EGUsphere, author comment AC2
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Reply on RC2

Noa Ligot et al.

Author comment on "Grain size modulates volcanic ash retention on crop foliage and potential yield loss" by Noa Ligot et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-687-AC2, 2023

Reviewer 2's comments

Abstract

Line 15 and throughout: 'ash fall' is commonly one word 'ashfall'

Corrected

Line 33: 'mean' should be 'means'

Corrected

Introduction

Line 40: 'is' should be 'are'

Corrected

Line 40: Define 'short-term'

The term "Short-term" is now defined:

Lines 38-41: *However, farming activities in these regions are exposed to short-term (i.e. usually less than one year) negative impacts of volcanic eruptions, an issue amplified by the expanding population living under volcanic risk.*

Line 44: True in areas where cropping farming dominates (e.g., Indonesia) but not in other countries where pastoral farming of livestock dominates

The sentence has been modified as follows:

Lines 41-43: *Where cropping activity dominates (for example, in Indonesia), widespread damage to agriculture during eruptive activity arises from crop exposure to ashfall.*

Line 48: Also food security issues in areas where farming is subsistence

The sentence has been modified as follows:

Lines 46-49: As a result, crop fields impacted by ash fall produce lower or poor-quality harvests that can translate into significant economic losses to farmers and food shortages at the local or even regional scale, and even more so when subsistence agriculture dominates *(Neild et al., 1998; Wilson et al., 2007; Ligot et al., 2022).*

Line 63: Expand/give examples

Examples are now given in the text:

Lines 61-64: *In parallel, new methodologies harvesting the potential of big Earth observation data acquired from satellite-based sensors (e.g., Landsat, MODIS and Sentinel) and interpretable machine learning are being developed to complement post-EIA studies (Biass et al., 2022).*

Line 67: I think its fair to say that tropical and semi-arid areas are increasingly being considered

The sentence has been modified to include these regions:

Lines 67-69: *Firstly, they lean on limited observational data acquired in post-EIA studies. Most of these have been conducted in temperate volcanic regions, but tropical and semi-arid environments are increasingly receiving attention.*

Line 72: Is there really no impact metric? Isn't thickness/loading used in this way currently? It's not perfect but it is still indicative of likely crop damage to some extent – as you use it to eliminate the possibility of structural damage later in the manuscript

Ash thickness or mass loading is the metric commonly used to describe hazard intensity. This was clearly stated in the original manuscript (Lines 69: *Secondly, it is assumed that ground ash accumulation (thickness or ash mass load) is the principal hazard intensity metric governing impact level on crops.*). An impact metric describes the damage caused by a given type of hazard. Here the reviewer's comment is not valid.

We slightly modified the sentence to clearly differentiate hazard and impact metrics as follows:

Line 69: Secondly, it is assumed that ground ash accumulation (thickness or ash mass load) is the principal hazard intensity metric governing impact level on crops. However, other volcanic (e.g. ash grain size, surface composition) and non-volcanic factors (e.g. environmental conditions, plant traits, crop development stage) play a key role in dictating impact and vulnerability (Jenkins et al., 2015; Ligot et al., 2022). Finally, current approaches lack an impact metric that can be applied to assess crop yield loss from ashfall.

Line 81: 'cm' to 'centimetres'

We replaced cm by kilograms per square meter throughout the text because the latter is the correct unit for ash mass load.

Line 84: Insert 'less severe' before 'disturbances'

Done

Line 84: Change 'blankets' to 'deposits'

Done

Line 85: Change ‘km2’ to ‘square kilometres’

Done

Line 85: Insert ‘structural’ before ‘integrity’

Done

Line 88: Is this always true? Reference? Wouldn’t the depth of cover or leachable chemistry of the deposit sometimes be the mechanism of loss?

We dismiss the first part of the reviewer’s comment that relates to ash deposit depth. Line 88 in the original manuscript refers explicitly to distal impacts (i.e. where thick deposits will not occur) of ashfall on vegetation.

