



Universiteit
Leiden
The Netherlands

From the root of variation: A metabolomics perspective to plant soil-feedback

Huberty, M.D.

Citation

Huberty, M. D. (2020, November 24). *From the root of variation: A metabolomics perspective to plant soil-feedback*. NIOO-thesis. Retrieved from <https://hdl.handle.net/1887/138402>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/138402>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/138402> holds various files of this Leiden University dissertation.

Author: Huberty, M.D.

Title: From the root of variation: A metabolomics perspective to plant soil-feedback

Issue date: 2020-11-24

References

- Akashi, T., Furuno, T., Takahashi, T., Ayabe, S.-I., 1994. Biosynthesis of triterpenoids in cultured cells, and regenerated and wild plant organs of *Taraxacum officinale*. *Phytochemistry, The International Journal of Plant Biochemistry* 36, 303–308. [https://doi.org/10.1016/S0031-9422\(00\)97065-1](https://doi.org/10.1016/S0031-9422(00)97065-1)
- Amin Mir, M., Sawhney, S.S., Jassal, M.M.S., 2013. Qualitative and quantitative analysis of phytochemicals of *Taraxacum officinale*. *Wudpecker J. Pharm. Pharmacology*, 1 2, 001–005. <https://doi.org/10.3390/ijms140612780>
- Andersen S.O., 2010. Insect cuticular sclerotization: A review. *Insect Biochem Mol Biol* 40(3):166–178, <https://doi.org/10.1016/j.ibmb.2009.10.007>
- Apprill, A., McNally, S., Parsons, R., Weber, L. (2015). Minor revision to V4 region SSU rRNA 806R gene primer greatly increases detection of SAR11 bacterioplankton. *Aquatic Microbial Ecology*, 75(2), 129–137. <https://doi.org/10.3354/ame01753>
- Audoin, C., Holderith, S., Romari, K., Thomas, O.P., Genta-Jouve, G., 2014. Development of a work-flow for high-performance thin-layer chromatography data processing for untargeted metabolomics. *JPC – J. Planar Chromatogr. – Mod. TLC* 27, 328–332. <https://doi.org/10.1556/JPC.27.2014.5.1>
- Badri, D. V., Zolla, G., Bakker, M. G., Manter, D. K., Vivanco, J. M. (2013). Potential impact of soil microbiomes on the leaf metabolome and on herbivore feeding behavior. *New Phytologist*, 198(1), 264–273. doi: 10.1111/nph.12124
- Bain J.F., 1991. The biology of Canadian weeds.: 96. *Senecio jacobaea* L. *Can J Plant Sci* 127–140. <https://doi.org/10.4141/cjps91-014>
- Bais, H. P., Vepachedu, R., Gilroy, S., Callaway, R. M., Vivanco, J. M., 2003. Allelopathy and exotic plant invasion: from molecules and genes to species interactions. *Science*, 301(5638), 1377–1380. doi: 10.1126/science.1083245
- Bardgett, R.D., van der Putten, W.H., 2014. Belowground biodiversity and ecosystem functioning. *Nature* 515, 505–511. <https://doi.org/10.1038/nature13855>
- Bayona, L.M., Verpoorte, R., Klinkhamer, P.G.L., Choi, Y.H., 2019. Thin-Layer Chromatography | Metabolomics., in: *Encyclopedia of Analytical Science*. Elsevier, pp. 59–75.
- Beckers, V., Dersch, L.M., Lotz, K., Melzer, G., Bläsing, O.E., Fuchs, R., ... , Wittmann, C., 2016. In silico metabolic network analysis of Arabidopsis leaves. *BMC Syst. Biol.* 10, 102. <https://doi.org/10.1186/s12918-016-0347-3>
- Behmer, S.T., David Nes, W., 2003. Insect sterol nutrition and physiology: a global overview, in: *advances in insect physiology*. Academic Press, pp. 1–72. [https://doi.org/10.1016/S0065-2806\(03\)31001-X](https://doi.org/10.1016/S0065-2806(03)31001-X)
- Behmer, S.T., Elias, D.O., Grebenok, R.J., 1999. Phytosterol metabolism and absorption in the generalist grasshopper, *Schistocerca americana* (Orthoptera: Acrididae). *Arch. Insect Biochem. Physiol.* 42, 13–25. [https://doi.org/10.1002/\(SICI\)1520-6327\(199909\)42:1<13::AID-ARCH3>3.0.CO;2-P](https://doi.org/10.1002/(SICI)1520-6327(199909)42:1<13::AID-ARCH3>3.0.CO;2-P)
- Behmer, S.T., Grebenok, R.J., Douglas, A.E., 2011. Plant sterols and host plant suitability for a phloem-feeding insect. *Funct. Ecol.* 25, 484–491. <https://doi.org/10.1111/j.1365-2435.2010.01810.x>
- Benjamini, Y., Hochberg, Y., 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological)*, 57(1), 289–300.
- Bennett, J.A., Klironomos, J., 2019. Mechanisms of plant–soil feedback: interactions among biotic and abiotic drivers. *New Phytologist* 222: 91– 96. <https://doi.org/10.1111/nph.15603>
- Berenbaum, M.R., 1995. Turnabout is fair play: Secondary roles for primary compounds. *J. Chem. Ecol.* 21, 925–940. <https://doi.org/10.1007/BF02033799>
- Berenbaum, M.R., Zangerl, A.R., 1993. Furanocoumarin metabolism in *Papilio polyxenes*: biochemistry, genetic variability, and ecological significance. *Oecologia* 95, 370–375. <https://doi.org/10.1007/BF00320991>
- Bever, J.D., 1994. Feedback between plants and their soil community in an oil field community. <https://doi.org/10.2307/1941601>
- Bever, J.D., 2003. Soil community feedback and the coexistence of competitors: conceptual frameworks and empirical tests. *New Phytol.* 157, 465–473. <https://doi.org/10.1046/j.1469-8137.2003.00714.x>

