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"DER NEBELNIEDERSCHLAG IM WALD UND SEINE MESSUNG"

(FOG PRECIPITATION IN FORESTS AND ITS MEASUREMENT)

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FOG PRECIPITATION IN FORESTS AND ITS MEASUREMENT

By: Dr. Rubner

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The study of the water cycle in the forest has for a long time been one of the most important questions in scientific forestry; it holds also great practical interest.

In spite of the complex character of growth processes, we know today that water in many cases plays a decisive role in the forest growth. Cessation of growth and poor growth are frequently connected with lack of water.

Water reaches tree roots directly by passing through the tree crowns to the soil; it may then be detained in the root zone by adhesion (reserve water) or else seep down to the ground water where the roots tap it either as ground water directly or through capillarity. In the latter cases, trees obtain their supply chiefly from the ground water; pines may use ground water standing at a depth of 5-6 m.

While the effect of precipitation upon those roots relying upon the direct water supply makes itself felt immediately, the ground water level responds only very gradually to precipitation; as a rule weeks and months are required for the ground water to reach its maximum after a period of heavy precipitation.

In supplying the forest with water, precipitation plays the most decisive role; by comparison the condensation of water vapor in the soil is of minor importance.1/ A complete knowledge of

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1/ Hartmann, Über den waldbaulichen Wert des Grundwassers. "On the silvicultural value of ground water". Mitteilung. aus Forstwirtschaft, und Forstwissenschaft, 1930.

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the precipitation received in the forest is at all events highly important in correctly estimating its water circulation.2/

2/ Cf. also H. Friedrich, Die Wasserwirtschaft im Erzgebirge. "Water circulation in the Erzgebirge". Sudetendeutsche F. - u. J.-Zeitg., 1931, No. 19 and 20.

As a rule, precipitation includes only rain and snow, but it must not be forgotten that the soil covered with forest may receive still another and not unimportant type of precipitation by condensation of very small water drops on plants.

In this it is useful to distinguish between condensation at temperatures above the freezing point and those below, or dew and fog on the one hand, and white frost and hoar-frost on the other.

Precipitation of dew and fog are distinguished by the fact that the former results from the cooling of moisture on cold objects (plant parts), whereas fog consists of very small water drops (approximately 0.02 mm. in diameter) which may remain hovering in the air, since their rate of fall is very slow on account of the air resistance. As soon as these little drops encounter such resistance, they collect into larger drops and then gently fall, changing their horizontal movement into a vertical one. For this reason, Süring calls such precipitation (in contrast to rain and snow) horizontal precipitation 1/; hoar-frost too, falls into this class.

1/ Cf. Linke, Niederschlagsmessungen unter Baumen "Precipitation measurements under trees" Meteorolog. Zeitschr. 1921, p.277.

Dense fog may contain 5 grams of water per cubic meter, so that to obtain 1 mm. of precipitation, all the water in a fog layer 200 meters in height would have to be caught (Hann, Meteorolog. Zeitschrift, 1916, p. 549).

When the diameter of a fog particle becomes approximately 0.1 mm., the hovering fog drops become a vertical rain shower.

Since precipitation from dew and fog are fundamentally different in origin, and since the former occurs after clear nights, there is in general no danger of confusing the two. For the rest, our measurements carried on in the forest for two years, have furnished no basis for assuming that dew forms on the surface of the tree crowns in such intensity as to add water to the forest soil. We may therefore, exclude dew precipitation entirely from the following discussion.

On horizontal precipitation not very much has been known thus far; the investigations undertaken are isolated and do not permit definite conclusions.

Thanks to numerous investigations, it has been known for some time, that the quantity of precipitation by fog and hoar-frost benefiting the forest may be increased. Every forester knows that on foggy days water drips from the trees, whereas the open field remains dry. Furthermore, hoar-frost shaken off the trees may under certain conditions make a snow-cascade possible, although there was no snow fall.

Primitive measurements were undertaken as early as 1899 by Ridgeway (U.S.A.), but they did not turn out satisfactorily.