As hinted by the reviewer, the presence of soluble compounds on ash surfaces has also been evoked to explain the deleterious effect of ash on vegetation (Miller, 1967; Cook et al., 1981; Mack, 1981; Wilson et al., 2007). The composition and abundance of such compounds on ash vary broadly (Ayris and Delmelle, 2012), depending on eruption style. If various chemical elements are always released when a fresh ash deposit is exposed to water, these are not necessarily harmful to plant leaves. In fact, through a foliar fertilisation effect, they could be beneficial (Ayris and Delmelle, 2012). Evidence of chemically-induced injuries to foliage affected by ashfall is scarce, and typically coincides with ash emissions from phreatic or phreatomagmatic eruptions (Le Guern et al., 1980; Magill et al., 2013). In this case, ash particles deposited on leaves may contain reduced sulphur minerals (elemental sulphur, pyrite) that produces sulphuric acid upon oxidation. This reaction creates highly acidic pH values locally at the leaf surface, which in turn can damage its cuticle. In the original manuscript (Line 69), we briefly mentioned ash surface composition as a factor (among others) playing a role in dictating impact.

We have revised the text thoroughly to clarify our working hypothesis (and the argument that underpins it) as follows:

Lines 89-103: *At distal sites, in the absence of structural damage to plants, the capacity of ashfall to initiate damage to crop yield hinges on the capacity of leaves coated with a thin ash deposit to operate photosynthesis and produce biomass. While the release of harmful chemical compounds from ash can cause leaf tissue injuries and affect photosynthesis, this effect, if occurring, is limited to ash emissions from phreatic and phreatomagmatic eruptions (Le Guern et al., 1980; Ayris and Delmelle, 2012). For purely magmatic explosive events, impact on crops over a wide area far from the volcano primarily relates to the shading effect exerted by the presence of solid particles on leaf surfaces, reducing light interception and decreasing photosynthetic activity (Thompson et al., 1984; Hirano et al., 1995). Thus, ash retention on foliage (i.e., the percentage of the leaf surface area covered with ash) is a critical variable for developing accurate models that can assess and predict widespread impacts on crop production from ashfall. Although ash grain size, leaf pubescence and ambient humidity have been suspected to affect ash retention on foliage, we are still lacking a (i) systematic investigation of factors controlling ash retention on foliage and (ii) quantitative impact metric reflecting crop production loss.*

Lines 477-480: Changes in LAI and premature biomass loss in ash-affected crops are interpreted as dependent on ash retention on leaves, a process influenced by grain size, plant traits and environmental conditions (Fig. 1). Here, we exclude the possible effect of ash surface composition on ash retention.

Lines 90-91: Evidence to support this point/reference needed

The following references have been inserted into the text:

Line 97: Thompson, J. R., Mueller, P. W., Flückiger, W., and Rutter, A. J.: The effect of dust on photosynthesis and its significance for roadside plants, Environ. Pollut. Control, 34, 171-190, doi: 10.1016/0143-1471(84)90056-4, 1984.

Line 97: Hirano, T., Kiyota, M., and Aiga, I.: Physical effects of dust on leaf physiology of cucumber and kidney bean plants, Environ. Pollut., 89, 255-261, doi: 10.1016/0269-7491(94)00075-O, 1995.

Materials and methods

Line 103: Rationale for choosing these two plant types needed

The rational for choosing tomato and chilli pepper plants were provided in the original submission (Lines 103-105: "[..] they have a similar stand in early growth period, but tomato has hairy leaves whereas chilli pepper has glabrous leaves" and Lines 26-27: "[..] two crop types commonly grown in volcanic regions").

Line 108: Clarify that the experiments took place in Belgium

We have added this information:

Line 115: *The experiment took place in Belgium.*

Line 112: Limitation that all plants the same age needs to be acknowledged. What height and leaf sizes?

The reviewer makes a good point. Our results are valid for tomato and chilli pepper plants when at the seven- and eight-leaf stage, respectively. For most plants, leaves overlap during growth as new leaves form from above. This means that youngest leaves could protect oldest leaves from falling ash particles, limiting their exposition. We have added this point to the limitations of our study at the end of the Discussion section.

Line 504: Another assumption made to evaluate the LAI trend over time is that the entire plant canopy received the same amount of ash. Although this was verified for tomato and chilli pepper when at the seven- and eight-leaf stage, respectively, it may not be necessarily the case at a later stage of their growth if upper leaves partly shield the surfaces of leaves located below them from direct exposure to ash.

The height of tomato and chilli pepper plants before ash application is now provided. Estimating the size of individual leaves is not straightforward as it varies with the leaf position on the stem. Instead, we provide the surface area of tomato's and chilli pepper's foliage as estimated by performing image analysis (using ImageJ) of the plants photos.