- Bezemer, T. M., Harvey, J. A., Kowalchuk, G. A., Korpershoek, H., van der Putten, W. H., 2006. Interplay between *Senecio Jacobaea* and plant, soil, and aboveground insect community composition. *Ecology*, 87(8), 2002–2013. doi: 10.1890/0012-9658(2006)87[2002:IBSJAP]2.0.CO;2
- Bezemer, T. M., Van Der Putten, W. H., Martens, H., Van der Voorde, T. F. J., Mulder, P. P. J., Kostenko, O., 2013. Above- and below-ground herbivory effects on below-ground plant–fungus interactions and plant–soil feedback responses. *Journal of Ecology*, 101(2), 325–333. doi: 10.1111/1365-2745.12045
- Bezemer, T.M., Van Dam, N. M., 2005. Linking aboveground and belowground interactions via induced plant defenses. *Trends in Ecology & Evolution*, 20(11), 617–624. doi: 10.1016/j.tree.2005.08.006
- Bezemer, T.M., De Deyn, G.B., Bossinga, T.M., Van Dam, N.M., Harvey, J.A., Van der Putten, W.H., 2005. Soil community composition drives aboveground plant–herbivore–parasitoid interactions. *Ecol Lett* 8: 652–661. <https://doi.org/10.1111/j.1461-0248.2005.00762.x>
- Bezemer, T.M., Fountain, M.T., Barea, J.M., Christensen, S., Dekker, S.C., Duyts, H., ... , Van der Putten, W.H., 2010. Divergent composition but similar function of soil food webs of individual plants: plant species and community effects. *Ecology* 91, 3027–3036. <https://doi.org/10.1890/09-2198.1>
- Bezemer, T.M., Jing, J., Bakx-Schotman, J.M.T., Bijleveld, E.-J., 2018. Plant competition alters the temporal dynamics of plant–soil feedbacks. *J. Ecol.* 106, 2287–2300. <https://doi.org/10.1111/1365-2745.12999>
- Bezemer, T.M., Lawson, C.S., Hedlund, K., Edwards, A.R., Brook, A.J., ... , Van der Putten, W.H., 2006. Plant species and functional group effects on abiotic and microbial soil properties and plant–soil feedback responses in two grasslands. *J. Ecol.* 94, 893–904. <https://doi.org/10.1111/j.1365-2745.2006.01158.x>
- Biere, A., Goverse, A., 2016. Plant-mediated systemic interactions between pathogens, parasitic nematodes, and herbivores above- and belowground. *Annual Review of Phytopathology*, 54(1), 499–527. doi: 10.1146/annurev-phyto-080615-100245
- Brinkman, E.P., Van der Putten, W.H., Bakker, E.-J., Verhoeven, K.J.F., 2010. Plant–soil feedback: experimental approaches, statistical analyses and ecological interpretations. *J. Ecol.* 98, 1063–1073.
- Brockett, B.F.T., Prescott, C.E., Grayston, S.J., 2012. Soil moisture is the major factor influencing microbial community structure and enzyme activities across seven biogeoclimatic zones in western Canada. *Soil Biol Biochem* 44: 9–20. <https://doi.org/10.1016/j.soilbio.2011.09.003>
- Brundrett, M.C., 2002. Coevolution of roots and mycorrhizas of land plants. *New Phytol.* 154, 275–304. <https://doi.org/10.1046/j.1469-8137.2002.00397.x>
- Bundy, J.G., Davey, M.P., Viant, M.R., 2009. Environmental metabolomics: a critical review and future perspectives. *Metabolomics* 5, 3. <https://doi.org/10.1007/s11306-008-0152-0>
- Burrows, S., Simpson, J.C.E., 1938. The triterpene group. Part IV. The triterpene alcohols of *Taraxacum* root. *J. Chem. Soc. Part II* 2042–2047. <https://doi.org/10.1039/JR9380002042>
- CABI, 2020. Crop Protection Compendium. Wallingford, UK: CAB International. www.cabi.org/cpc.
- Cao, K.-A. L., Rohart, F., Gonzalez, I., Dejean, S., Abadi, A., Gautier, B., ... Lique, B., 2020. mixOmics: Omics data integration project (Version 6.10.9). doi: 10.18129/B9.bioc.mixOmics
- Caporaso, J. G., Lauber, C. L., Walters, W. A., Berg-lyons, D., Huntley, J., Fierer, N., ... Knight, R., 2012. Ultra-high-throughput microbial community analysis on the Illumina HiSeq and MiSeq platforms. *The ISME Journal*, 6(8), 1621–1624. doi: 10.1038/ismej.2012.8
- Cardoso, P., Barton, P.S., Birkhofer, K., Chichorro, F., Deacon, C., Fartmann, T., ... Samways, M.J., 2020. Scientists' warning to humanity on insect extinctions. *Biol. Conserv.* 242, 108426. <https://doi.org/10.1016/j.biocon.2020.108426>
- Castro-Moretti, F.R., Gentzel, I.N., Mackey, D., Alonso, A.P., 2020. Metabolomics as an emerging tool for the study of plant–pathogen interactions. *metabolites* 10, 52. <https://doi.org/10.3390/metabo10020052>
- Chadha, A., Florentine, S.K., Chauhan, B.S., Long, B., Jayasundera, M., 2019. Influence of soil moisture regimes on growth, photosynthetic capacity, leaf biochemistry and reproductive capabilities of the invasive agronomic weed; *Lactuca serriola*. *PLOS ONE* 14, e0218191. <https://doi.org/10.1371/journal.pone.0218191>
- Chen, H.-J., Inbaraj, B.S., Chen, B.-H., 2012. Determination of phenolic acids and flavonoids in *Taraxacum formosanum* Kitam by liquid chromatography-tandem mass spectrometry coupled with a post-column derivatization technique. *Int. J. Mol. Sci.* 13, 260–285. <https://doi.org/10.3390/ijms13010260>

- Choi, J., Yoon, K.D., Kim, J., 2018. Chemical constituents from *Taraxacum officinale* and their α -glucosidase inhibitory activities. *Bioorg. Med. Chem. Lett.* 28, 476–481. <https://doi.org/10.1016/j.bmcl.2017.12.014>
- Chong, J., Soufan, O., Li, C., Caraus, I., Li, S., Bourque, G., Wishart, D.S., Xia, J., 2018. MetaboAnalyst 4.0: towards more transparent and integrative metabolomics analysis. *Nucleic Acids Res* 46: W486–W494. <https://doi.org/10.1093/nar/gky310>
- Cocuron, J.-C., Anderson, B., Boyd, A., Alonso, A.P., 2014. Targeted metabolomics of *Physaria fendleri*, an industrial crop producing hydroxy fatty acids. *Plant Cell Physiol.* 55, 620–633. <https://doi.org/10.1093/pcp/pcu011>
- Cocuron, J.-C., Casas, M.I., Yang, F., Grotewold, E., Alonso, A.P., 2019. Beyond the wall: High-throughput quantification of plant soluble and cell-wall bound phenolics by liquid chromatography tandem mass spectrometry. *J. Chromatogr. A* 1589, 93–104. <https://doi.org/10.1016/j.chroma.2018.12.059>
- Compant, S., Duffy, B., Nowak, J., Clément, C., Barka, E.A., 2005. Use of plant growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. *Appl. Environ. Microbiol.* 71, 4951–4959. <https://doi.org/10.1128/AEM.71.9.4951-4959.2005>
- Constancias, F., Saby, N.P.A., Terrat, S., Dequiedt, S., Horrigue, W., Nowak, V., ... , Ranjard, L. 2015, Contrasting spatial patterns and ecological attributes of soil bacterial and archaeal taxa across a landscape. *Microbiologyopen* 4: 518–531. <https://doi.org/10.1002/mbo3.256>
- Cortois, R., Schröder-Georgi, T., Weigelt, A., Van der Putten, W. H., De Deyn, G. B., 2016. Plant–soil feedbacks: role of plant functional group and plant traits. *Journal of Ecology*, 104(6), 1608–1617. doi: 10.1111/1365-2745.12643
- Crockford, D.J., Holmes, E., Lindon, J.C., Plumb, R.S., Zirah, S., Bruce, S.J., ... Stumpf, C.L., Nicholson, J.K., 2006. Statistical heterospectroscopy, an approach to the integrated analysis of NMR and UPLC-MS data sets: application in metabolomic toxicology studies. *Anal. Chem.* 78, 363–371. <https://doi.org/10.1021/ac051444m>
- Da Silva, R.R., Wang, M., Nothias, L.-F., Hooft, J.J.J. van der, Caraballo-Rodríguez, A.M., Fox, E., Balunas, M.J., Klassen, J.L., Lopes, N.P., Dorrestein, P.C., 2018. Propagating annotations of molecular networks using in silico fragmentation. *PLOS Comput. Biol.* 14, e1006089. <https://doi.org/10.1371/journal.pcbi.1006089>
- Darandeh N, Hadavi E (2012) Effect of pre-harvest foliar application of citric acid and malic acid on chlorophyll content and post-harvest vase life of *Lilium* cv. Brunello. *Front Plant Sci* 2: 106. <https://doi.org/10.3389/fpls.2011.00106>
- De Hollander, M. 2017. nioo-knaw/hydra: 1.3.3. doi: 10.5281/zenodo.884028
- De Long, J.R., Fry, E.L., Veen, G.F., Kardol, P., 2019. Why are plant–soil feedbacks so unpredictable, and what to do about it? *Funct. Ecol.* 33, 118–128. <https://doi.org/10.1111/1365-2435.13232>
- Dechassa, N., Schenk, M. K. (2004). Exudation of organic anions by roots of cabbage, carrot, and potato as influenced by environmental factors and plant age. *Journal of Plant Nutrition and Soil Science*, 167(5), 623–629. doi: 10.1002/jpln.200420424
- Díaz, K., Espinoza, L., Madrid, A., Pizarro, L., Chamy, R., 2018. Isolation and identification of compounds from bioactive extracts of *Taraxacum officinale* Weber ex F. H. Wigg. (Dandelion) as a potential source of antibacterial agents. *Evid.-Based Complement. Altern. Med. ECAM* 2018, 2706417. <https://doi.org/10.1155/2018/2706417>
- Djoumbou Feunang, Y., Eisner, R., Knox, C., Chepelev, L., Hastings, J., Owen, G., ... , Wishart, D.S., 2016. ClassyFire: automated chemical classification with a comprehensive, computable taxonomy. *J. Cheminformatics* 8, 61. <https://doi.org/10.1186/s13321-016-0174-y>
- Dostál, P., Müllerová, J., Pyšek, P., Pergl, J., Klinerová, T. 2013. The impact of an invasive plant changes over time. *Ecology Letters*, 16(10), 1277–1284. doi: 10.1111/ele.12166
- Dostálek, T., Münzbergová, Z., Kladiřová, A., Macel, M., 2016. Plant–soil feedback in native vs. invasive populations of a range expanding plant. *Plant Soil* 399, 209–220. <https://doi.org/10.1007/s11104-015-2688-x>
- Dupont, P.-Y., Eaton, C.J., Wargent, J.J., Fechtner, S., Solomon, P., Schmid, J., Day, R.C., Scott, B., Cox, M.P., 2016. Fungal endophyte infection of ryegrass reprograms host metabolism and alters development. *New Phytologist* 208, 1227–1240. <https://doi.org/10.1111/nph.13614>

