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Determination of Fog-Droplet Deposition Velocity from a Simple Weighing Method

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ABSTRACT

Fog water deposition can represent an important part of the atmospheric water, nutrient and pollutant inputs in specific areas such as mountainous or coastal regions (Shimadera *et al.*, 2011). In order to determine the potential of fog water deposition on plants, a field experiment has been performed in the northeast of France to determine fog droplet deposition velocity on different types of plants. The main objective is to improve deposition models by enabling them to accurately account for water inputs from fog or low clouds at ground level.

The flux of deposited fog water was estimated by exposing plants to fog and weighing them with a precision balance. Contrary to other flux measurement methods, the weighing method is simple to set up. Three plant types (small conifers, grass and cabbages) plus bare soil were used as impaction and deposition surfaces. A Particulate Volume Monitor (PVM-100) provided the liquid water content (LWC) to calculate fog droplet deposition velocities, and a Fog Monitor (FM-120), the characterization of the droplet size distribution.

Two fog events with different features (visibility, LWC and droplet number) were compared with regard to deposition velocity.

When wind speed was below 4 m s⁻¹, mean fog droplet deposition velocities ranged from less than 2.2 cm s⁻¹ on bare soil to 40 cm s⁻¹ on cypress. Thus, the impaction of fog droplets can be an important part of fog water deposition on plants.

Keywords: Atmospheric aerosols; Liquid water content; Fog; Droplets; Aerosol deposition; Measurement techniques; Leaf area index.

INTRODUCTION

It has been reported that fog water deposition can have a significant impact on plant canopies regarding its contribution to the water budget and the chemical exposition of the canopy (Weathers and Likens, 1997). Studies about fog water inputs on forest canopies have shown that ecosystems are exposed to higher ion concentrations through fog water than through precipitation (Fenn and Kiefer, 1999; Collett Jr *et al.*, 2002; Thalmann *et al.*, 2002; Watanabe *et al.*, 2006; Shimadera *et al.*, 2011). Besides, acidic fogs are directly related to forest decline (Schemenauer, 1986; Pandis *et al.*, 1990; Barker and Ashenden, 1992; Cape, 1993; Igawa *et al.*, 2002). Fog water deposition could also explain some of the differences in soil contamination between deposition

models and fields observations after the Fukushima accident (Katata, 2014; Hososhima and Kaneyasu, 2015). Deposition rate and deposition velocity values can be directly incorporated in operational models used in emergency situations. The deposition of fog droplets is a phenomenon rarely taken into account in deposition models of pollutants and even in the fog life cycle modelling. Actually, the removal of liquid water from the atmosphere as a result of fog water deposition can affect the formation and development processes of fog (Mazoyer, 2016). Techniques developed to assess fog water deposition fluxes usually include throughfall (Pahl *et al.*, 1995), canopy water balance method (Lovett, 1988) and the eddy covariance method (Dollard and Unsworth, 1983; Vong and Kowalski, 1995; Eugster *et al.*, 2006; Beiderwieden *et al.*, 2008; Schmid *et al.*, 2011). Even though the canopy water balance method is direct and simple, uncertainties are important because it requires knowledge of the canopy characteristics (leaf area, 3D structure). As for the eddy covariance method, flux measurements are difficult to set up in complex terrain. Eddy covariance studies quantify flux of fog water over the canopy which is different from

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the gross flux of water deposition at the canopy or ground levels (Eugster *et al.*, 2006). High variability of deposition velocity values were noticed with those methods. Reported values show that fog water deposition velocity ranged from 2.1 to 8.0 cm s⁻¹ for short vegetation with a horizontal wind speed between 1.1 and 9 m s⁻¹ while, for forests it ranged from 1 to 92 cm s⁻¹ with values of wind speed between 1 to 15 m s⁻¹ (Katata, 2014). Most studies about fog deposition on plants focused on one plant species. Our field study provides new and deeper insights on the contribution of fog water deposition on different types of short vegetation that could further being extrapolated to large scale canopies. The aim of this paper is to compare fog deposition on different types of plants and assess the amount of deposited water based on a single weighing method using a precision balance. Deposition velocity of fog droplets are then derived from these measurements.

MATERIALS AND METHODS

Site Description

The field experiments were carried out at ANDRA's

(The French National Radioactive Waste Management Agency) atmospheric platform located in Houdelaincourt (48.5623N; 5.5055E) in the North-Eastern part of France. The site is at the top of a small hill (395 m above sea level) covered with grassland and surrounded by fields; at about 1.5 km from the first village and roads. This rural site was chosen because of the high occurrence of fogs and the availability of electrical supply and security. Apart from two small prefabricated shelters, the site is free of any construction. Measurements were performed during three days from October 31 till November 2, 2015. The whole experimental set-up included a precision balance, usual meteorological instruments and fog characterization instrumentation: Visibilimeter, Particle Volume Monitor (PVM-100) and Fog Monitor (FM-120) (Fig. 1).

Meteorological Measurements

Table 1 presents instruments deployed on site and the main parameters measured. A visibilimeter (Sentry Visibility Sensor, Envirotech Sensors Inc.) was used to measure visibility and to trigger fog water collectors for visibility below 1,000 m. A Particulate Volume Monitor (PVM-100),

