	Top layer	Middle layer	Lower layer	Total
Control	6.324 $\pm$ 1.30	6.770 $\pm$ 1.00	4.704 $\pm$ 0.35	17.798
Soil + cattle dung	4.891 $\pm$ 0.36	5.225 $\pm$ 0.09	4.802 $\pm$ 0.45	14.918
Soil + rice husk ash	5.804 $\pm$ 0.15	4.750 $\pm$ 0.40	4.930 $\pm$ 0.60	15.484

Note:  $p > 0.05$  (n=3,  $\pm$  SE)

### CONCLUSION

The present study investigated glyphosate leaching in soil columns amended with cattle dung or rice husk ash with the aim of predicting its mobility in soils. Results revealed no significant difference ( $p > 0.05$ ) on glyphosate mobility between the control and column with cattle dung or rice husk ash. However, there was an increase of 10% and 9% of glyphosate residue in soils amended with cattle dung and rice husk ash respectively. This indicates the potential of these organic amendments in enhancing glyphosate leaching. There was increasing glyphosate leaching over the period of incubation, reaching a maximum at the 10th day interval (30% of the initially applied doses). Then the leaching declined but increased steadily over time. Thus, at the end of the incubation period (65 days), the leaching recorded was only 16% of the initially applied glyphosate. The result of post-leaching residue analysis showed more glyphosate content at the top soils (17.020  $\mu\text{g g}^{-1}$ ) compared to middle (16.745  $\mu\text{g g}^{-1}$ ) and lower layer (14.436  $\mu\text{g g}^{-1}$ ) hence suggesting its low mobility. This is attributed to its strong adsorption by mineral and organic surfaces. Therefore, based on the present result, it can be concluded that even with the soil application of these residues which may likely increases glyphosate desorption still had low mobility of this herbicide.

### ACKNOWLEDGMENTS

The authors would like to thank Universiti Putra Malaysia for providing a financial support to complete this study through UPM/GP/IPS/2016-9471900 research grant. The PhD scholarship to the first author provided by tertiary education trust fund (Tetfund) Nigeria through Zamfara State College of Education, Maru, Nigeria is also highly acknowledged.

### REFERENCES

- Al-Rajab, A. J., S. Amellal and M. Schiavon. 2008. Sorption and leaching of  $^{14}\text{C}$ -glyphosate in agricultural soils. *Agronomy for Sustainable Development* 28(3): 419–428. <https://doi.org/10.1051/agro:2008014>
- Aldana, G. O., C. Hazlerigg, E. Lopez-capel and D. Werner. 2020. Agrochemical leaching reduction in biochar-amended tropical soils of Belize. *Soil Science* 1–13. <https://doi.org/10.1111/ejss.13021>
- Aronsson, H., M. Stenberg and B. Ulén. 2011. Leaching of N, P and glyphosate from two soils after herbicide treatment and incorporation of a ryegrass catch crop. *Soil Use and Management* 27(March): 54–68. <https://doi.org/10.1111/j.1475-2743.2010.00311.x>