- Dyer, L. A., Philbin, C. S., Ochsenrider, K. M., Richards, L. A., Massad, T. J., Smilanich, A. M., ... Jeffrey, C. S., 2018. Modern approaches to study plant–insect interactions in chemical ecology. *Nature Reviews Chemistry*, 2(6), 50–64. doi: 10.1038/s41570-018-0009-7
- Ernst, M., Kang, K.B., Caraballo-Rodríguez, A.M., Nothias, L.-F., Wandy, J., Chen, C., ... , van der Hooft, J.J.J., 2019. MolNetEnhancer: enhanced molecular networks by integrating metabolome mining and annotation tools. *Metabolites* 9, 144. <https://doi.org/10.3390/metabo9070144>
- Etalo, D. W., Jeon, J.-S., Raaijmakers, J. M., 2018. Modulation of plant chemistry by beneficial root microbiota. *Natural Product Reports*, 35(5), 398–409. doi: 10.1039/C7NP00057J
- Ettema, C.H., Wardle, D.A., 2002. Spatial soil ecology. *Trends Ecol. Evol.* 17, 177–183. [https://doi.org/10.1016/S0169-5347\(02\)02496-5](https://doi.org/10.1016/S0169-5347(02)02496-5)
- Fernandez, O., Béthencourt, L., Quero, A., Sangwan, R.S., Clément, C., 2010. Trehalose and plant stress responses: friend or foe? *Trends Plant Sci* 15: 409–417. <https://doi.org/10.1016/j.tplants.2010.04.004>
- Ferreira, C.M.H., Soares, H.M.V.M., Soares, E.V., 2019. Promising bacterial genera for agricultural practices: An insight on plant growth-promoting properties and microbial safety aspects. *Sci. Total Environ.* 682, 779–799. <https://doi.org/10.1016/j.scitotenv.2019.04.225>
- Fichou, D., Ristivojević, P., Morlock, G.E., 2016. Proof-of-Principle of rTLC, an open-source software developed for image evaluation and multivariate analysis of planar chromatograms. *Anal. Chem.* 88, 12494–12501. <https://doi.org/10.1021/acs.analchem.6b04017>
- Fierer, N., 2017. Embracing the unknown: disentangling the complexities of the soil microbiome. *Nat. Rev. Microbiol.* 15, 579–590. <https://doi.org/10.1038/nrmicro.2017.87>
- Fierer, N., Jackson, R.B., 2006. The diversity and biogeography of soil bacterial communities. *Proc. Natl. Acad. Sci. U. S. A.* 103, 626–631. <https://doi.org/10.1073/pnas.0507535103>
- Forero, L.E., Grenzer, J., Heinze, J., Schittko, C., Kulmatiski, A., 2019. Greenhouse- and field-measured plant-soil feedbacks are not correlated. *Front. Environ. Sci.* 7. <https://doi.org/10.3389/fenvs.2019.00184>
- Galati, G., Gandin, A., Jolivet, Y., Larbat, R., Hehn, A., 2019. Untargeted Metabolomics Approach Reveals Diverse Responses of *Pastinaca Sativa* to Ozone and Wounding Stresses. *Metabolites* 9. <https://doi.org/10.3390/metabo9070153>
- Ge, Y., Sun, M., Salomé-Abarca, L.F., Wang, M., Choi, Y.H., 2018. Investigation of species and environmental effects on rhubarb roots metabolome using ¹H NMR combined with high performance thin layer chromatography. *Metabolomics Off. J. Metabolomic Soc.* 14, 137. <https://doi.org/10.1007/s11306-018-1421-1>
- González, I., Cao, K.-A. L., Davis, M. J., Déjean, S., 2012. Visualising associations between paired ‘omics’ data sets. *BioData Mining*, 5(1), 19. doi: 10.1186/1756-0381-5-19
- Gundale, M.J., Wardle, D.A., Kardol, P., Nilsson, M.-C., 2019. Comparison of plant–soil feedback experimental approaches for testing soil biotic interactions among ecosystems. *New Phytol.* 221, 577–587. <https://doi.org/10.1111/nph.15367>
- Gweon, H. S., Oliver, A., Taylor, J., Booth, T., Gibbs, M., Read, D. S., ... , Schonrogge, K., 2015. PIPITS: an automated pipeline for analyses of fungal internal transcribed spacer sequences from the Illumina sequencing platform. *Methods in Ecology and Evolution*, 6(8), 973–980. doi: 10.1111/2041-210X.12399
- Hagel, J.M., Mandal, R., Han, B., Han, J., Dinsmore, D.R., Borchers, C.H., ... , Facchini, P.J., 2015. Metabolome analysis of 20 taxonomically related benzyloquinoline alkaloid-producing plants. *BMC Plant Biol.* 15, 220. <https://doi.org/10.1186/s12870-015-0594-2>
- Hall, R.D., 2011. *Biology of Plant Metabolomics*. Wiley-Blackwell.
- Hannula, S.E., Kielak, A.M., Steinauer, K., Huberty, M., Jongen, R., Long, J.R.D., ... , Bezemer, T.M., 2019a. Time after Time: Temporal variation in the effects of grass and forb species on soil bacterial and fungal communities. *mBio* 10. <https://doi.org/10.1128/mBio.02635-19>
- Hannula, S.E., Zhu, F., Heinen, R., Bezemer, T.M., 2019b. Foliar-feeding insects acquire microbiomes from the soil rather than the host plant. *Nat. Commun.* 10, 1254. <https://doi.org/10.1038/s41467-019-09284-w>

- Hänsel, R., Kartarahardja, M., Huang, J.-T., Bohlmann, F., 1980. Sesquiterpenlacton- β -d-glucopyranoside sowie ein neues eudesmanolid aus *Taraxacum officinale*. *Phytochemistry* 19, 857–861. [https://doi.org/10.1016/0031-9422\(80\)85126-0](https://doi.org/10.1016/0031-9422(80)85126-0)
- Hanson, C.A., Fuhrman, J.A., Horner-Devine, M.C., Martiny, J.B.H., 2012. Beyond biogeographic patterns: processes shaping the microbial landscape. *Nat Rev Microbiol* 10: 497–506. <https://doi.org/10.1038/nrmicro2795>
- Hartmann, T., 1999 Chemical ecology of pyrrolizidine alkaloids. *Planta* 207: 483–495. <https://doi.org/10.1007/s004250050508>
- Hawkes, C., Kivlin, S., Du, J., Eviner, V., 2013. The temporal development and additivity of plant-soil feedback in perennial grasses. *Plant and Soil*, 369, 141–150.
- Heil, M., Bostock, R. M., 2002. Induced Systemic Resistance (ISR) against pathogens in the context of induced plant defences. *Annals of Botany*, 89(5), 503–512. doi: 10.1093/aob/mcf076
- Heinen, R., Biere, A., Bezemer, T.M., 2019. Plant traits shape soil legacy effects on individual plant–insect interactions. *Oikos n/a*, 1–13. <https://doi.org/10.1111/oik.06812>
- Heinen, R., Hannula, S.E., Long, J.R.D., Huberty, M., Jongen, R., Kielak, A., ... , Bezemer, T.M., 2020. Plant community composition steers grassland vegetation via soil legacy effects. *Ecol. Lett.* 23, 973–982. <https://doi.org/10.1111/ele.13497>
- Heinen, R., Sluijs, M., Biere, A., Harvey, J.A., Bezemer, T.M., 2018. Plant community composition but not plant traits determine the outcome of soil legacy effects on plants and insects. *J. Ecol.* 1217–1229. <https://doi.org/10.1111/1365-2745.12907>
- Hendriks, M., Visser, E.J.W., Visschers, I.G.S., Aarts, B.H.J., De Caluwe, H., Smit-Tiekstra, A.E., ... , Mommer, L., 2015. Root responses of grassland species to spatial heterogeneity of plant–soil feedback. *Funct. Ecol.* 29, 177–186. <https://doi.org/10.1111/1365-2435.12367>
- Hervé, M.R., Erb, M., 2019. Distinct defense strategies allow different grassland species to cope with root herbivore attack. *Oecologia* 191: 127–139. <https://doi.org/10.1007/s00442-019-04479-w>
- Hfaiedh, M., Brahmi, D., Zourgui, L., 2016. Hepatoprotective effect of *Taraxacum officinale* leaf extract on sodium dichromate-induced liver injury in rats. *Environ. Toxicol.* 31, 339–349. <https://doi.org/10.1002/tox.22048>
- Hill, E.M., Robinson, L.A., Abdul-Sada, A., Vanbergen, A.J., Hodge, A., Hartley, S.E., 2018. Arbuscular mycorrhizal fungi and plant chemical defence: effects of colonisation on aboveground and belowground metabolomes. *J Chem Ecol* 44: 198–208. <https://doi.org/10.1007/s10886-017-0921-1>
- Hol, W.H.G., 2011. The effect of nutrients on pyrrolizidine alkaloids in *Senecio* plants and their interactions with herbivores and pathogens. *Phytochem. Rev.* 10, 119–126. <https://doi.org/10.1007/s11101-010-9188-7>
- Houston, K., Tucker, M.R., Chowdhury, J., Shirley, N., Little, A., 2016. The plant cell wall: a complex and dynamic structure as revealed by the responses of genes under stress conditions. *Front. Plant Sci.* 7. <https://doi.org/10.3389/fpls.2016.00984>
- Hu, C., Kitts, D.D., 2003. Antioxidant, prooxidant, and cytotoxic activities of solvent-fractionated dandelion (*Taraxacum officinale*) flower extracts in vitro. *J. Agric. Food Chem.* 51, 301–310. <https://doi.org/10.1021/jf0258858>
- Hu, L., Robert, C.A.M., Cadot, S., Zhang, X., Ye, M., Li, B., ... , Erb, M., 2018. Root exudate metabolites drive plant-soil feedbacks on growth and defense by shaping the rhizosphere microbiota. *Nat. Commun.* 9, 2738. <https://doi.org/10.1038/s41467-018-05122-7>
- Huang, W., Bont, Z., Hervé, M. R., Robert, C. A. M., Erb, M., 2020. Impact of seasonal and temperature-dependent variation in root defense metabolites on herbivore preference in *Taraxacum officinale*. *Journal of Chemical Ecology*, 46(1), 63–75. doi: 10.1007/s10886-019-01126-9
- Huberty, M., Hae Choi, Y., Heinen, R., Bezemer, T.M., 2020b. Aboveground plant metabolomic responses to plant-soil feedbacks and herbivory. *Figshare*. doi: 10.6084/m9.figshare.8834537
- Huberty, M., Martis, B., van Kampen, J., Choi, Y.H., Vrieling, K., Klinkhamer, P.G.L., Bezemer, T.M., 2020a. Soil inoculation alters leaf metabolic profiles in genetically identical plants. *J. Chem. Ecol.* <https://doi.org/10.1007/s10886-020-01156-8>
- Hulten, M. van, Pelser, M., Van Loon, L.C., Pieterse, C.M.J., Ton, J., 2006. Costs and benefits of priming for defense in *Arabidopsis*. *Proc. Natl. Acad. Sci.* 103, 5602–5607. <https://doi.org/10.1073/pnas.0510213103>