Marloth,[1] was probably the first to undertake competent mea-

1/ Marloth, Über die Wassermengen Welche Straucher und Baume aus treibendem Nebel und aus Wolken auffangen. "On the quantities of water caught by shrubs and trees from drifting fog and clouds". Meteorolog. Zeitschr. 1906, p. 547.

surements on the Tafelberg in South Africa, frequent in fogs (1902-3). On the plateau, 1082 m. in height, he set up 2 rain-gauges, one of the ordinary type and a second, above which a bundle of reed grass (Calamagrostis, Tr.) enclosed in a metal gauge was attached. The receiving surface of the rain-gauge was 19.63 sq. cm., that of the bundle was 137.1 square cm. The ratio was therefore approximately I.7.

The results of his observations from Dec. 21, 1902, until Jan. 1, 1903, was striking in that the open gauge caught nothing, whereas the covered one contained 387 mm. of water. A second reading on Jan. 21 again showed no catch in the open gauge, but 371 mm. in the closed one. A third observation yielded much the same result; in a total of 56 days there were only 126 mm. in the open rain-gauge, and 2027 mm. in the closed one. This means an excess in the latter of approximately 1900 mm. Further observations of Marloth were intended to overcome the objection that the fog catcher in an isolated position caught more fog precipitation than would one located in the middle of a forest over which the fog cloud has passed. The fog would therefore, reach the rain gauge or the stand poorer in moisture. This proved indeed to be the case, since the gauge of the fog catcher in the interior of a thicket collected approximately only one-third the precipitation caught by the fog catcher standing in an isolated position in the open field.

If there were a possibility of particularly extreme conditions being responsible for the South African observations, this is certainly not the case with the investigations carried on by Linke,[2]

2/ Meteorolog. Zeitschr. 1916, p. 141 and 1921, p. 277.

in the Taunus Mountains.

He set up an ordinary rain gauge near the regular one of the Station at an altitude of 800 m. with approximately 1000 mm. of precipitation and 200 foggy days. This gauge was placed underneath a dense group of 100-year old spruce immediately adjacent to the edge of the forest. After one year's observation the gauge under the spruce had caught approximately 66% more precipitation than the isolated gauge.

But could be wind driven rain

On fog-free days (approximately 165) the annual precipitation in the open is 62.9 mm., under the spruce only 42.4 mm., approximately only two-thirds. About one-third is lost by evaporation, by run-off along the stem, and by direct absorption. At that, the loss is considerably greater during the summer than in winter, because hour-frost and snow are caught more easily by the gauge than rain.

On days with continuous fog there resulted a great excess of precipitation in the gauge underneath the spruce; an average winter month showing on such foggy days 123% more precipitation. In the average summer month, the increase was 79%, and for the total annual precipitation, 66%. This amount, according to Linke, is added to the forest soil, an increase over the amount received by the soil of open areas. In this calculation the amount running down the stem has not been considered.

Linke continued his observations of 1915 for another three years. As the first year's measurement had been made immediately under the edge of the stand where only the rain and snow blown against the stand are arrested and caught in the gauge but also, where the fog cloud meets its first obstacle and on which naturally most drops are deposited plentifully, a second rain gauge was set up somewhat deeper in the stand.

The four-year observation period, 1915-18, compared with the station gauges, showed the following excess percentage. A indicates the gauge at the edge of the forest, and B, the one in the stand.

1915-1918

	Jan.	Feb.	Mar.	Apr.	May	June
A	190	225	149	169	180	104%
B	148	181	113	103	107	87
No. of foggy days 1915-18 .	23	18	16	16	18	12

	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	157	136	151	159	301	154%
B	99	88	108	112	259	160
No. of foggy days 1915-18 .	14	18	17	23	24	26

	Winter	Spring	Summer	Autumn	Annual	
A	184	162	131	152	157	)
B	159	107	90	139	123	) yearly
No. of foggy days.	22	15	14	21	18.4	) average

From these figures the reader will clearly see the greater catch of precipitation at the edge of the stand for the reasons given.