- Battaglin, W. A., M.T. Meyer, K.M. Kuivila and J.E. Dietze. 2014. Glyphosate and its degradation product AMPA occur frequently and widely in U.S. soils, surface water, groundwater, and precipitation. *Journal of the American Water Resources Association* 50(2): 275–290. <https://doi.org/10.1111/jawr.12159>
- Berzins, A., M. Jansons, K. Kalniece, K. Shvirksts, K. Afanasjeva, R. Kasparinskis, M. Grube, V. Bartkevics and O. Muter 2019. Modeling the mobility of glyphosate from two contrasting agricultural soils in laboratory column experiments. *Journal of Environmental Science and Health, Part B* 54(7): 539–548.
- Borggaard, O. K. and A. L. Gimsing. 2008. Fate of glyphosate in soil and the possibility of leaching to ground and surface waters: a review. *Pest Management Science* 64: 441–456. <https://doi.org/10.1002/ps>
- Cheah, U., C. Kirkwood, and K. Lum. 1997. Adsorption, desorption and mobility of four commonly used pesticides in Malaysian agricultural soils. *Pesticide Science* 50:53–63.
- De Jonge, H., L.W. De Jonge, and O.H. Jacobsen. 2000. [14C]glyphosate transport in undisturbed topsoil columns. *Pest Management Science* 56(10): 909–915. [https://doi.org/10.1002/1526-4998\(200010\)56:10<909::AID-PS227>3.0.CO;2-5](https://doi.org/10.1002/1526-4998(200010)56:10<909::AID-PS227>3.0.CO;2-5)
- Garba, J., A.W. Samsuri, S. Ahmad-Hamdani and R.Othman.2017. Carbon and phosphorus mineralization from soils amended with cattle dung or rice husk ash. *Journal of Environmental and Agricultural Sciences* 10: 84–94.
- Garba, J., A.W. Samsuri, R. Othman and M.S. Ahmad Hamdani. 2018. Simplified method for derivatization of extractable glyphosate and aminomethylphosphonic acid and their determination by high performance liquid chromatography. *Environmental Research & Technology* 1(2): 19–30.
- Garba, J., W.A. Samsuri, R. Othman and A.H. Muhammad Saiful. 2019. Evaluation of adsorptive characteristics of cattle dung and rice husk ash for removal of aqueous glyphosate and aminomethylphosphonic acid. *Scientific Reports* 9: 1–10. <https://doi.org/10.1038/s41598-019-54079-0>
- Gimsing, A. L., C. Szilas and O.K. Borggaard. 2007. Sorption of glyphosate and phosphate by variable-charge tropical soils from Tanzania. *Geoderma* 138(1–2), 127–132. <https://doi.org/10.1016/j.geoderma.2006.11.001>
- Ismail, B. S., Z.A. Kadir, K. Jusoh and N. Mat.2002. Adsorption-desorption, mobility and degradation of 14 c-glyphosate in two soil series. *Jurnal Sains Nuklear Malaysia* 20(1): 17–29.
- Kjær, J., V. Ernsten, VO.H. Jacobsen, N. Hansen, L.W. de Jonge and P. Olsen.2011. Transport modes and pathways of the strongly sorbing pesticides glyphosate and pendimethalin through structured drained soils. *Chemosphere* 84(4): 471–479. <https://doi.org/10.1016/j.chemosphere.2011.03.029>
- Landry, D., S. Douset, J.C. Fournier and F. Andreux. 2005. Leaching of glyphosate and AMPA under two soil management practices in Burgundy vineyards (Vosne-Romanée, 21-France). *Environmental Pollution* 138(2): 191–200. <https://doi.org/10.1016/j.envpol.2005.04.007>
- Masiol, M.,B. Gianni and M. Prete.2018. Herbicides in river water across the northeastern Italy: Occurrence and spatial patterns of glyphosate, aminomethylphosphonic acid, and glufosinate ammonium. *Environmental Science and Pollution Research* 25: 24368–24378.
- Novak, J. M., W.J. Busscher, D.W. Watts, D.A. Laird, M.A. Ahmedna and M.A.S. Niandou. 2010. Short-term CO<sub>2</sub> mineralization after additions of biochar and switchgrass to a Typic Kandudult. *Geoderma* 154(3–4): 281–288. <https://doi.org/10.1016/j.geoderma.2009.10.014>
- Okada, E., J.L. Costa and F. Bedmar. 2016. Adsorption and mobility of glyphosate in different soils under no-till and conventional tillage. *Geoderma* 263: 78–85. <https://doi.org/10.1016/j.geoderma.2015.09.009>
- Padilla, J. T. and H.M. Selim. 2018. Glyphosate transport in two Louisiana agricultural soils : miscible displacement studies and numerical modeling. *Soil System* 2(53): 1-18 <https://doi.org/10.3390/soilsystems2030053>
- Piccolo, A.A., G. Celano and M. Arienzo. 1994. Adsorption and desorption of glyphosate in some European soils. *Journal of Environmental Science and Health B*, 29(6): 1105–1115.
- Poiger, T. I.J. Buerge, A. Bächli, M. Müller and M.E. Balmer. 2017. Occurrence of the herbicide glyphosate and its metabolite AMPA in surface waters in Switzerland determined with on-line

- solid phase extraction LC-MS/MS. *Environmental Science and Pollution Research* 24: 1588–1596.
- Ronco, A.E., D.J.G. Marino, M. Abelando, P. Almada and C.D. Apartin. 2016. Water Quality of the main tributaries of the Paraná Basin: Glyphosate and AMPA in surface water and bottom sediment. *Environmental Monitoring and Assessments* 188 (8) 458.
- Solomon, K. R., A. Anadón, A.L. Cedeira, J. Marshall and L.H. Sanin. 2007. Environmental and human health assessment of aerially applied glyphosate in Colombia. *Review in Environmental Contamination and Toxicology* 190: 43–125. Retrieved from <http://www.cicad.oas.org/en/glifosateFinalReport.pdf%5Cnpapers2://publication/uuid/1913970B-6789-4649-BD2F-6C726C3CB60D>
- Song, W. and M. Guo.2012. Quality variations of poultry litter biochar generated at different pyrolysis temperatures. *Journal of Analytical and Applied Pyrolysis* 94: 138–145. <https://doi.org/10.1016/j.jaap.2011.11.018>
- Sprankle, P., W.F. Meggitt, D. Penner, S.W. Science and N. May. 1975. Rapid inactivation of glyphosate in the soil rapid inactivation of glyphosate in the soil. *Weed Science* 23(3): 224–228.
- Torretta, V, I.A. Katsoyiannis, P.Viotti, E.C. Rada. 2018. Critical review of the effects of glyphosate exposure to the environment and humans through the food supply chain. *Sustainability* 10, 950.
- Van Bruggen, A.H., M.M. He , K. Shin, V. Mai, K. Jeong, M. Finckh and J.J. Morris. 2018. Environmental and health effects of the herbicide glyphosate. *Science of the Total Environment* 616:255–268.
- Vereecken, H. 2005. Mobility and leaching of glyphosate: A review. *Pest Management Science* 61(12): 1139–1151. <https://doi.org/10.1002/ps.1122>
- Zhang, J., F. Lü, C. Luo, L. Shao, and P. He. 2014. Humification characterization of biochar and its potential as a composting amendment. *Journal of Environmental Sciences (China)* 26(May): 390–397. [https://doi.org/10.1016/S1001-0742\(13\)60421-0](https://doi.org/10.1016/S1001-0742(13)60421-0)