- Inderjit, Wardle, D.A., Karban, R., Callaway, R.M., 2011. The ecosystem and evolutionary contexts of allelopathy. *Trends Ecol. Evol.* 26, 655–662. <https://doi.org/10.1016/j.tree.2011.08.003>
- Jayachandran Nair, C.V., Ahamad, S., Khan, W., Anjum, V., Mathur, R., 2017. Development and validation of High-performance Thin-layer Chromatography Method for Simultaneous Determination of Polyphenolic Compounds in Medicinal Plants. *Pharmacogn. Res.* 9, S67–S73. https://doi.org/10.4103/pr.pr_122_16
- Joosten, L., Mulder, P.P.J., Klinkhamer, P.G.L., Van Veen, J.A., 2009. Soil-borne microorganisms and soil-type affect pyrrolizidine alkaloids in *Jacobaea vulgaris*. *Plant Soil* 325, 133. <https://doi.org/10.1007/s11104-009-9963-7>
- Kanehisa, M., Goto, S., 2000. KEGG: Kyoto Encyclopedia of Genes and Genomes. *Nucleic Acids Res* 28(1): 27–30. <https://doi.org/10.1093/nar/28.1.27>
- Karban, R., Baldwin, I. T., 1997. Induced responses to herbivory. Chicago: Chicago University Press.
- Khare, E., Mishra, J., Arora, N.K., 2018. Multifaceted interactions between endophytes and plant: developments and prospects. *Front. Microbiol.* 9. <https://doi.org/10.3389/fmicb.2018.02732>
- Kim, H.K., Choi, Y.H., Verpoorte, R., 2010. NMR-based metabolomic analysis of plants. *Nat. Protoc.* 5, 536–549. <https://doi.org/10.1038/nprot.2009.237>
- Kleine, S., Müller, C., 2011. Intraspecific plant chemical diversity and its relation to herbivory. *Oecologia* 166: 175–186. <https://doi.org/10.1007/s00442-010-1827-6>
- Kos, M., Bukovinsky, T., Mulder, P. P., Bezemer, T. M., 2015a. Disentangling above-and belowground neighbor effects on the growth, chemistry, and arthropod community on a focal plant. *Ecology*, 96(1), 164–175. doi: 10.1890/14-0563.1
- Kos, M., Tuijl, M. A. B., De Roo, J., Mulder, P. P. J., Bezemer, T. M., 2015b. Plant–soil feedback effects on plant quality and performance of an aboveground herbivore interact with fertilisation. *Oikos*, 124(5), 658–667. doi: 10.1111/oik.01828
- Kos, M., Tuijl, M. A. B., De Roo, J., Mulder, P. P. J., Bezemer, T. M., 2015c. Species-specific plant–soil feedback effects on above-ground plant–insect interactions. *Journal of Ecology*, 103(4), 904–914. doi: 10.1111/1365-2745.12402
- Kostenko, O., Bezemer, T.M., 2013 a. Intraspecific variation in plant size, secondary plant compounds, herbivory and parasitoid assemblages during secondary succession. *Basic Appl. Ecol.* 14, 337–346. <https://doi.org/10.1016/j.baae.2013.02.006>
- Kostenko, O., Mulder, P.P.J., Bezemer, T.M., 2013 b. Effects of root herbivory on pyrrolizidine alkaloid content and aboveground plant-herbivore-parasitoid interactions in *Jacobaea vulgaris*. *J Chem Ecol* 39: 109–119. <https://doi.org/10.1007/s10886-012-0234-3>
- Kostenko, O., van de Voorde, T. F. J., Mulder, P. P. J., van der Putten, W. H., Bezemer, T. M., 2012. Legacy effects of aboveground-belowground interactions. *Ecology Letters*, 15(8), 813–821. doi: 10.1111/j.1461-0248.2012.01801.x
- Kuhlisch, C., Pohnert, G., 2015. Metabolomics in chemical ecology. *Nat. Prod. Rep.* 32, 937–955. <https://doi.org/10.1039/C5NP00003C>
- Kulmatiski, A., Beard, K. H., Heavilin, J., 2012. Plant–soil feedbacks provide an additional explanation for diversity–productivity relationships. *Proceedings of the Royal Society of London B: Biological Sciences*, 279(1740), 3020–3026. doi: 10.1098/rspb.2012.0285
- Kulmatiski, A., Beard, K. H., Stevens, J. R., Cobbold, S. M., 2008. Plant–soil feedbacks: A meta-analytical review. *Ecology Letters*, 11, 980–992. <https://doi.org/10.1111/j.1461-0248.2008.01209.x>
- Kusano, M., Redestig, H., Hirai, T., Oikawa, A., Matsuda, F., Fukushima, A., . . . , Saito, K., 2011. Covering chemical diversity of genetically-modified tomatoes using metabolomics for objective substantial equivalence assessment. *PLOS ONE* 6, e16989. <https://doi.org/10.1371/journal.pone.0016989>
- Kuzina, V., Ekstrøm, C.T., Andersen, S.B., Nielsen, J.K., Olsen, C.E., Bak, S., 2009. Identification of defense compounds in *Barbarea vulgaris* against the herbivore *Phyllotreta nemorum* by an ecometabolomic approach. *Plant Physiol.* 151, 1977–1990. <https://doi.org/10.1104/pp.109.136952>
- Latz, E., Eisenhauer, N., Rall, B.C., Allan, E., Roscher, C., Scheu, S., Jousset, A., 2012. Plant diversity improves protection against soil-borne pathogens by fostering antagonistic bacterial communities. *J. Ecol.* 100, 597–604. <https://doi.org/10.1111/j.1365-2745.2011.01940.x>