In the interior of the stand, there is a material increase in precipitation; in winter by nearly 60%; in autumn by 39%; in spring by 7%; whereas for the summer it amounts to minus 10%.

But the last two figures, too, are still strikingly high if it is borne in mind that without the "horizontal precipitation" an average precipitation of only approximately 70% in spruce forests can be expected. This is therefore to be considered in the above figures for spring and summer; there would then result an excess of 37% or 20%, as a consequence of the caught horizontal precipitations.

This, it is true, is correct only if the rain-gauge is set up in the stand in such wise that it caught a rainfall equivalent to the average, a supposition which probably does not hold in reality. To obtain an average for the precipitation reaching the forest soil, a single small gauge is insufficient. A set-up of the apparatus in an opening or within the reach of drippings from the tree crowns may cause, as has been shown by Hoppe, very considerable deviations, up to 47% of the total rain received in the open country, and this under the same spruce! However important the four-year precipitation records of Linke may be, this deviation is of the greatest importance and prevents us from generalizing from the results. Linke himself pointed out this fact.

Let us now compare with these data from the Taunus precipitation records of the Karlsberg station in Silesia, having 120 foggy days 1/ at an altitude of 740 m. above sea-level.

1/ J. Schubert, Niederschlag, Bodenfeuchtigkeit, Schneedecke in Waldbestanden und im Freien. "Precipitation, soil humidity, snow cover in forest stands and in the open". Meteorolog. Zeitschr. 1927, No. 4/5.

With precipitation of 800 mm. in the open, the forest precipitation underneath an 80- to 100-year old spruce showed the very high percentage of 89 for the whole year, of 85 for the summer (observation years 1882-96).

Schubert then proceeds to a selection of the foggy days at this station, on which days the precipitation can only originate from the thick fog (30 days during the years 1881-85). He found that out of these 30 days, the fog precipitation is absent from the forest rain gauge on approximately 13 days, while small amounts of water were found in the rain gauges in the open. Generally speaking, he found the amount of measurable precipitation originating in dense fog to be greater in all free gauges than in the forest, whereas the quantity of fog water in the forest exceeded at times the quantity in the open country. The figures are however very small, amounting in only 5 cases to more than 0.5 mm.

On the basis of these observations Schubert believes that the small quantity of water originating in fog alone cannot increase the percentage of the forest share; nevertheless, a relative increase of precipitation is found in the forest on foggy days.

Observations at Sonneberg,1/ during August and September and

1/ Altitude above sea-level 777 m.; 1231 mm. of precipitation in the open; 1041 mm. in a spruce forest; 125 foggy days.

extending over ten years, allowed investigators to recognize from six month averages an increase in the forest precipitation by approximately 3%, an increase of the number of foggy days per month by 11, namely from 5 to 16. Averaging all stations, the frequency of fogs increased from summer to autumn by nearly six days, but in winter it remained nearly unchanged, whereas there was an increase of 10 percent in precipitation in the forest.

These conclusions are the exact opposite to those of Linke, even if one supposes an essentially more frequent fog formation in the Taunus (200 as compared with 120 days); yet it appears questionable whether in view of the approximately equal elevation, total precipitation, and forest (spruce!), the precipitation percentage caught in the forest can be so very different.

As the last publication bearing on the subject I must mention the work of Descombes "The Influence of Deforestation upon the occult Precipitations." 2/

2/ Annuaire de la Société météorologique de France, 1920.

I follow in this the critical remarks of W. Schmidt in his summary published in the Centralblatt f. d. ges. Forstwesen, 1921.

At Bordeaux-Floirac, an artificial plant, 30 cm. in height, wrapped in wool, daily yielded 0.6 mm. excess in precipitation. Under the climatic conditions there prevailing, it is probably less a question of fog precipitation than of dew condensation. Descombes, from this small artificial plant and the excess condensation water yielded by it, applies this to conditions to be found in a tree 10 meters in height. He thus obtains the very high figure of 1190 mm.

of 'occult precipitation', that is, as much in condensation of fog and dew as in the annual quantity of rain.