Line 121: They were exposed to ash six weeks after sowing, when tomato and chilli pepper plants were at the seven- and eight-leaf stage, respectively. The corresponding plant heights were -40 and ~30 cm. The foliage surface area was ~400 and ~100 cm^2 for tomato and chilli pepper, respectively;

Lines 119-128: What was the morphology of the particles in relation to natural ash deposits?

The reviewer's comment duplicates a remark made by Reviewer 1 (R1.4). We kindly refer the Editor to our corresponding reply.

Lines 119-128: No surface chemistry on synthetic ash material – does/does not influence ash retention and adherence?

The most abundant soluble elements from ash are usually calcium, chlorine, sodium and sulphur. They originate from the dissolution of sulphate and halide salts formed on the ash surface during gas/aerosols-ash interactions in the eruption plume. In the cases of phreatic and phreatomagmatic eruptions, water-soluble hydrothermal minerals eroded from the conduit may also be present in the ash material (Óskarsson, 1980; Christenson, 2000; Delmelle et al., 2007). As suggested by the reviewer, soluble compounds are absent in the surface of our ash material (obtained by grinding a volcanic rock). Thus, we can dismiss surface composition as a factor that could have influenced ash retention on tomato and chilli pepper plants in our experimental study. Controlled experiments could be designed to assess the effect of soluble salts on ash retention on leaf surfaces.

Line 129: Only one very thin ash deposit thickness (~0.6 mm) tested. Ash thickness effect on retention not considered.

The reviewer is correct and is/her concern echoes that already made by reviewer 1 (R1.6). We kindly refer the Editor to our corresponding reply.

Line 131: Where is Fig. S1 in-text reference

We thank the reviewer for spotting this omission. Fig. S1 has become Fig. S2 in the revised manuscript. Fig. S2 is used in Line 144:

Line 144: The grain size distribution of the six ash size ranges was measured between 0.04 and 2000 µm by laser diffraction (Beckman Coulter LS13 320) (Fig. S2).

Line 136: Did you immediately dose with ash after spraying?

Line 138: Were the plants moved between ashfall and photography? Or was the ash applied in the photography box?

These two remarks were also formulated by reviewer 1 (R1.8). We kindly refer the Editor to our corresponding reply.

Lines 138-156: How would this method scale up for use in a real-world situation? Needs to be included in discussion

Our data acquisition method was designed specifically for our experiments, where we had full control on various parameters. It would be very difficult and impractical to scale it up in a real-world situation. We had no intention to use it in natural conditions and we did not plan for it. We dismiss the reviewer's request to include this aspect in the discussion.

Lines 161-164: Wouldn't this limitation apply to all measurements taken in this study? Any idea of the magnitude of this impact on the results? How is this accounted for?

The issue of how the error on our measurements has been treated is also raised by reviewer 1 (R1.11). We kindly refer the editor to our corresponding reply.

Results

Line 173: How is leaf pubescence included in Fig. 1?

The results obtained for tomato plant, which has pubescent leaves, are shown in Fig. 1a, whereas those for chilli pepper, which has glabrous leaves are shown in Fig. 1b. The figure caption has been clarified as follows:

Lines 217-222: *Percentage of foliar cover coated with ash for tomato plant, i.e. which has pubescent leaves, (a) and chilli pepper plant, which has glabrous leaves (b). The percentage of foliage cover was measured for the six grain size ranges tested in dry and wet conditions at leaf surfaces. Each boxplot represents 15 repetitions. The median value sits within the box and represents the centre of the data. Fifty % of the data values lie above the median and 50% lie below the median. Measurement outliers are displayed as dots.*

Line 176: Add 'significant' before 'effect'

Done

Lines 183-184: Explain the points and boxplots in the caption

The caption of Fig. 1 has been modified to include the required information as follows:

Lines 220-222 *Each boxplot represents 15 repetitions. The median value sits within the box and represents the centre of the data. Fifty % of the data values lie above the median and 50% lie below the median. Measurement outliers are displayed as dots.*

Line 201: Change 'that ash 63 μm in diameter' to 'that ash with a median of 63 μm in diameter'

Done

Figure 2: Did leaf pubescence influence these curves? Was there enough data to quantify this?