- Latz, E., Eisenhauer, N., Rall, B.C., Scheu, S., Jousset, A., 2016. Unravelling linkages between plant community composition and the pathogen-suppressive potential of soils. *Sci. Rep.* 6, 23584. <https://doi.org/10.1038/srep23584>
- Latz, E., Eisenhauer, N., Scheu, S., Jousset, A., 2015. Plant identity drives the expression of biocontrol factors in a rhizosphere bacterium across a plant diversity gradient. *Funct. Ecol.* 29, 1225–1234. <https://doi.org/10.1111/1365-2435.12417>
- Lauber, C.L., Ramirez, K.S., Aanderud, Z., Lennon, J., Fierer, N., 2013. Temporal variability in soil microbial communities across land-use types. *ISME J.* 7, 1641–1650. <https://doi.org/10.1038/ismej.2013.50>
- Lepinay, C., Vondráková, Z., Dostálek, T., Münzbergová, Z., 2018. Duration of the conditioning phase affects the results of plant-soil feedback experiments via soil chemical properties. *Oecologia* 186, 459–470. <https://doi.org/10.1007/s00442-017-4033-y>
- Li, X.-Z., Starratt, A. N., Cuppels, D. A., 1998. Identification of tomato leaf factors that activate toxin gene expression in *Pseudomonas syringae* pv. *tomato* DC3000. *Phytopathology*, 88(10), 1094–1100. doi: 10.1094/PHYTO.1998.88.10.1094
- Liseč, J., Meyer, R.C., Steinfath, M., Redestig, H., Becher, M., Witucka-Wall, H., Fiehn, O., ... , Willmitzer, L., 2008. Identification of metabolic and biomass QTL in *Arabidopsis thaliana* in a parallel analysis of RIL and IL populations. *Plant Journal* 53: 960–972. <https://doi.org/10.1111/j.1365-313X.2007.03383.x>
- Liu, L., Xiong, H., Ping, J., Ju, Y., Zhang, X., 2010. *Taraxacum officinale* protects against lipopolysaccharide-induced acute lung injury in mice. *J. Ethnopharmacol.* 130, 392–397. <https://doi.org/10.1016/j.jep.2010.05.029>
- Liu, X., Vrieling, K., Klinkhamer, P.G.L., 2017. Interactions between Plant Metabolites Affect Herbivores: A Study with Pyrrolizidine Alkaloids and Chlorogenic Acid. *Front. Plant Sci.* 8, 1–14. <https://doi.org/10.3389/fpls.2017.00903>
- Loewus, F.A., Murthy, P.P.N., 2000. Myo-Inositol metabolism in plants. *Plant Sci.* 150, 1–19. [https://doi.org/10.1016/S0168-9452\(99\)00150-8](https://doi.org/10.1016/S0168-9452(99)00150-8)
- Lundberg, D.S., Lebeis, S.L., Paredes, S.H., Yourstone, S., Gehring, J., Malfatti, S., Tremblay, ... , Dangl, J.L., 2012. Defining the core *Arabidopsis thaliana* root microbiome. *Nature* 488, 86–90. <https://doi.org/10.1038/nature11237>
- Ma, H., Pineda, A., van der Wurff, A.W.G., Bezemer, T.M., 2018. Carry-over effects of soil inoculation on plant growth and health under sequential exposure to soil-borne diseases. *Plant Soil*. <https://doi.org/10.1007/s11104-018-3837-9>
- Ma, H., Pineda, A., van der Wurff, A.W.G., Raaijmakers, C., Bezemer, T.M., 2017. Plant–soil feedback effects on growth, defense and susceptibility to a soil-borne disease in a cut flower crop: species and functional group effects. *Front. Plant Sci.* 8, 2127. <https://doi.org/10.3389/fpls.2017.02127>
- Macel, M., 2011. Attract and deter: a dual role for pyrrolizidine alkaloids in plant–insect interactions. *Phytochem Rev* 10: 75–82. <https://doi.org/10.1007/s11101-010-9181-1>
- Mahmood, A., Kataoka, R., 2020. Metabolite profiling reveals a complex response of plants to application of plant growth-promoting endophytic bacteria. *Microbiol. Res.* 234, 126421. <https://doi.org/10.1016/j.micres.2020.126421>
- Maldini, M., D'Urso, G., Pagliuca, G., Petretto, G.L., Foddai, M., Gallo, F.R., ... , Pintore, G., 2019. HPTLC-PCA complementary to hrms-pca in the case study of *Arbutus unedo* antioxidant phenolic profiling. *Foods* 8. <https://doi.org/10.3390/foods8080294>
- Marti, G., Erb, M., Boccard, J., Glauser, G., Doyen, G.R., Villard, ... , Wolfender, J.-L., 2013. Metabolomics reveals herbivore-induced metabolites of resistance and susceptibility in maize leaves and roots. *Plant Cell Environ.* 36, 621–639. <https://doi.org/10.1111/pce.12002>
- Martinez, A., 2017. pairwiseAdonis: Pairwise multilevel comparison using adonis. R 542 package version 0.0.1.
- Martinez-Medina, A., Flors, V., Heil, M., Mauch-Mani, B., Pieterse, C. M. J., Pozo, M. J., ... , Conrath, U., 2016. Recognizing plant defense priming. *Trends in Plant Science*, 21(10), 818–822. doi: 10.1016/j.tplants.2016.07.009
- Mazzoleni, S., Bonanomi, G., Incerti, G., Chiusano, M.L., Termolino, P., Mingo, A., Senatore, M., ... , Lanzotti, V., 2015. Inhibitory and toxic effects of extracellular self-DNA in litter: a mechanism for negative plant–soil feedbacks? *New Phytol.* 205, 1195–1210. <https://doi.org/10.1111/nph.13121>
- Micallef, S. A., Channer, S., Shiaris, M. P., Colón-Carmona, A., 2009. Plant age and genotype impact the progression of bacterial community succession in the *Arabidopsis* rhizosphere. *Plant Signaling & Behavior*, 4(8), 777–780. doi: 10.4161/psb.4.8.9229