For mountainous regions, Descombes arrives at the conclusion that the addition of precipitation by fog equals several times the ordinary precipitation, in a single instance by fifteen times.

For this reason, according to Descombes the advantages to be gained from forestation would be very considerable and hardly conceivable.

W. Schmidt raised, however, serious objections against this method of drawing inferences. He says:

> It is incorrect to generalise from results obtained in a given place.
>
> The method of computation from an experiment studied on a small scale to conditions on a far larger scale is very dangerous.
>
> Generally, the supply of water vapor is not as inexhaustible as might be supposed by this combination.

These critical remarks of W. Schmidt are fully shared by the writer.

From the publications quoted concerning horizontal precipitation the following conclusions may be drawn:

(1) Forest investigations must be interested in horizontal precipitation, even if the results thus far obtained are only partly correct and are limited to certain regions with frequent fogs.

(2) A simple reliable measuring instrument is still lacking for horizontal precipitation; the same holds true for a uniform unit for this type of precipitation. Such a unit is required so that the data obtained are comparable with each other.

(3) Of the investigations undertaken thus far the results of Linke obtained in the Taunus are comparable in themselves for our conditions; but his figures need checking if only in view of the data given by Schubert.

During the search for a usable measuring apparatus for fog precipitation, Dr. Alt, Director of the Saxon State Meteorological Station at Dresden, made the suggestion of using glass staffs, set up above an ordinary gauge, as is shown in fig. 1. To keep off vertical precipitation, a corresponding roof had to be built above the arrangement.

This fogmeter (as we shall call it briefly in the following pages) was constructed for the first time in the fall of 1928 by the technician of the Saxon Meteorological Institute. It was set up in October 1928 in the immediate vicinity of the district forest office at Kriegwald in the Erzgebirge, in an enclosure at an altitude of 745 m. above sea-level (Nm 3/4 in the sketch of fig.2). This site had been chosen first because in our experience the frequency of fog days (128) per year is great 1/ in that region, and second, because

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1/ On the basis of a 20 year observation (1886-1905),

Average number of foggy days at Kriegwald distributed as follows over the different months:

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
14	11	12	11	8	7	5	5	10	12	17	16	128

Forstmeister Kirchner is a very reliable councellor and observer, whom we wish to thank especially in this connection.2/

2/ My former assistant, Chief Forester Priemer, also rendered valuable service in the installation of the fog station.

The effect of the fogmeter is most simple: the little fog particles, hitting the glass staffs, are caught there, run along these staffs and thus are received by the gauge. The whole problem is to determine the size of the catchment surface and its ratio to the horizontal catchment surface of the fogmeter.

The number of staffs was for a short time 57; later it was reduced to 56. With a diameter of the single staff of 6 mm. and a length of 97.5 cm. (it is true, 10 cm. lie below the margin of the rain-gauge) we have a vertical catchment surface of the single staff of 0.00585 m^2, for 56 staffs 0.328 m^2 or approximately 1/3 m^2. We thus computed as catchment surface not the surface of the staff, nor half its surface, but the area of the maximum diameter, since normally one must reckon with a parallel hitting of the little drops upon the staffs in one direction. The horizontal catchment surface of the fogmeter amounts to 1/20 m^2.

The first observation period ran from Oct. 12 to Nov. 17, 1928. According to the observations of Forestmaster Kirchner in October there were measured 35.3 mm. in the fogmeter, whereas the readings in the rain-gauge of the Station gave only 19.2 mm. In the November period the ratio was 51.9 to 67.5 mm.

Those figures are valid, however, only for a horizontal catchment surface of 1 m^2 above which there stand 20/3 m^2 of a vertical catchment surface, as will be seen without difficulty from the experiment arrangement. To reach a uniform measure in the measurement of horizontal precipitation, I suggest for a measuring unit, a vertical catchment plane of one m^2 above a horizontal catchment plane of the same size. In our case, we should have only 3/20 of the above figures of 35.3 and 51.9 mm. as unit measure of horizontal precipitation (5.3 or 7.8 mm.). It goes without saying that these figures give no indication as to horizontal precipitation in the forest; further investigations were required for this.