The influence of leaf pubescence is discussed in the original submission (Lines 259-276): *We also note that for the ash grain size ranges 125-250 and 250-500 μm in dry conditions, coverage of tomato leaves by ash was significantly greater, on average by ~30 and ~20%, respectively, compared to chilli pepper leaves.*

Lines 219-220: Link this to the function of these parts of the leaves in the discussion

Leaf folds have no particular function. They consist of different tissues, i.e. the blade and veins of expanding leaves. We do not think that more needs to be said about leaf folds.

Figure 3: Could before photos be included too? The figure needs a scale

We thank the reviewer for his/her suggestion. Photos of control plants have been added to Fig. 3. We also provide the surface area value of the processed plant images (~800 cm^2) in the figure caption.

Discussion

Lines 233-236: Was this experimental or field data?

Miller (1967)'s study reports field data, whereas Johnson and Lovaas (1969) and Witherspoon and Taylor (1970)'s are experimental measurements.

We have clarified this as follows:

Lines 280-287: *The increased ash retention when grain size decreases is in accordance with the field observations of Miller (1967) after the 1963 eruption of Irazú volcano, Costa Rica, who found a higher degree of retention of the smaller particles by crop foliage (alfalfa, maize, bean, beet, cabbage, carrot, pea, pepper, potato, radish and squash). Johnson and Lovaas (1969) and Witherspoon and Taylor (1970) reached a similar conclusion after dusting various crops (i.e. alfalfa, maize, squash, soybean, sorghum, peanut and clover) with quartz powders differing in grain size (88-175 and 175-350, and 44-88 and 88-175 μm, respectively).*

Line 243: Only true if considering a homogenous ash composition

Reviewer 2 is correct. The sentence has been modified as follows:

Lines 290-293: *Ignoring aggregation processes and considering a constant particle bulk density, the coarser the particles, the larger their terminal fall velocity and thus, kinetic energy (Dellino et al., 2005; Benson, 2015), simply reflecting that mass increases with grain size.*

Line 285: Is spraying the leaves with water an accurate representation of common humid environment?

The reviewer makes a good point. In natural environments, plant leaf surface moisture mainly originates from rainwater, dew and plant guttation. Spraying the leaves with ~1.5 g of water is probably most representative of a light rain or dew, which is characterised by a relatively homogeneous deposit made of droplets with comparable sizes (Hughes and Brimblecombe, 1994; Levia et al., 2017). In contrast, guttation tends to lead to the formation of bigger droplets located on the hydathodes, i.e. pore of the leaves allowing water exudation and mostly located at the tips and margins or edges of the leaves (Singh, 2014). Since guttation is a relatively minor process responsible for surface humidity at leaf surfaces (Singh, 2016), we assume that spraying water on plant leaves can reproduce reasonably conditions found in a humid environment. We contend that a heavy rain (which we did not intend to simulate) can remobilise ash particles and erode the ash deposit. We have inserted a new sentence into the Discussion section:

Line 339-343: *Enhanced ash retention on wet leaves likely relates to the surface tension generated by water molecules present on the leaf surface (Tabor, 1977; Israelachvili, 2011). Conversely, as plant leaves are hydrophobic (Bhushan and Jung, 2006), more water on leaves, such as after a heavy or prolonged light rain, could lead to formation of large water droplets able to erode particles from the leaf surface, thereby reducing ash retention.*

Line 289: How does the density of the phonolite used compare to the density of other ash deposits?

It seems that the reviewer has misunderstood. We always refer to the ash deposit's bulk density, i.e. accounting for pore space between individual particles. The density of the phonolite is that of the dense volcanic rock (i.e. typically 2.6-2.8 g cm^{-3}) prior to grinding. It is not the density of the ash deposit. We did not measure the density of the ash deposit formed on the leaf surfaces. Instead, we used a bulk density value (1 g cm^{-3}) typical for an ash deposit made of particles in a size range similar to those tested in our study (Eychenne et al., 2012).

Line 300: Change 'Recalling' to 'Considering'

Done

Line 304 and elsewhere: Define the 'cm-thick deposit' threshold specifically

A similar suggestion was made by reviewer 1 (R1.6). We kindly refer the Editor to our corresponding reply.

Line 317: How does the Q value for Belgium compare to Q values for more commonly volcanically active countries?

Adding Q values for more commonly volcanically active countries is not required because the final result; i.e. crop yield loss, is a ratio that is not influenced by Q.