- Mills, K.E., Bever, J.D., 1998. Maintenance of diversity within plant communities: soil pathogens as agents of negative feedback. *Ecology* 79, 1595–1601. [https://doi.org/10.1890/0012-9658\(1998\)079\[1595:MODWPC\]2.0.CO;2](https://doi.org/10.1890/0012-9658(1998)079[1595:MODWPC]2.0.CO;2)
- Moghe, G.D., Last, R.L., 2015. Something old, something new: conserved enzymes and the evolution of novelty in plant specialized metabolism. *Plant Physiol.* 169, 1512–1523. <https://doi.org/10.1104/pp.15.00994>
- Morlock, G.E., Ristivojevic, P., Chernetsova, E.S., 2014. Combined multivariate data analysis of high-performance thin-layer chromatography fingerprints and direct analysis in real time mass spectra for profiling of natural products like propolis. *J. Chromatogr. A* 1328, 104–112. <https://doi.org/10.1016/j.chroma.2013.12.053>
- Nagler, M., Nägele, T., Gilli, C., Fragner, L., Korte, A., Platzer, ... , Weckwerth, W., 2018. Eco-metabolomics and metabolic modeling: making the leap from model systems in the lab to native populations in the field. *Front. Plant Sci.* 9. <https://doi.org/10.3389/fpls.2018.01556>
- Nelson, A.C., Kursar, T.A., 1999. Interactions among plant defense compounds: a method for analysis. *Chemoecology* 9, 81–92. <https://doi.org/10.1007/s000490050037>
- Nijjer, S., Rogers, W.E., Siemann, E., 2007. Negative plant–soil feedbacks may limit persistence of an invasive tree due to rapid accumulation of soil pathogens. *Proc. R. Soc. Lond. B Biol. Sci.* 274, 2621–2627. <https://doi.org/10.1098/rspb.2007.0804>
- Nilsson, R. H., Larsson, K.-H., Taylor, A. F. S., Bengtsson-Palme, J., Jeppesen, T. S., Schigel, D., ... Abarenkov, K., 2019. The UNITE database for molecular identification of fungi: handling dark taxa and parallel taxonomic classifications. *Nucleic Acids Research*, 47(D1), D259–D264. doi: 10.1093/nar/gky1022
- O'Brien, S.L., Gibbons, S.M., Owens, S.M., Hampton-Marcell, J., Johnston, E.R., Jastrow, J.D., ... , Antonopoulos, D.A., 2016. Spatial scale drives patterns in soil bacterial diversity. *Environ. Microbiol.* 18, 2039–2051. <https://doi.org/10.1111/1462-2920.13231>
- Oda, Y., Star, B., Huisman, L.A., Gottschal, J.C., Forney, L.J., 2003. Biogeography of the purple nonsulfur bacterium *Rhodospseudomonas palustris*. *Appl Environ Microbiol* 69: 5186–5191. <https://doi.org/10.1128/AEM.69.9.5186-5191.2003>
- Ogegbo, O.L., Eyob, S., Parmar, S., Wang, Z.-T., Bligh, S.W.A., 2012. Metabolomics of four TCM herbal products: application of HPTLC analysis. *Anal. Methods* 4, 2522–2527. <https://doi.org/10.1039/C2AY25373A>
- Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., ... , Wagner, H., 2018. vegan: Community Ecology Package. R package version 2.5-2. <https://CRAN.R-project.org/package=vegan>.
- Olanrewaju, O. S., Babalola, O. O. 2019. Streptomyces: implications and interactions in plant growth promotion. *Applied Microbiology and Biotechnology*, 103(3), 1179–1188. doi: 10.1007/s00253-018-09577-y
- Oliverio, A.M., Bradford, M.A., Fierer, N., 2017. Identifying the microbial taxa that consistently respond to soil warming across time and space. *Glob. Change Biol.* 23, 2117–2129. <https://doi.org/10.1111/gcb.13557>
- Pandey, S.S., Singh, S., Babu, C.S.V., Shanker, K., Srivastava, N.K., Shukla, A.K., Kalra, A., 2016. Fungal endophytes of *Catharanthus roseus* enhance vindoline content by modulating structural and regulatory genes related to terpenoid indole alkaloid biosynthesis. *Scientific Reports* 6, 26583. <https://doi.org/10.1038/srep26583>
- Pangesti, N., Weldegergis, B.T., Langendorf, B., Van Loon, J.J.A., Dicke, M., Pineda, A., 2015. Rhizobacterial colonization of roots modulates plant volatile emission and enhances the attraction of a parasitoid wasp to host-infested plants. *Oecologia* 178, 1169–1180. <https://doi.org/10.1007/s00442-015-3277-7>
- Papazian, S., Girdwood, T., Wessels, B.A., Poelman, E.H., Dicke, M., Moritz, T., Albrechtsen, B.R., 2019. Leaf metabolic signatures induced by real and simulated herbivory in black mustard (*Brassica nigra*). *Metabolomics* 15, 130. <https://doi.org/10.1007/s11306-019-1592-4>
- Parada, A. E., Needham, D. M., Fuhrman, J. A., 2016. Every base matters: assessing small subunit rRNA primers for marine microbiomes with mock communities, time series and global field samples. *Environmental Microbiology*, 18(5), 1403–1414. doi: 10.1111/1462-2920.13023
- Patterson, D.T., 1995. Effects of environmental stress on weed/crop interactions. *Weed Sci.* 43, 483–490. <https://doi.org/10.1017/S0043174500081510>
- Peñuelas, J., Sardans, J., 2009. Ecological metabolomics. *Chem. Ecol.* 25, 305–309. <https://doi.org/10.1080/02757540903062517>

- Petermann, J.S., Fergus, A.J.F., Turnbull, L.A., Schmid, B., 2008. Janzen-connell effects are widespread and strong enough to maintain diversity in grasslands. *Ecology* 89, 2399–2406. <https://doi.org/10.1890/07-2056.1>
- Peters, K., Gorzolk, K., Bruelheide, H., Neumann, S., 2018. Seasonal variation of secondary metabolites in nine different bryophytes. *Ecology and Evolution*, 8(17), 9105–9117. doi: 10.1002/ece3.4361
- Peters, K., Worrich, A., Weinhold, A., Alka, O., Balcke, G., Birkemeyer, C., Bruelheide, H., ... , Van Dam, N.M., 2018. Current challenges in plant eco-metabolomics. *Int. J. Mol. Sci.* 19, 1385. <https://doi.org/10.3390/ijms19051385>
- Pichersky, E., Lewinsohn, E., 2011. Convergent evolution in plant specialized metabolism. *Annu. Rev. Plant Biol.* 62, 549–566. <https://doi.org/10.1146/annurev-arplant-042110-103814>
- Pieterse, C. M. J., Wees, S. C. M. Van, Pelt, J. A. Van, Knoester, M., Laan, R., Gerrits, H., ... Van Loon, L. C., 1998. A novel signaling pathway controlling induced systemic resistance in *Arabidopsis*. *The Plant Cell*, 10(9), 1571–1580. doi: 10.1105/tpc.10.9.1571
- Pieterse, C. M. J., Zamioudis, C., Berendsen, R. L., Weller, D. M., Van Wees, S. C. M., Bakker, P. A. H. M., 2014. Induced systemic resistance by beneficial microbes. *Annual Review of Phytopathology*, 52(1), 347–375. doi: 10.1146/annurev-phyto-082712-102340
- Pineda, A., Kaplan, I., Bezemer, T.M., 2017. Steering soil microbiomes to suppress aboveground insect pests. *Trends Plant Sci.* 22, 770–778. <https://doi.org/10.1016/j.tplants.2017.07.002>
- Pineda, A., Kaplan, I., Hannula, S.E., Ghanem, W., Bezemer, T.M., 2020. Conditioning the soil microbiome through plant–soil feedbacks suppresses an aboveground insect pest. *New Phytol.* n/a. <https://doi.org/10.1111/nph.16385>
- Pineda, A., Zheng, S.-J., Van Loon, J.J.A., Pieterse, C.M.J., Dicke, M., 2010. Helping plants to deal with insects: the role of beneficial soil-borne microbes. *Trends Plant Sci.* 15, 507–514. <https://doi.org/10.1016/j.tplants.2010.05.007>
- Quast, C., Pruesse, E., Yilmaz, P., Gerken, J., Schweer, T., Yarza, P., ... Glöckner, F. O., 2013. The SILVA ribosomal RNA gene database project: improved data processing and web-based tools. *Nucleic Acids Research*, 41(D1), D590–D596. doi: 10.1093/nar/gks1219
- Ramos, A.E.F., Evanno, L., Poupon, E., Champy, P., Beniddir, M.A., 2019. Natural products targeting strategies involving molecular networking: different manners, one goal. *Nat. Prod. Rep.* 36, 960–980. <https://doi.org/10.1039/C9NP00006B>
- Ratcliffe, R.G., Shachar-Hill, Y., 2001. Probing plant metabolism with NMR. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 52, 499–526. <https://doi.org/10.1146/annurev.arplant.52.1.499>
- Reynolds, H.L., Packer, A., Bever, J.D., Clay, K., 2003. Grassroots Ecology: Plant–microbe–soil interactions as drivers of plant community structure and dynamics. *ecology* 84, 2281–2291. <https://doi.org/10.1890/02-0298>
- Ristok, C., Poeschl, Y., Dudenhöffer, J.-H., Ebeling, A., Eisenhauer, N., Vergara, F., ... , Weinhold, A., 2019. Plant species richness elicits changes in the metabolome of grassland species via soil biotic legacy. *J. Ecol.* 0. <https://doi.org/10.1111/1365-2745.13185>
- Rojas, J.C., Wyatt, T.D., Birch, M.C., 2000. flight and oviposition behavior toward different host plant species by the cabbage moth, *Mamestra brassicae* (L.) (Lepidoptera: Noctuidae). *J. Insect Behav.* 13, 247–254. <https://doi.org/10.1023/A:1007792332046>
- RStudio Team. 2016. RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL <http://www.rstudio.com/>.
- Rudrappa, T., Czymbek, K.J., Paré, P.W., Bais, H.P., 2008. Root-secreted malic acid recruits beneficial soil bacteria. *Plant Physiol* 148: 1547–1556. <https://doi.org/10.1104/pp.108.127613>
- Ryu, S.B., Wang, X., 1996. Activation of phospholipase D and the possible mechanism of activation in wound-induced lipid hydrolysis in castor bean leaves. *Biochim. Biophys. Acta BBA - Lipids Lipid Metab.* 1303, 243–250. [https://doi.org/10.1016/0005-2760\(96\)00096-3](https://doi.org/10.1016/0005-2760(96)00096-3)
- Saeed, A.I., Sharov, V., White, J., Li, J., Liang, W., Bhagabati, N., ... Quackenbush J. 2003 TM4: a free, open-source system for microarray data management and analysis. *Biotechniques*. 34(2):374–8. <https://doi.org/10.2144/03342mt01>
- Salomé-Abarca, L.F., van der Pas, J., Kim, H.K., van Uffelen, G.A., Klinkhamer, P.G.L., Choi, Y.H., 2018. Metabolic discrimination of pine resins using multiple analytical platforms. *Phytochemistry* 155, 37–44. <https://doi.org/10.1016/j.phytochem.2018.07.011>