The fogmeter set up in 1928 was perhaps still in need of supplementation. On the other hand the glass staffs were quite fragile, particularly on the sudden occurrence of hoar-frost. In the second place, given a strongly agitated atmosphere, in addition to the fog rain, and snow, precipitations were blown laterally into the device thus interfering with the result.

At the suggestion of Dr. Alt, we therefore used aluminum instead of glass staffs. To obviate lateral penetration of rain and snow, we made the roof larger, although naturally this has its limits (fig. 3). Thus the penetration referred to could not be prevented altogether, so that on such rainy and snowy days the observations no doubt lose in value.

All the same, the results have not been measurably disturbed thereby, and the fog observations did not lose in value, for we calculated separately the measurements taken on rainy and snowy days. In addition, the result was assured by the set-up of several fogmeters, especially during 1931.[1]

[1] In table 1 the total fog precipitation plus the added rain and snow is quoted in parenthesis with the pure fog precipitation.

To find out whether fog precipitation on horizontal areas stands really in a direct ratio to the size of the vertical catchment plane, at the suggestion of Dr. Alt, we set up two fogmeters under one roof in the camp, the one with 56, the other with 28 staffs (fig. 3). If the above supposition holds, the second fogmeter would have to indicate about half the precipitation of the first. As a matter of fact, table 1, under the rubric Measuring Apparatus No. 3 and 4, shows that this supposition is justified.

A complete agreement is impossible for the sole reason that with a horizontal catchment plane of the same size the more densely arranged 56 staffs cover each other better, thus allowing somewhat less fog to reach the staffs in the rear. This is in agreement with the fact that the percentage in fogmeter 4, with staffs at twice the distance, frequently amounts to more than 50%. On the average, during 1931, the result is exactly 50%.

We may say therefore, that the fogmeter functions with a degree of precision that can reasonably be expected. It is therefore a practical apparatus.

In 1929 we set up two fogmeters with 56 staffs each, at a distance of approximately 250 m. from the Office of the Forest District of Kriegwald, in a 95-year old normal spruce stand (31 l), and along the southern margin of the spruce plantation north of it (31 p) at a distance of about 10 m. from the edge of the stand, on a somewhat elevated place, so that the fogmeter stood somewhat above the spruce tops (cf. fogmeters 1 and 2 on sketch of fig. 2, and fig. 3 and 5). We expected the fogmeter standing in the old spruce forest to show, on the average, lower fog precipitation as a result of the fog-water caught by the stand than the fogmeter standing in the plantation. The average of the 1929 observations gave the exact opposite; in the forest 9.09 mm. per m² of vertical catchment plane and in the plantation only 6.80 mm. of fog precipitation water were measured; including the vertical precipitation added for the reasons set forth above, the figures are 9.63 or 9.37, from which it will be seen that in the forest only very small quantities were blown in laterally. In 1930 the true fog precipitation in the forest is somewhat lower than in the plantation. In 1931, on the other hand, the proportion is reversed.

At all events, the result is striking and unexpected, since it is to be supposed that the fog is secreted not only on the edge of the stand (by the stems and lower branches), but also that, as a result of the reduction of the wind motion in the stand, fog elimination is likewise reduced.

The reasons for this contrary behavior have not yet been cleared up. We intended to make a special investigation, but the difficulty of obtaining days with continuous fogs for our observations has not yet permitted the carrying out of this project. Furthermore, for this purpose we need complicated registering apparatus, which we did not have at our disposal.

It should be pointed out that the camp fogmeter No. 3 in all cases shows less fog precipitation than the forest fogmeter. Whether the reason must be sought in the fact that the fog driven above the experiment stand has already lost water on the spruce crowns does not seem so certain on the basis of what has been said above.