Line 320: Define 'harvest index'

We have defined the harvest index in the revised manuscript:

Lines 379-380: *[…] harvest index, i.e. the fraction of the total aboveground biomass allocated to the harvested parts of the plant*

Line 342: Evidence/reference that 'ash deposition on leaves neither halt plant growth nor production of new leaves…'

We have added two references as per the reviewer's request:

Line 407: Neild, J., O'Flaherty, P., Hedley, P., Underwood, R., Johnston, D., Christenson, B., and Brown, P.: Impact of a volcanic eruption on agriculture and forestry in New Zealand, Ministry of Agriculture and Forestry, New Zealand, 99/2, 88 pp., 1998.

Line 407: Ligot, N.: Crop vulnerability to tephra fall in volcanic regions: field, experimental and modelling approaches, Earth and Life Institute, UCLouvain, Belgium, 285 pp., 2022.

Lines 357-359: Why are these equal?

The assumption that the canopy-to-biomass ratio is equal for tomato and chilli pepper is based on previous studies, and which are cited in the original submission (Kleinhenz et al., 2006; Elia and Conversa, 2012; Poorter et al., 2015). In our model, we hypothesised that the percentage of leaf biomass covered with ash which dies is also equal for both crops. In the absence of information on this ratio, it was the simplest and most logical approach.

Three references already used in the original submission (Line 156) have been added to the text to justify why the leaf-to-canopy biomass ratio and percentage of leaf biomass covered with ash which dies are set equal for both crops.

Line 419: Kleinhenz, V., Katroschan, K.-U., Schütt, F., and Stützel, H.: Biomass accumulation and partitioning of tomato under protected cultivation in the humid tropics, Eur. J. Hort. Sci., 71, 173-182, 2006.

Line 419: Elia, A. and Conversa, G.: Agronomic and physiological responses of a tomato crop to nitrogen input, Eur. J. Agron., 40, 64-74, doi: 10.1016/j.eja.2012.02.001, 2012.

Line 419: Poorter, H., Jagodziński, A., Ruiz-Peinado, R., Kuyah, S., Luo, Y., Oleksyn, J., Usol'tsev, V., Buckley, T., Reich, P., and Sack, L.: How does biomass distribution change with size and differ among species? An analysis for 1200 plant species from five continents, New Phytol., 208, doi: 10.1111/nph.13571, 2015.

Figure 5: Show the same graphs for chilli pepper plants in this figure

The experimental results obtained for chilli pepper have been added to Fig. 6.

Lines 379-381: Why were these distributions selected?

The reason for choosing these distributions is provided in the original submission:

Lines 447: *We posited that the values taken by factors (iii) and (iv) follow a gaussian distribution (Table S5), whereas variable (i) and (ii), which are always in the range 0-1 and positive, respectively, are described by a truncated gaussian distribution.*

Line 405: Change 'in chilli pepper exposed' to 'and chilli pepper crops exposed'

Done

Line 412: Change 'mean' to 'method'

Done

Lines 414-419: More information on this is needed to demonstrate how the approach can be scaled up from a greenhouse set-up, please

The idea behind this paragraph is not to scale up from a greenhouse to the real-world situation, but rather to present a perspective arising from our study. Our greenhouse experiment allows the identification of ash grain size, leaf surface humidity and plant pubescent as important factors dictating ash retention on plant foliage, and ultimately biomass production. Ash retention by plant foliage is influenced by various and difficult-to-constrain *in-situ* factors. While our experimental study has unveiled just a few, its results suggest that ash retention could be approximated based on plant *LAI* estimates. Since *LAI* can be retrieved from several satellite-born sensors, we argue that there is a real opportunity to monitor ash impacts on crops by exploiting the high flux of Earth observation data generated in real time.

Conclusions

Lines 489-492: It is unclear how this method and its results would add anything to existing mitigation efforts. Needs further explanation on the practical ways that this data could assist in an event

Reviewer 1 made a similar comment (R1.16). We kindly refer the Editor to our corresponding reply.

References

Ayris, P. M. and Delmelle, P.: The immediate environmental effects of tephra emission, Bull. Volcanol., 74, 1905-1936, doi: 10.1007/s00445-012-0654-5, 2012.

Christenson, B. W.: Geochemistry of fluids associated with the 1995–1996 eruption of Mt. Ruapehu, New Zealand: signatures and processes in the magmatic-hydrothermal system, J. Volcanol. Geotherm. Res., 97, 1-30, doi: 10.1016/S0377-0273(99)00167-5, 2000.