- Sampaio, B. L., Edrada-Ebel, R., Costa, F. B. D. 2016. Effect of the environment on the secondary metabolic profile of *Tithonia diversifolia*: a model for environmental metabolomics of plants. Scientific Reports, 6, 29265. doi: 10.1038/srep29265
- Sardans, J., Peñuelas, J., Rivas-Ubach, A., 2011. Ecological metabolomics: overview of current developments and future challenges. Chemoecology 21, 191–225. <https://doi.org/10.1007/s00049-011-0083-5>
- Scherling, C., Ulrich, K., Ewald, D., Weckwerth, W., 2009. A Metabolic Signature of the Beneficial Interaction of the Endophyte *Paenibacillus* sp. Isolate and In Vitro–Grown Poplar Plants Revealed by Metabolomics. MPMI 22, 1032–1037. <https://doi.org/10.1094/MPMI-22-8-1032>
- Schulze, E.D., 1986. Whole-plant responses to drought. Funct. Plant Biol. 13, 127–141. <https://doi.org/10.1071/pp9860127>
- Schütz, K., Carle, R., Schieber, A., 2006. Taraxacum--a review on its phytochemical and pharmacological profile. J. Ethnopharmacol. 107, 313–323. <https://doi.org/10.1016/j.jep.2006.07.021>
- Schweiger, R., Baier, M.C., Persicke, M., Müller, C., 2014. High specificity in plant leaf metabolic responses to arbuscular mycorrhiza. Nat. Commun. 5, 3886. <https://doi.org/10.1038/ncomms4886>
- Shannon, P., Markiel, A., Ozier, O., Baliga, N.S., Wang, J.T., Ramage, D., Amin, N., Schwikowski, B., Ideker, T., 2003. Cytoscape: a software environment for integrated models of biomolecular interaction networks. Genome Res. 13, 2498–2504. <https://doi.org/10.1101/gr.1239303>
- Šmilauer, P., Lepš, J., 2014. Multivariate analysis of ecological data using CANOCO 5 by Petr Šmilauer. Cambridge Core. <https://doi.org/10.1017/CBO9781139627061>
- Smith-Ramesh, L.M., Reynolds, H.L., 2017. The next frontier of plant–soil feedback research: unraveling context dependence across biotic and abiotic gradients. J. Veg. Sci. n/a-n/a. <https://doi.org/10.1111/jvs.12519>
- Speek, T. A. A., Schaminée, J. H. J., Stam, J. M., Lotz, L. A. P., Ozinga, W. A., van der Putten, W. H. (2015). Local dominance of exotic plants declines with residence time: a role for plant–soil feedback? AoB PLANTS, 7. doi: 10.1093/aobpla/plv021
- Steinbrenner, A.D., Gómez, S., Osorio, S., Fernie, A.R., Orians, C.M., 2011. Herbivore-induced Changes in Tomato (*Solanum lycopersicum*) Primary Metabolism: A Whole Plant Perspective. J. Chem. Ecol. 37, 1294–1303. <https://doi.org/10.1007/s10886-011-0042-1>
- Stobiecki, M., Kachlicki, P., 2005. Metabolomics and metabolite profiling — can we achieve the goal? Acta Physiol. Plant. 27, 109–116. <https://doi.org/10.1007/s11738-005-0043-1>
- Tautenhahn, R., Patti, G.J., Rinehart, D., Siuzdak, G., 2012. XCMS Online: A web-based platform to process untargeted metabolomic data. Anal. Chem. 84, 5035–5039. <https://doi.org/10.1021/ac300698c>
- Tedersoo, L., Anslan, S., Bahram, M., Polme, S., Riit, T., Liiv, I., ... Abarenkov, K. (2015). Shotgun metagenomes and multiple primer pair-barcode combinations of amplicons reveal biases in metabarcoding analyses of fungi. MycoKeys, (10), 1–43.
- Thorpe, W.H., Crombie, A.C., Hill, R., Darrah, J.H., 1947. The behaviour of wireworms in response to chemical stimulation. J Exp Biol 23: 234–266.
- Thorsteinson, A.J., Nayar, J.K., 1963. Plant phospholipids as feeding stimulants for grasshoppers. Can. J. Zool. 41, 931–935. <https://doi.org/10.1139/z63-067>
- Tikunov, Y.M., Vos, R.C.H. de, Paramás, A.M.G., Hall, R.D., Bovy, A.G., 2010. A role for differential glycoconjugation in the emission of phenylpropanoid volatiles from tomato fruit discovered using a metabolic data fusion approach. Plant Physiol. 152, 55–70. <https://doi.org/10.1104/pp.109.146670>
- Van Dam, N.M., Oomen, M.W.A.T., 2008. Root and shoot jasmonic acid applications differentially affect leaf chemistry and herbivore growth. Plant Signal. Behav. 3, 91–98. <https://doi.org/10.4161/psb.3.2.5220>
- Van Dam, N.M., Van der Meijden, E., 2011. A role for metabolomics in plant ecology, in: Annual Plant Reviews Volume 43. John Wiley & Sons, Ltd, pp. 87–107. <https://doi.org/10.1002/9781444339956.ch4>

- Van Dam, N.M., Vuister, L.W.M., Bergshoeff, C., de Vos, H., Van Der Meijden, E., 1995. The “Raison D’être” of pyrrolizidine alkaloids in *Cynoglossum officinale*: Deterrent effects against generalist herbivores. *J Chem Ecol* 21: 507–523. <https://doi.org/10.1007/BF02033698>
- Van de Mortel, J.E., De Vos, R.C.H., Dekkers, E., Pineda, A., Guillod, L., Bouwmeester, K., Van Loon, J.J.A., ... , Raaijmakers, J.M., 2012. Metabolic and transcriptomic changes induced in *Arabidopsis* by the rhizobacterium *Pseudomonas fluorescens* SS1011[W][OA]. *Plant Physiol* 160: 2173–2188. <https://doi.org/10.1104/pp.112.207324>
- Van de Voorde, T. F. J., Van der Putten, W. H., & Bezemer, T. M., 2011. Intra- and interspecific plant–soil interactions, soil legacies and priority effects during old-field succession. *Journal of Ecology*, 99(4), 945–953. doi: 10.1111/j.1365-2745.2011.01815.x
- Van de Voorde, T.F.J., Ruijten, M., Van der Putten, W.H., Bezemer, T.M., 2012. Can the negative plant–soil feedback of *Jacobaea vulgaris* be explained by autotoxicity? *Basic Appl. Ecol.* 13, 533–541. <https://doi.org/10.1016/j.baec.2012.08.012>
- Van de Voorde, T.F.J., Van der Putten, W.H., Bezemer, T.M., 2011. Intra- and interspecific plant–soil interactions, soil legacies and priority effects during old-field succession. *J. Ecol.* 99, 945–953. <https://doi.org/10.1111/j.1365-2745.2011.01815.x>
- van de Voorde, T.F.J., van der Putten, W.H., Bezemer, T.M., 2012. The importance of plant–soil interactions, soil nutrients, and plant life history traits for the temporal dynamics of *Jacobaea vulgaris* in a chronosequence of old-fields. *Oikos* 121, 1251–1262. <https://doi.org/10.1111/j.1600-0706.2011.19964.x>
- Van der Heijden, M.G.A., Bardgett, R.D., Van Straalen, N.M., 2008. The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. *Ecol. Lett.* 11, 296–310. <https://doi.org/10.1111/j.1461-0248.2007.01139.x>
- Van der Putten, W.H., Bardgett, R.D., Bever, J.D., Bezemer, T.M., Casper, B.B., Fukami, T., Kardol, P., Klironomos, ... , Wardle, D.A., 2013. Plant-soil feedbacks: the past, the present and future challenges. *J. Ecol.* 101, 265–276. <https://doi.org/10.1111/1365-2745.12054>
- Van der Putten, W.H., Bradford, M.A., Pernilla Brinkman, E., Van de Voorde, T.F.J., Van Veen, G.F., 2016. Where, when and how plant–soil feedback matters in a changing world. *Funct. Ecol.* n/a-n/a. <https://doi.org/10.1111/1365-2435.12657>
- Van der Putten, W.H., Van Dijk, C., Peters, B. a. M., 1993. Plant-specific soil-borne diseases contribute to succession in foredune vegetation. *Nature* 362, 53–56. <https://doi.org/10.1038/362053a0>
- Van Loon, L. C., Bakker, P. A. H. M., Pieterse, C. M. J., 1998. Systemic resistance induced by rhizosphere bacteria. *Annual Review of Phytopathology*, 36(1), 453–483. doi: 10.1146/annurev.phyto.36.1.453
- Van Oosten, V.R., Bodenhausen, N., Reymond, P., Van Pelt, J.A., Van Loon, L.C., Dicke, M., Pieterse, C.M.J., 2008. Differential effectiveness of microbially induced resistance against herbivorous insects in *Arabidopsis*. *Mol. Plant-Microbe Interact.* MPMI 21, 919–930. <https://doi.org/10.1094/MPMI-21-7-0919>
- Vandenkoornhuyse, P., Quaiser, A., Duhamel, M., Van, A.L., Dufresne, A., 2015. The importance of the microbiome of the plant holobiont. *New Phytol.* 206, 1196–1206. <https://doi.org/10.1111/nph.13312>
- Verpoorte, R., Choi, Y. H., Kim, H. K. 2007. NMR-based metabolomics at work in phytochemistry. *Phytochemistry Reviews*, 6(1), 3–14. doi: 10.1007/s11101-006-9031-3
- Viaene, T., Langendries, S., Beirinckx, S., Maes, M., Goormachtig, S. 2016. *Streptomyces* as a plant’s best friend? *FEMS Microbiology Ecology*, 92(8). doi: 10.1093/femsec/fiw119
- Vickery, M.L., Vickery, B., 1981. Secondary plant metabolism. *Second. Plant Metab.*
- Vílchez J.I., García-Fontana, C., Román-Naranjo, D., González-López, J., Manzanera, M., 2016. Plant drought tolerance enhancement by trehalose production of desiccation-tolerant microorganisms. *Front Microbiol* 7. <https://doi.org/10.3389/fmicb.2016.01577>
- Vivanco, J.M., Bais, H.P., Stermitz, F.R., Thelen, G.C., Callaway, R.M., 2004. Biogeographical variation in community response to root allelochemistry: novel weapons and exotic invasion. *Ecol. Lett.* 7, 285–292. <https://doi.org/10.1111/j.1461-0248.2004.00576.x>
- Vos, M., Wolf, A.B., Jennings, S.J., Kowalchuk, G.A., 2013. Micro-scale determinants of bacterial diversity in soil. *FEMS Microbiol Rev* 37: 936–954. <https://doi.org/10.1111/1574-6976.12023>