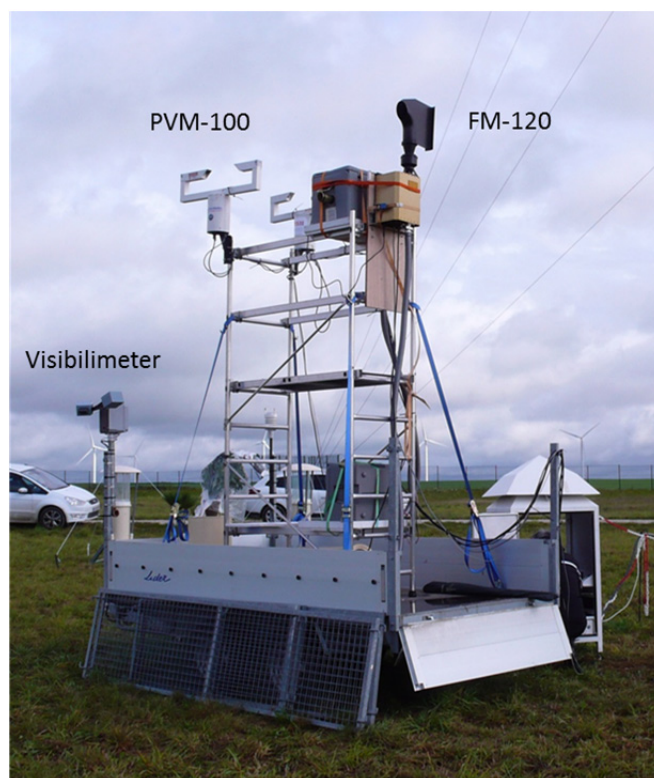


Fig. 1. Experimental set-up with Visibilimeter, PVM-100 and FM-120.

Table 1. Instruments deployed on the experiment site of Houdelaincourt.

Instrument	Measured parameter	Measurement frequency
Visibilimeter	Visibility (m)	2 min
Particulate Volume Monitor (PVM-100)	Liquid Water Content, LWC (g m ⁻³)	2 min
Fog Monitor 120 (FM-120)	Size distribution of fog droplets	0.1 s
Weather Transmitter (WXT520)	Wind speed (m s ⁻¹)	2 min
Balance (KA15s)	Mass of container + plants + fog water (g)	20 min

developed by Gerber Scientific Inc. (Gerber, 1991) provided the liquid water content (LWC) in the air in g m^{-3} . The PVM-100 is a forward scattering laser spectrometer with laser beam that crosses the air over a length of 42 cm. The light scattered by fog droplets is registered and thank to a linear relationship between LWC and the registered signal, the LWC can be determined for droplet sizes from 3 to 45 μm . The Fog Monitor 120 (DMT FM-120, Droplet Measurement Technologies) is a forward scattering probe with an active ventilation forcing the air flux into a small measurement chamber. It is used to measure the size distribution of cloud droplets between 1.5 and 50 μm . Particles are categorized into 30 particle size bins, with a measurement frequency of 10 Hz. The FM-120 was equipped with a swivel inlet to follow the wind direction change and to have a co-linear sampling flux. An intercomparison on data of FM-120 and PVM-100 was performed for the two fog events studied to ensure that size distribution of droplets measured by FM-120 corresponded to LWC values of PVM-100. Based on size distribution data provided by the FM-120, the number density (N) and the mass density (M) of each size bin (i) at a time (t) were computed using following Eqs. (1) and (2):

$$N(i, t) = \frac{n(i, t)}{TAS \times DOF \times \Delta t_{FM}} \quad (1)$$

$$M(i, t) = \frac{\pi}{6} \times \rho_w \times N(i, t) \times d_p(i)^3 \quad (2)$$

where n is the number of droplets for a size bin (i); TAS for True Air Speed, the speed of the air in the inlet; DOF the Depth of Field which is the sampling surface multiplied by the width of the laser beam; Δt_{FM} the sampling time; ρ_w the density of water and $d_p(i)$ the particle diameter of the size bin. Number density distribution $P_N(i, t)$ and mass density distribution $P_M(i, t)$ of a size bin (i) were obtained using Eq. (3) and (4):

$$P_N(i, t) = \frac{N(i, t)}{\sum_{i=1}^{30} N(i, t)} \quad (3)$$

$$P_M(i, t) = \frac{M(i, t)}{\sum_{i=1}^{30} M(i, t)} \quad (4)$$

A Weather Transmitter probe (WXT520), developed by Vaisala was set up to measure wind speed and direction (ultrasonic anemometer). The transmitter also provided data on precipitation, atmospheric pressure, temperature and relative humidity.

Measurement of Fog Water Deposition on Plants

Our experimental set-up is similar to the one described by Trautner and Eiden (1988) who used a balance to monitor fog deposition on spruce trees. The net flux of water deposited over different canopies was measured using an outdoor precision balance (KA15s by METTLER TOLEDO) on a 350×280 mm plate. Balance KA15s can weigh a maximal load of 15 kg with a 0.1 g precision. The K line of balances is designed for high-precision weighing in hazardous areas including wet areas. The mechanical structure of the balance absorbs impacts and lateral forces to protect the load cell from external influences. During our experiment three plant species: cypress (*Cypressus gold crest*), cabbage (*Brassica oleracea*) and grass (*Carex panicea*) were planted in rectangular plastic containers of $705 \times 400 \times 165$ mm, each representing a specific deposition surface (Fig. 2(a)). Cypress was chosen for its 3-dimensional structure, cabbage because it is an edible leaf vegetable with more or less 2D flat structure, grass for short vegetation and its ubiquitous occurrence in the terrestrial environment. A fourth container filled with soil represents the “bare soil”. Each container was exposed to fog during 20 minutes, and then weighted on the precision balance. Before fog exposition each container was weighed for the tare. To get proper weighing measurements the balance was temporarily covered with a protection hood (measurement chamber) (Fig. 2(b)) to avoid wind-induced fluctuations. The whole equipment was settled under a camp tent in order not to be exposed to the elements. The total mass (TM) including the container mass, soil, plants and deposited water was registered every 20 minutes (Δt), from the beginning to the end of the fog event. The beginning of the “fog event” was accounted for when the visibility



Fig. 2. Experimental set-up of the weighing method: (a) plastic containers each containing one of the three plant species; (b) balance (without plants) under a shelter to prevent weighing disturbances from wind fluctuations.

decreased below 1,000 m. Mass change (Δm) at a time $t + \Delta t$ is obtained following Eq. (5):

$$\Delta m(t + \Delta t) = TM(t + \Delta t) - TM(t) \quad (5)$$

Water streaming from the plant onto the ground disposed in the container is part of the mass weighed by the balance. Mass change determined every 20 minutes is considered due to fog droplet deposition. Uncertainty on flux measurement (1–5%) are calculated based on the balance precision (± 0.1 g) and uncertainty on the weighing time (± 1 min.) over 20 min. of fog exposure.