A graph representing the average water quantity observed in the various months in fogmeters 1 and 3 is found in fig. 6. The years 1928 and 1929 showed relatively high fog precipitation in the autumn months, in contrast to the years 1930 and 1931. The year 1930 again shows much fog precipitation in April. The quantity of water has been computed on the basis of our measuring unit (see above).

The absolute quantities are very small in the vegetation months (May to September inclusive). As we shall see presently, these figures must be approximately doubled for our forest.

Since the set up of the protected fogmeters could give only an intimation but no solution to the question of real fog precipitation in the forest, we set up rain-gauges in the forest in the spring of 1930, again with the kind help of Dr. Alt. In this we were favored by the fact that the State Meteorological Station could place at our disposal four rain-gauges each with 1/2 m^2 of catchment surface.

From what has been said above one would think the value of precipitation measurements in the forest by means of ordinary rain-gauges of 1/20 m^2 of catchment plane very problematical. But we would expect that a set up of four rain-gauges of 1/2 m^2 each in the proper distribution would register correctly the real average of the forest share of the entire quantity of precipitation. The fogmeter remained standing in the middle of the group of rain-gauges No. 7-10 (cf. fig. 5 and sketch in fig. 7).

Two ordinary small rain-gauges were placed beside the fogmeter in the plantation (fig.4), and served as control, for which purpose we had in addition the Station rain-gauge in the Forest farm of Kriegwald.

The daily readings of the 6 rain-gauges and 4 fogmeters required much time and labor and were carried out to our entire satisfaction by Mr. Körner attached to the office of the Forest District, during 1930-1931.

It was from the beginning arranged to make the observations in the frost-free season of the extended vegetation period, to save time and money. At the same time, the water circulation of the forest is particularly important during this period of the year.

The total figures per month and per year are given in table 1 (p.139).

From this we see that the precipitation in rain-gauges 5 and 6 shows very good and harmonious results.

In part considerable differences were obtained from the figures of the Station rain-gauge, although the latter was placed only at a distance of about 250 m., though within the Forest farm.

Table 1. Fog and Rain Precipitation by Months and Years

	Place	Gauge	1928 Oct. 12-31	1928 Nov. 1-17	1928 Total	1929 May 19-31	1929 June	1929 July	1929 Aug.	1929 Sept.	1929 Oct.	1929 Nov.	1929 Dec. 1-15	1929 Total
Fog precipitation (mm) per 1/3 m^2 of vertical catchment plane (in No.4 per 1/6 m^2)	Plantation	1	-	-	-	0.47	0.32	0.01	0.03	0.00	1.03	2.45	2.19	6.50
			-	-	-	-	0.89	(0.43)	-	(0.28)	(1.41)	-	(3.41)	(9.37)
	Forest	2				0.62	0.25	0.01	0.01	0.00	0.78	4.44	2.98	9.09
								(0.13)	-	(0.03)	(0.82)	-	(3.33)	(9.63)
	Camp	3	1.76	2.60	4.36	0.95	0.37	0.00	0.02	0.00	0.69	3.30	2.37	7.67
						-	(0.43)	(0.15)	-	(0.05)	(1.06)	-	(3.30)	(9.16)
		4	-	-	-	0.39	0.10	0.00	0.00	0.00	0.38	2.03	1.55	4.45
			-	-	-	-	(0.14)	(0.05)	-	-	(0.46)	-	(2.10)	(5.17)
	Average	(1 + 3)/2	-	-	-	0.71	0.33	0.01	0.03	0.00	0.86	2.88	2.28	7.19
		5	-	-	-		(0.66)	(0.29)	-	(0.17)	(1.24)	-	(3.36)	(9.24)
Total precipitation in mm.	Plantation	6	-	-	-	Numbers in parenthesis - Total fog precipitation plus added rain and snow blown in.								
	Average Precipitation in the station rain-gauge	(5 + 6)/2	-	-	-	-	-	-	-	-	-	-	-	-
			19.2	67.5	86.7	24.1	90.8	106.7	59.0	24.6	125.5	33.7	20.5	384.9
	Forest	7	-	-	-	-	-	-	-	-	-	-	-	-
		8	-	-	-	-	-	-	-	-	-	-	-	-
		9	-	-	-	-	-	-	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-	-	-	-	-
	Average	(7-10)/4												
	Percentage of forest share	(7/10)/(5/6)	-	-	-	-	-	-	-	-	-	-	-	-

Table 1 (Cont'd.)