- Vrieling, K., Soldaat, L.L., Smit, W., 1990 The influence of pyrrolizidine alkaloids of *Senecio Jacobaea* on *Tyria Jacobaeae*, *Brachycaudus Cardii* and *Haplothrips Senecionis*. *Neth J Zool* 41: 228–239. <https://doi.org/10.1163/156854291X00162>
- Vurukonda, S.S.K.P., Vardharajula, S., Shrivastava, M., SkZ, A., 2016. Enhancement of drought stress tolerance in crops by plant growth promoting rhizobacteria. *Microbiol. Res.* 184, 13–24. <https://doi.org/10.1016/j.micres.2015.12.003>
- Wagner, H., Bladt, S., Zgainski, E.M., 1984. *Plant drug analysis*, ISBN 0-387-13195-7.
- Walling, L.L., 2000. The myriad plant responses to herbivores. *J. Plant Growth Regul.* 19, 195–216. <https://doi.org/10.1007/s003440000026>
- Wang, J., Zhang, T., Li, L., Li, J., Feng, Y., Lu, Q., 2017. The patterns and drivers of bacterial and fungal β -diversity in a typical dryland ecosystem of northwest China. *Front Microbiol* 8: 2126. <https://doi.org/10.3389/fmicb.2017.02126>
- Wang, M., Carver, J.J., Phelan, V.V., Sanchez, L.M., Garg, N., Peng, Y., ... , Bandeira, N., 2016. Sharing and community curation of mass spectrometry data with Global Natural Products Social Molecular Networking. *Nat. Biotechnol.* 34, 828–837. <https://doi.org/10.1038/nbt.3597>
- Wang, M., De Deyn, G.B., Bezemer, T.M., 2019a Separating effects of soil microorganisms and nematodes on plant community dynamics. *Plant Soil* 441: 455–467. <https://doi.org/10.1007/s11104-019-04137-3>
- Wang, M., Ruan, W., Kostenko, O., Carvalho, S., Hannula, S.E., Mulder, P.P.J., Bu, F., Van der Putten, W.H., Bezemer, T.M., 2019b Removal of soil biota alters soil feedback effects on plant growth and defense chemistry. *New Phytol* 221: 1478–1491. <https://doi.org/10.1111/nph.15485>
- Warashina, T., Umehara, K., Miyase, T., 2012. Constituents from the roots of *Taraxacum platycarpum* and their effect on proliferation of human skin fibroblasts. *Chem. Pharm. Bull. (Tokyo)* 60, 205–212. <https://doi.org/10.1248/cpb.60.205>
- Wardle, D. A., Bardgett, R. D., Klironomos, J. N., Setälä, H., Van der Putten, W. H., Wall, D. H., 2004. Ecological linkages between aboveground and belowground Biota. *Science*, 304(5677), 1629–1633. doi: 10.1126/science.1094875
- Waring, B.G., Álvarez-Cansino, L., Barry, K.E., Becklund, K.K., Dale, S., Gei, M.G., ... , Schnitzer, S.A., Powers, J.S., 2015. Pervasive and strong effects of plants on soil chemistry: a meta-analysis of individual plant ‘Zinke’ effects. *Proc. R. Soc. B Biol. Sci.* 282. <https://doi.org/10.1098/rspb.2015.1001>
- Weng, J.-K., Philippe, R.N., Noel, J.P., 2012. The rise of chemodiversity in plants. *Science* 336, 1667–1670. <https://doi.org/10.1126/science.1217411>
- Widarto, H. T., Van Der Meijden, E., Lefeber, A. W. M., Erkelens, C., Kim, H. K., Choi, Y. H., Verpoorte, R., 2006. Metabolomic differentiation of *Brassica rapa* following herbivory by different insect instars using two-dimensional nuclear magnetic resonance spectroscopy. *Journal of Chemical Ecology*, 32(11), 2417–2428. doi: 10.1007/s10886-006-9152-6
- Williams, C.A., Goldstone, F., Greenham, J., 1996. Flavonoids, cinnamic acids and coumarins from the different tissues and medicinal preparations of *Taraxacum officinale*. *Phytochemistry* 42, 121–127. [https://doi.org/10.1016/0031-9422\(95\)00865-9](https://doi.org/10.1016/0031-9422(95)00865-9)
- Wubs, E. R. J., Bezemer, T. M., 2016. Effects of spatial plant–soil feedback heterogeneity on plant performance in monocultures. *Journal of Ecology*, 104(2), 364–376. doi: 10.1111/1365-2745.12521
- Wubs, E. R. J., Bezemer, T. M., 2018. Temporal carry-over effects in sequential plant–soil feedbacks. *Oikos*, 127(2), 220–229. doi: 10.1111/oik.04526
- Xue P.-P., Carrillo Y., Pino V., Minasny B., McBratney A.B., 2018. Soil properties drive microbial community structure in a large scale transect in south eastern Australia. *Sci Rep* 8: 1–11. <https://doi.org/10.1038/s41598-018-30005-8>
- Xue, W., Bezemer, T. M., Berendse, F., 2018. Density-dependency and plant-soil feedback: former plant abundance influences competitive interactions between two grassland plant species through plant-soil feedbacks. *Plant and Soil*, 428(1), 441–452. doi: 10.1007/s11104-018-3690-x

- Zhang, K., Delgado-Baquerizo, M., Zhu, Y.-G., Chu, H., 2020. Space is more important than season when shaping soil microbial communities at a large spatial scale. *mSystems* 5. <https://doi.org/10.1128/mSystems.00783-19>
- Zhou, D., Huang, X.-F., Guo, J., dos-Santos, M.L., Vivanco, J.M., 2018. *Trichoderma gamsii* affected herbivore feeding behaviour on *Arabidopsis thaliana* by modifying the leaf metabolome and phytohormones. *Microb. Biotechnol.* 11, 1195–1206. <https://doi.org/10.1111/1751-7915.13310>
- Zhou, S., Lou, Y.-R., Tzin, V., Jander, G., 2015. Alteration of plant primary metabolism in response to insect herbivory. *Plant Physiol* 169: 1488–1498. <https://doi.org/10.1104/pp.15.01405>
- Zhu, F., Heinen, R., Sluijs, M. van der, Raaijmakers, C., Biere, A., Bezemer, T.M., 2018. Species-specific plant–soil feedbacks alter herbivore-induced gene expression and defense chemistry in *Plantago lanceolata*. *Oecologia* 1–11. <https://doi.org/10.1007/s00442-018-4245-9>