Theoretical Approach

The deposition of fog droplets is characterized by a deposition velocity V_g encompassing turbulent deposition and droplet sedimentation, being considered as the main processes of fog droplet deposition (Dollard and Unsworth, 1983), following Eq. (6):

$$V_g = V_s + V_t \quad (6)$$

where V_s is the sedimentation velocity and V_t the turbulent impaction component. The sedimentation velocity component can be calculated based on the droplet diameter, following Eq. (7):

$$V_s = \frac{(\rho_p - \rho_{air}) \times d_p^2 \times g \times C_c}{18 \times \mu_{air}} \quad (7)$$

where ρ_p and ρ_{air} are the density of the particle and the density of the air, respectively; d_p is the diameter of the particle; g is the gravitational acceleration; C_c the Cunningham factor and μ_{air} the viscosity of air. For fog droplets ranging from 2 to 50 microns and assuming a droplet density of 1, the corresponding s velocities range between 0.01 cm s^{-1} and 8 cm s^{-1} .

Fog droplet velocity V_g is also defined as the flux density of water F divided by the liquid water content LWC in the air at a given height. These measured parameters allow to compute the fog deposition velocity of droplet, following Eq. (8).

$$V_g = \frac{F}{LWC} \quad (8)$$

The net flux of deposited water is the mass of water deposited by fog per unit of time and per unit of ground surface. To determine the uncertainty of deposition velocity obtained by the weighing method, the relative uncertainty of flux measurement (1–5%) and the precision of LWC measurement (10%) are taken into account. In addition, based on the droplet size distribution and using Eq. (7), sedimentation velocities V_s can be calculated and the respective contribution of turbulent and sedimentation process in fog droplet deposition can also be quantified.

Characterization of the Plant Canopy

In order to compare fog deposition on different plant

types, it is essential to characterize the canopy (density, foliar structure) based on the Leaf Area Index (LAI). The Leaf Area Index is generally considered as the total one-sided area of photosynthetic tissue per unit of ground surface area (leaf area/ground area, $\text{m}^2 \text{ m}^{-2}$) (Fowler et al., 2009). However this definition is only suitable for broadleaved trees with flat leaves. For coniferous trees, a projected leaf area is calculated to take into account the foliar structure complexity (Joslin et al., 1990). Many other definitions are proposed depending on the plant type and the measurement techniques (Jonckheere et al., 2004). It is noteworthy that the definition of the LAI will influence the calculated deposition leaf area. Two main procedures allow to calculate LAI: direct and indirect measurements (Fowler et al., 2009). Direct methods are considered as the most precise (Jonckheere et al., 2004) but are not often used for forest because they are very time consuming. For low size vegetation (grass and cabbage), the LAI was not directly measured; a geometric mean value was calculated from the literature data. Thus for cabbage a LAI of 2.4 was derived from 6 values ranging from 1.2 to 4.0 (Dawson, 1998). For grass, (Fowler et al., 2009) have computed an average LAI of 4.5 based on 87 values ranging from 0.4 to 16.2.

Contrary to low vegetation canopies, the cypress used for the experiment were not representative of a coniferous tree forest. Indeed the young plants were 50 cm high and densely planted (22 plants per container i.e., 91 plants per m^2). Such high plant density was chosen to obtain a surface deposition corresponding mostly to needles and branches, thus limiting possible fog water deposition on soil. To assess the LAI of cypress, a direct method was applied on a sample of 12 plants. For each young plant, branches were separated into categories based on their length; the number of branches was then computed for each category. For each category, one branch was chosen to determine the number of smaller branches and so on until we could count the number of needle leaves for one small branch to eventually evaluate the number of needle-leaves for one sampling. The needle-leaf shape was assimilated to a sharp triangular surface and an average leaf area was computed for each smaller branch. Therefore the total leaf area of each plant could be assessed and the average leaf area of one sampling could be calculated and applied to the whole 22 cypress. Another point to consider with a forest canopy is the “edge effect” (Templer et al., 2015) meaning that trees on a forest edge are more exposed to fog deposition than elsewhere in the forest (e.g., interior zone). To account for this effect with regard to the cypress structure and plant density, young plants were spray-painted. Droplets of paint could only reach parts of the plants directly facing the spray. Thus it depended on their respective position inside the container. The percentage of the total foliar area intercepting droplets was evaluated by a scrutinized defoliation prior to the determination of the painted leaf area percentage. The interception area for the 22 young plants was evaluated at 5 m^2 leading to a Leaf Area Index of 20. Even if high values of LAI are commonly found for coniferous forest, e.g., LAI of 14 for Douglas-fir trees (Agam and Berliner, 2006), a LAI of 20 is high but can be explained by the high

density of cypress in the container.

RESULTS AND DISCUSSION

Main Characteristics of the Fog Event

Microphysical parameters of two fog events are depicted on Figs. 3 and 4. The visibility is inversely related to LWC and to the number density of fog droplets. During the night of the 31st October 2015 (fog event 1), the visibility dropped from more than 1,000 m to less than 200 m between 1:30 and 2:00 a.m. while the LWC increased to 0.11 g m^{-3} . During this dense fog, visibility stayed below 200 m from 1:30 a.m. to 2:00 a.m.; the average LWC value was 0.12 g m^{-3} with a standard deviation of 0.01 from 2:00 a.m. to 9:45 a.m., while the average particle density was 46 droplets per cm^{-3} with a standard deviation of 6. The fog reached its mature stage rapidly, in less than 30 minutes with a very low visibility and high LWC. The second fog event studied (fog event 2) began at 4 p.m. on 1st November and lasted until 10:30 a.m. on 2nd November. Visibility varied a lot between 50 m and more than 1,000 m before 10:00 a.m. The weighing stage corresponds to the period between 4:00 p.m. and 10:00 a.m. the day after (visibility was less than 200 m). This event was particularly interesting for fog deposition because mean LWC was 0.13 g m^{-3} with a standard deviation of 0.03. For the second fog event, the average droplet concentration was 34 droplets per cm^{-3} with a standard deviation of 6 during the weighing stage.