Cook, R. J., Barron, J. C., Papendick, R. I., and Williams, G. J.: Impact on agriculture of the mount St. Helens eruptions, Science, 211, 16-22, doi: 10.1126/science.211.4477.16, 1981.

Delmelle, P., Lambert, M., Dufrêne, Y., Gerin, P., and Óskarsson, N.: Gas/aerosol–ash interaction in volcanic plumes: New insights from surface analyses of fine ash particles, Earth. Planet. Sci. Lett., 259, 159-170, doi: 10.1016/j.epsl.2007.04.052, 2007.

Elia, A. and Conversa, G.: Agronomic and physiological responses of a tomato crop to nitrogen input, Eur. J. Agron., 40, 64-74, doi: 10.1016/j.eja.2012.02.001, 2012.

Eychenne, J., Le Pennec, J.-L., Troncoso, L., Gouhier, M., and Nedelec, J.-M.: Causes and consequences of bimodal grain-size distribution of tephra fall deposited during the August 2006 Tungurahua eruption (Ecuador), Bull. Volcanol., 74, 187-205, doi: 10.1007/s00445-011-0517-5, 2012.

Hughes, R. N. and Brimblecombe, P.: Dew and guttation: formation and environmental significance, Agricultural and Forest Meteorology, 67, 173-190, doi: doi.org/10.1016/0168-1923(94)90002-7, 1994.

Johnson, J. E. and Lovaas, A. I.: Progress report on simulated fallout studies, Colorado State University, pp., 1969.

Kleinhenz, V., Katroschan, K.-U., Schütt, F., and Stützel, H.: Biomass accumulation and partitioning of tomato under protected cultivation in the humid tropics, Eur. J. Hort. Sci., 71, 173-182, 2006.

Le Guern, F., Bernard, A., and Chevrier, R. M.: Soufrière of guadeloupe 1976–1977 eruption — mass and energy transfer and volcanic health hazards, Bulletin Volcanologique, 43, 577-593, doi: 10.1007/BF02597694, 1980.

Levia, D. F., Hudson, S. A., Llorens, P., and Nanko, K.: Throughfall drop size distributions: a review and prospectus for future research, WIREs Water, 4, e1225, doi: doi.org/10.1002/wat2.1225, 2017.

Mack, R. N.: Initial effects of ashfall from mount St. Helens on vegetation in eastern Washington and adjacent Idaho, Science, 213, 537-539, doi: 10.1126/science.213.4507.537, 1981.

Magill, C., Wilson, T., and Okada, T.: Observations of tephra fall impacts from the 2011 Shinmoedake eruption, Japan, Earth Planets Space, 65, 18, doi: 10.5047/eps.2013.05.010, 2013.

Miller, C. F.: Operation ceniza-arena: The retention of fallout particles from volcan Irazu (Costa Rica) by plant and people. Part 2, Stanford Research Institute, San Francisco, California, MU-4890, 247 pp., 1967.

Óskarsson, N.: The interaction between volcanic gases and tephra: fluorine adhering to tephra of the 1970 hekla eruption, J. Volcanol. Geotherm. Res., 8, 251-266, doi: 10.1016/0377-0273(80)90107-9, 1980.

Poorter, H., Jagodziński, A., Ruiz-Peinado, R., Kuyah, S., Luo, Y., Oleksyn, J., Usol'tsev, V., Buckley, T., Reich, P., and Sack, L.: How does biomass distribution change with size and differ among species? An analysis for 1200 plant species from five continents, New Phytol., 208, doi: 10.1111/nph.13571, 2015.

Singh, S.: Chapter Three - Guttation: new insights into agricultural implications, in: Adv. Agron., edited by: Sparks, D. L., Academic Press, 97-135, doi:

doi.org/10.1016/B978-0-12-802139-2.00003-2, 2014.

Singh, S.: Guttation: mechanism, momentum and modulation, The Botanical Review, 82, 149-182, doi: 10.1007/s12229-016-9165-y, 2016.

Wilson, T. M., Kaye, G., Stewart, C., and Cole, J.: Impacts of the 2006 eruption of Merapi volcano, Indonesia, on agriculture and infrastructure, Institute of Geological and Nuclear Sciences, New Zealand, 64 pp., 2007.

Witherspoon, J. P. and Taylor, F. G., Jr.: Interception and retention of a simulated fallout by agricultural plants, Health Phys., 19, 493-499, doi: 10.1097/00004032-197010000-00003, 1970.