The size distribution of fog droplets and its contribution to the liquid water content in the air is essential to assess fog droplet deposition velocity. Figs. 5 and 6 illustrate the contribution of each droplet size class to the total number density representing the number of droplets per cm^3 and to the total mass density i.e., the mass of liquid water per m^3 every minute. For fog event 1, droplets between 10 and 20 μm and droplets between 20 to 50 μm represented respectively about 10% and less than 5% of the total number of droplets, but more than 40% and about 50% of the mass of water during the mature phase. In the case of fog event 2, the percentage of droplets ranging between 10 and 20 μm fluctuated mostly between 15 to 20% of the total number density whereas the percentage of 20 to 50 μm droplets was slightly higher than for event 1 and reached 5%. Beside, LWC was higher for the second event due to the contribution of droplets between 10 to 20 μm and very large droplets between 20 to 50 μm . In terms of mass density, large droplets (10 to 50 μm) represented up to 90% of the condensed water mass in the air. These results are in agreement with the fact that higher LWCs are mainly induced by a great number of large droplets (10 to 50 μm).

Deposition and Evaporation Rates

The weighing method described allows to quantify fog water deposition on different canopies by measuring the mass of water deposited during fog events. Weighing data from the early stage of both fogs events could not be

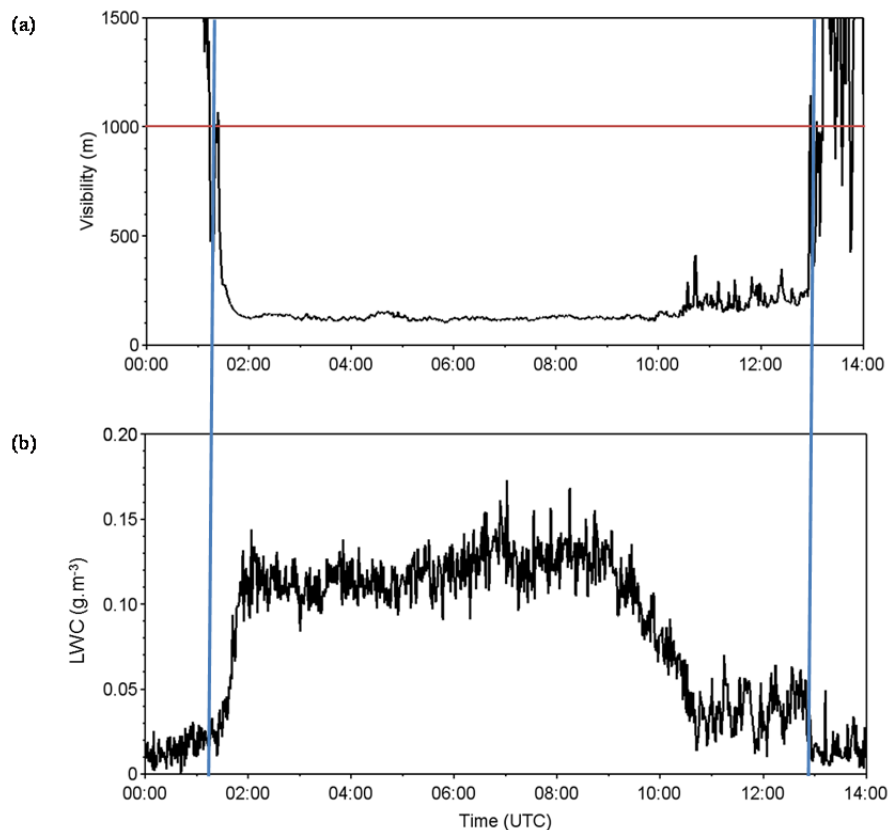


Fig. 3. Evolution of visibility (< 1000 m: fog) (a) and Liquid Water Content (LWC) (b) measured by the PVM-100 during the 31 October 2015 fog event.

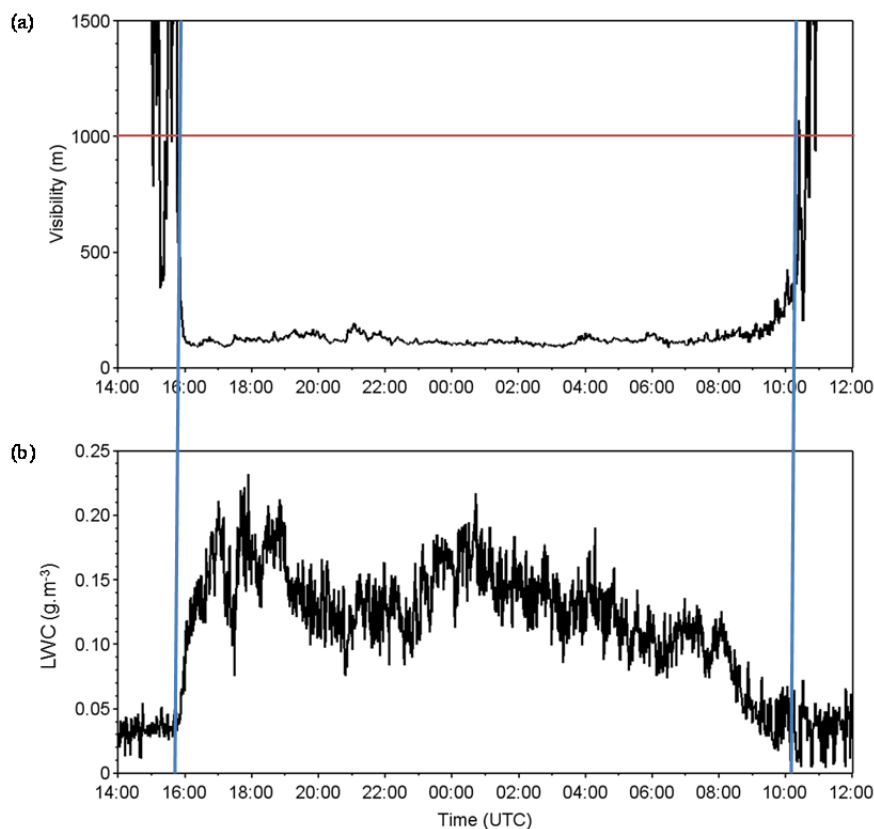


Fig. 4. Evolution of visibility (< 1000 m: fog) (a) and Liquid Water Content (LWC) (b) measured by the PVM-100 during the 1–2 November 2015 fog event.

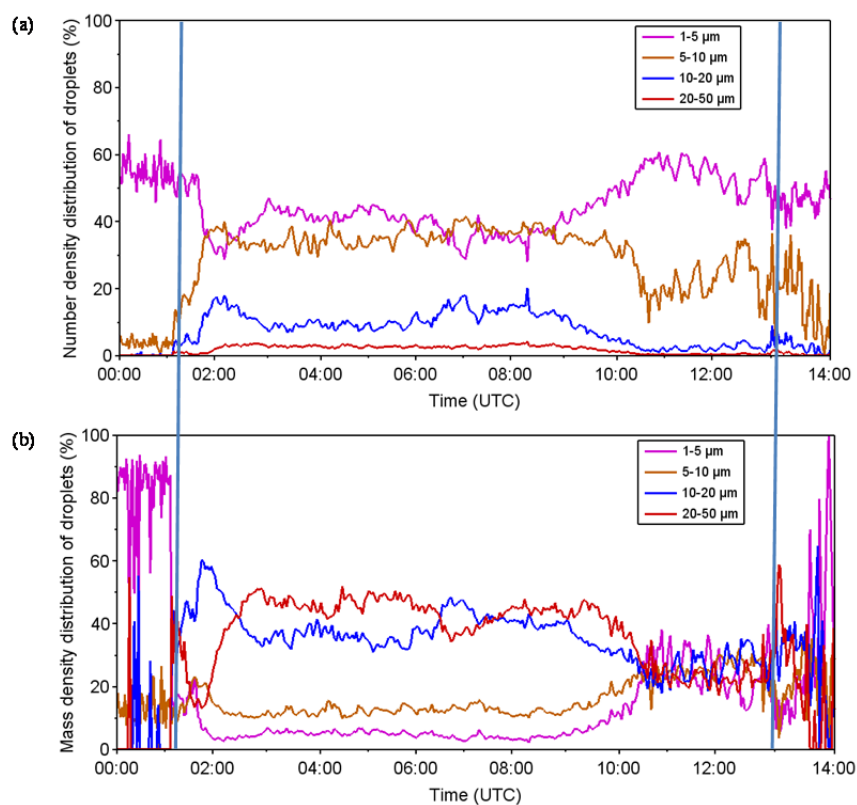


Fig. 5. Percentage of each droplet size class to the total number density (a) and to the total mass density (b) based on the FM120 data of 31 October 2015 fog event.

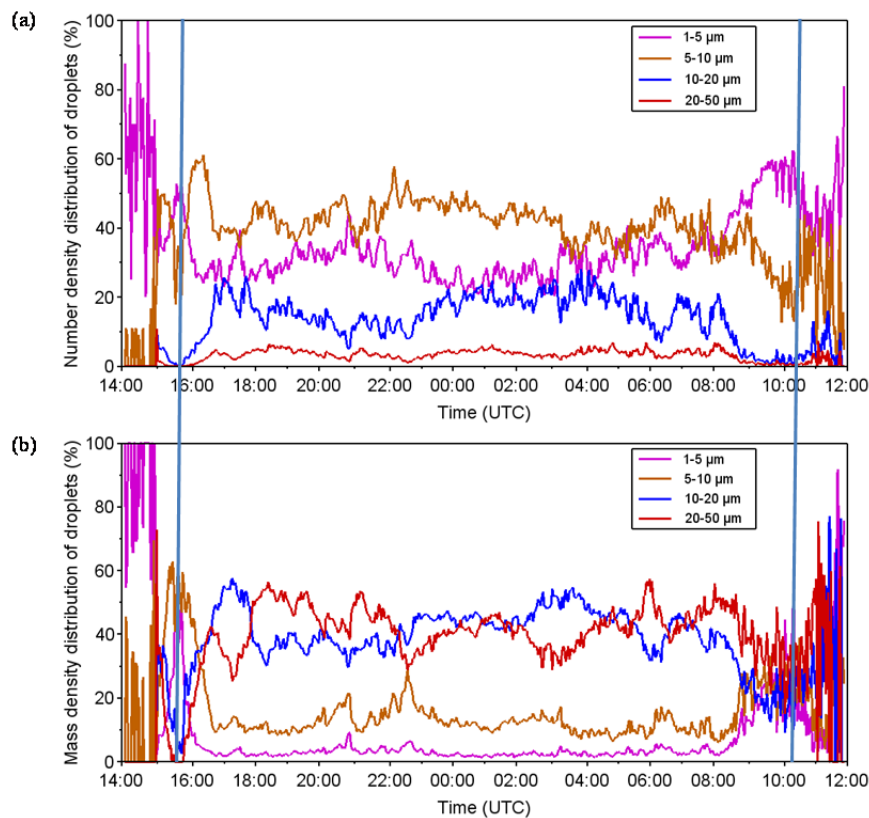


Fig. 6. Percentage of each droplet size class to the total number density and to the total mass density based on the FM120 data of 1–2 November 2015 fog event.

recorded because operators were not permanently on the experimental site but staying in alert at a camp about 15 km away. Figs. 7 and 8 show the results of the net flux of water $\Delta m/\Delta t$, where Δm is the mass of water deposited during a time interval Δt , in $\text{g h}^{-1} \text{m}^{-2}$ of soil which in our case corresponds to the container surface. This specific area is chosen to compare deposition fluxes of different plants planted on the same normalized surface.

At the beginning of the fog event 1, the net flux of water reaches a maximum for every plant just before 2:00 a.m., around $260 \text{ g m}^{-2} \text{ h}^{-1}$ for cypress, $180 \text{ g m}^{-2} \text{ h}^{-1}$ for grass, $100 \text{ g m}^{-2} \text{ h}^{-1}$ for cabbage (Fig. 7). For bare soil the maximum is $130 \text{ g m}^{-2} \text{ h}^{-1}$ after 2:00 a.m. Indeed deposition area for vegetation canopy is more important than for bare soil. These maxima result from the deposition of large droplets between 10 to 20 μm . The percentage of large droplet peak between 1:00 a.m. and 2:00 a.m. (Fig. 5(a)) and decreases just after 2:00 a.m., consequently does the flux. Until the end of fog event 1, net fluxes of water on cabbage and grass are comparable. Deposition on cypress is a more complex phenomenon than on short vegetation canopies, mostly because of its 3D structure and overall size which represents an obstacle to the air flow and which may influence turbulent movements just above the surface. Therefore cypress tends to intercept a larger quantity of water droplets but the deposition rate is strongly variable and does not depend only on the LWC and the droplet diameter. During fog event 2 (Fig. 8), the net flux of water for cypress is at least twice the deposition rates on cabbages and grass. The net

flux of water on bare soil is close to that on short vegetation for both events. For fog event 2 the net flux of water on bare soil is below $10 \text{ g m}^{-2} \text{ h}^{-1}$ (less than for fog event 1) even though the average LWC is higher.

During fog event 1, for short vegetation the evaporation process prevails at the same time around 7:00 a.m. and net flux of water around $50 \text{ g m}^{-2} \text{ h}^{-1}$ is observed (Fig. 7).

Deposition Velocity

In order to point out the dominant process of fog droplet deposition, deposition velocities V_g were calculated based on net flux of water $\Delta m/\Delta t$ and LWC values, then compared to sedimentation velocities V_s (Eq. (7)) for 3 droplet sizes (Figs. 9 and 10). As seen previously (Figs. 3 and 4), most 10 μm . Therefore theoretical sedimentation velocities were calculated for droplets of 10 μm , 20 μm and 50 μm , using Eq. (7).

Regarding fog event 1, the mean deposition velocity was $10 \pm 1 \text{ cm s}^{-1}$ for bare soil, $13 \pm 1 \text{ cm s}^{-1}$ for cabbage cm s^{-1} , $16 \pm 2 \text{ cm s}^{-1}$ for grass and $31 \pm 4 \text{ cm s}^{-1}$ for cypress (Table 2).

Deposition velocities are similar for short vegetation (grass or cabbage) and bare soil confirming the observation by Price and Clark (2014) who have shown that there were only small velocity differences between low canopies they experimented on. The canopy types tested by (Price and Clark, 2014) included artificial grass, metalized artificial grass, real live turf, real dead turf, real live long turf and real dead long turf. For cypress the mean deposition velocity

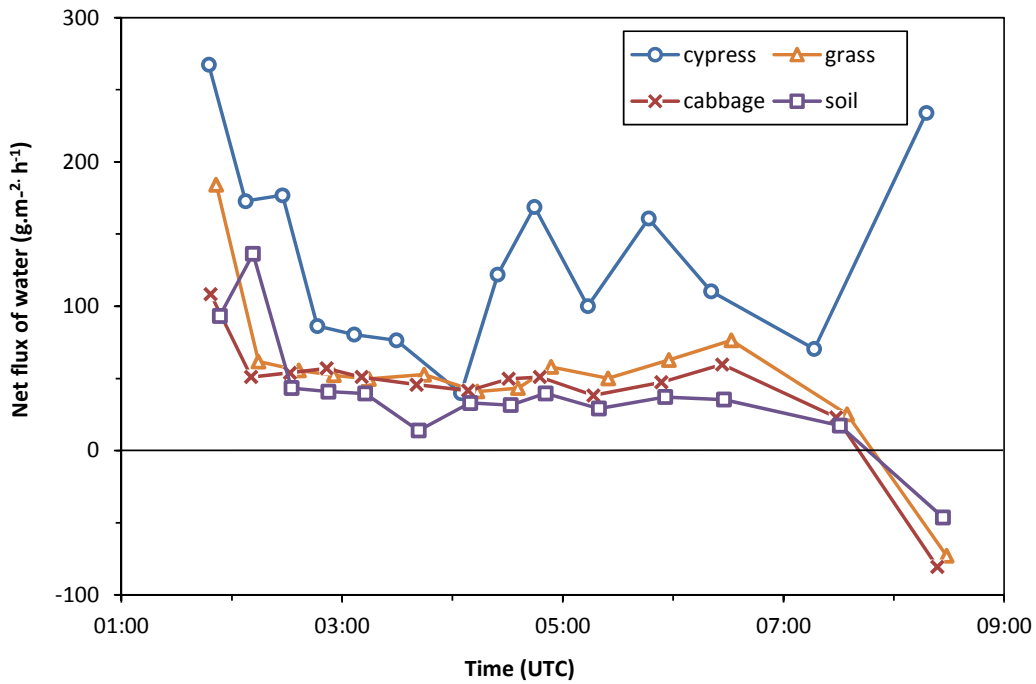


Fig. 7. Net flux of water during 31 October 2015 fog event measured by weighing method.

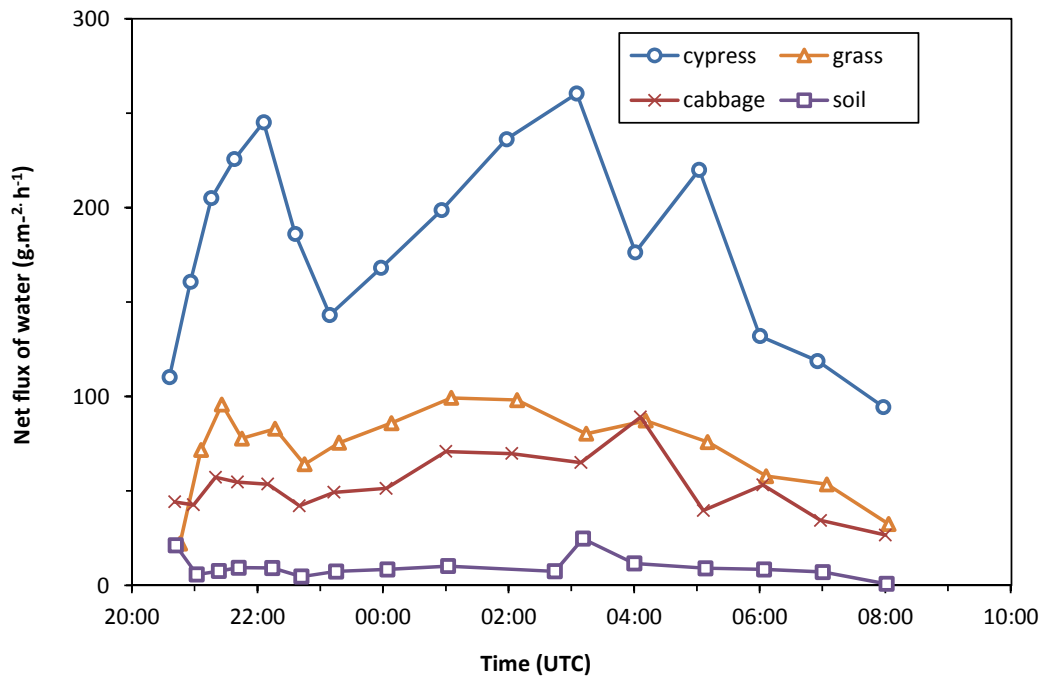


Fig. 8. Net flux of water during 1–2 November 2015 fog event measured by weighing method.

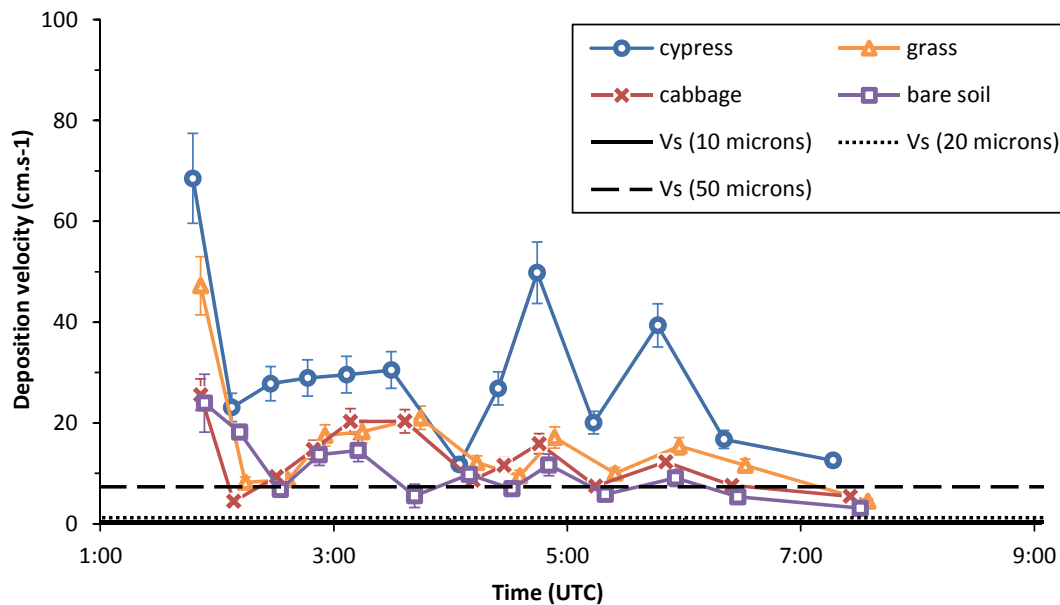
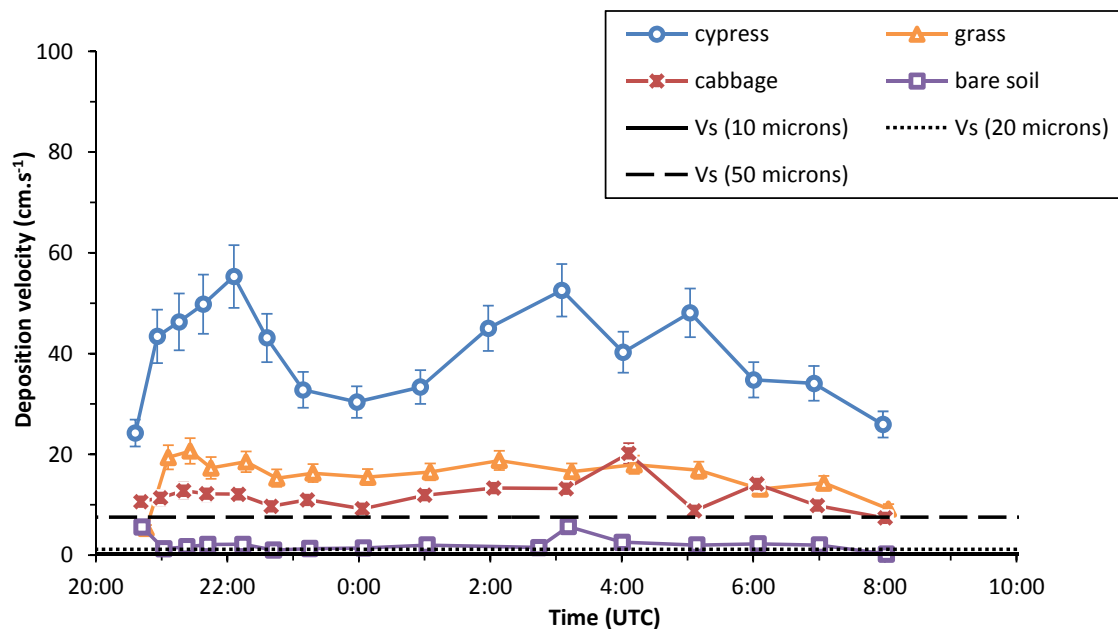
is 3 times higher than the mean deposition velocity on bare soil. This can be explained by turbulent process around the tree components that may contribute in a significant way to the droplet impaction thus leading to higher deposition. As Herckes *et al.* (2002) observed for cloud deposition, the contribution of sedimentation compared to impaction of fog droplets can be negligible on vegetation surface.

During both fog events, 20 to 50 μm droplets represented 40% of the LWC during the mature phase. If dominant

process of fog deposition is sedimentation, deposition velocity values should range from 1.2 to 7.6 cm s^{-1} respectively, corresponding to sedimentation velocities calculated for 20 and 50 μm droplets. Surprisingly the deposition velocity on bare soil (10 cm s^{-1}) is higher than values of sedimentation velocity calculated for 20 and 50 μm droplets. As observed from Table 2 and Fig. 9, the standard deviation for deposition velocity on bare soil is 4.6 and the values are ranging from 24 to 3 cm s^{-1} . Therefore for fog event 1, it is not possible

Table 2. Mean deposition velocity for fog event 131 October 2015 and fog event 2 during 1–2 November 2015.

Surface	Mean V_d (cm s^{-1})	Standard deviation of V_d	Mean V_d (cm s^{-1})	Standard deviation of V_d
	31/10/15	31/10/15	01–02/11/15	01–02/11/15
bare soil	10.3	4.6	2.2	0.9
cabbage	12.6	5.2	11.7	2.0
grass	15.5	6.7	15.7	2.7
cypress	31.1	11.8	40.0	8.0

**Fig. 9.** Deposition velocity during 31 October 2015 fog event and sedimentation velocity for 10, 20, 50 μm droplets.**Fig. 10.** Deposition velocity during 1–2 November 2015 and sedimentation velocity for 10, 20, 50 μm droplets.

to highlight the dominant process of fog deposition on bare soil. For fog event 2 (01–02/11/2015), mean deposition velocity was $2.2 \pm 0.2 \text{ cm s}^{-1}$ for bare soil, $12 \pm 1 \text{ cm s}^{-1}$ for cabbage, $16 \pm 2 \text{ cm s}^{-1}$ for grass and $40 \pm 4 \text{ cm s}^{-1}$ for

cypress (Table 2). As for fog event 1, there is a higher deposition rate on every type of vegetation than on bare soil. Mean deposition velocity on bare soil is in the same order of magnitude than sedimentation velocities for very

large particles, ranging from 20 to 50 μm (Fig. 10). In this case sedimentation is supposed to be the key process of droplet deposition on bare soil.

Deposition velocities acquired by weighing method are compared to values obtained by eddy covariance and throughfall method found in the literature. Thalmann *et al.* (2002) determined fog deposition fluxes of inorganic compounds on grass and needle leaf forest (spruces) using the eddy covariance method. Based on this flux data, Katata (2014) calculated deposition velocities of 7.5 cm s^{-1} for spruce (LAI = 6.4) and 2.7 cm s^{-1} for grass. Deposition velocity on grass and needle-leaf trees obtained by weighing method are on average respectively 6 and 5 times greater than deposition velocity found with eddy covariance method by Thalmann *et al.* (2002). For spruce forest, deposition velocities ranging from 19 to 39 cm s^{-1} for cloud droplets were found by (Pahl *et al.*, 1995) using throughfall collectors. Those values are closer to deposition velocity on cypress (31 \pm 4 and 40 \pm 4 cm s^{-1}) than values obtained by eddy covariance. Throughfall measurement and the weighing approach are quite similar because fog water deposited on canopy surface level is measured whereas for the eddy covariance method a net flux of water defined as the difference between upward flux and downward flux is measured above the canopy. Holwerda *et al.* (2006) demonstrated that net fog water fluxes measured at 4 m above a forest in Puerto Rico could represent only ~40% of the fluxes at the canopy level itself due to the condensation of water vapor as the air moves upslope. Furthermore for fog deposition on needle leaf forest, deposition velocities are ranging from 1 to 92 cm s^{-1} mainly for high elevation sites (Katata, 2014). Such large range of velocity can be explained by the variety of applied methods during different fog event and on various experimental sites. Thus even if the container covered by small cypress may not be representative of a real needle leaf forest, the edge effect visible in both cases was taken into account to assess deposition velocities for cypress thanks to the spray painting experiment.

During fog event 1 the mean wind speed 4 m above the ground level was 3.8 m s^{-1} while lower 2.8 m s^{-1} , is recorded for the event 2. For wind speed above 4 m s^{-1} some adaptations of the weighing method might be necessary to use precision balance.

CONCLUSION

The aim of this paper was to estimate the fog droplet deposition rate and the velocity of fog deposition on different plant types via field experiment. Deposition velocities obtained by the weighing method indicate the importance of the turbulent process of fog deposition on vegetation. Whatever the fog event, there is a higher deposition rate on every type of vegetation than on bare soil. In addition, the higher the plant height and the more complex the plant leaf, the higher the deposition velocities. Indeed, for the two fog events studied, fog deposition on vegetation canopies is more important than deposition on bare soil. Further experimentation is required to quantify the effect of wind speed on fog water deposition. In very windy conditions, the

precision balance sensitivity may require some adaptations to cope with wind-induced measurement artefacts.

Even if transposing the results obtained on 50 cm-tall cypress to a needle leaf forest may be complex, the present experiment shows that the “edge effect” must be taken into account with regard to fog deposition.

When compared to values from previous studies, there is an important discrepancy between deposition velocities obtained by the weighing method and those acquired by eddy covariance. One reason may be that the fog water flux measured at the canopy level is greater than the net fog water flux above the canopy (Eugster *et al.*, 2006; Holwerda *et al.*, 2006). Moreover, the deposition process depends on many variables, including turbulent conditions, the size distribution of particles, the canopy type and the topography of the field site; thus, it is important to acquire a wide range of data for different conditions. Due to the few assumptions it requires, the weighing method can be set up easily in various terrestrial environments, making it possible to acquire valuable and relevant parameters for fog modeling. The weighing method is suitable for comparing fog deposition on different surfaces or objects at the same time.

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