	Place	Gauge	1930 Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total	Remarks
Fog precipitation (mm) per 1/3 m^2 of vertical catchment plane (in No. 4 per 1/6 m^2)	Plantation	1	2.85 (2.95)	0.69 (1.21)	0.75 (0.76)	0.10 (1.61)	0.27 (2.58)	0.38 (0.52)	0.61 (0.71)	0.04 (0.30)	5.69 (10.64)	(1) Fog observation during the entire mo. Precip. obser. only from 6-8-30. (2) as a result of unsuitable set up of roof above fogmeter No fog prec. 3-4
	Forest	2	2.06 -	0.69 (1.07)	0.67 -	0.15 (0.27)	0.37 (0.50)	0.42 -	1.05 (1.07)	0.14 (0.16)	5.54 (6.22)	
	Camp	3	2.76 -	0.97 (2.15)	-(2) -	0.07 -	0.13 (0.18)	0.30 -	0.33 -	0.04 (0.10)	4.50 (5.89)	
		4	1.76	0.39 (0.74)	-(2) -	0.02 -	0.06 (0.08)	0.22 -	0.22 -	0.02 (0.06)	2.69 (3.10)	
	Average	$\frac{1+3}{2}$	2.80 (2.86)	0.83 (1.68)	0.75 (0.76)	0.09 (0.84)	0.20 (1.38)	0.37 (0.41)	0.47 (0.52)	0.04 (0.20)	5.52 (8.65)	
Total precipitation in mm.	Plantation	5	-	-	53.4	124.1	142.2	69.7	139.0	18.6	547.0	
		6	-	-	53.7	126.0	140.0	69.6	135.0	15.0	542.3	
	Average	$\frac{5+6}{2}$	-	-	53.6	125.1	141.1	69.7	137.0	16.3	544.8	
	Precipitation in the station rain-gauge	-	-	-	49.7	137.1	160.7	77.2	139.0	20.7	584.4	
	Forest	7	-	-	32.5	83.6	94.1	39.3	85.0	6.2	340.7	
		8	-	-	38.5	73.9	89.3	35.0	75.6	4.2	316.5	
		9	-	-	36.0	118.3	130.4	52.0	106.4	7.1	452.2	
		10	-	-	37.3	102.5	115.3	42.5	30.5	5.3	393.4	
	Average	$\frac{7-10}{4}$	-	-	39.6	94.0	107.3	42.4	89.4	5.7	375.7	
	Percentage of forest share	$\frac{7/10}{5/6}$	-	-	72.0	75.1	76.0	60.8	66.0	31.2	68.2	

Table 1 (Cont'd.)

	Place	Gauge	1931 May	June	July	Aug.	Sept.	Oct.	Total
Fog Precipitation (mm) per 1/3 m² of vertical catchment plane (In No. 4 per 1/6 m²)	Plantation	1	0.43	0.20	0.11	0.05	0.25	0.30	1.34
			(0.68)	(0.25)	(0.33)	(0.53)	(1.11)	(0.36)	(3.29)
	Forest	2	0.61	0.84	0.17	0.12	0.87	0.21	2.22
			-	(0.32)	(0.41)	(0.69)	(2.32)	-	(4.56)
		3	0.55	0.14	0.10	0.27	0.87	0.12	2.05
	Camp	4	0.28	0.06	0.04	0.13	0.44	0.08	1.03
	Average	(1 + 3)/2	0.46	0.17	0.11	0.16	0.56	0.21	1.69
			(0.62)	(0.21)	(0.22)	(0.40)	(0.99)	(0.24)	(2.68)
Total precipitation in mm.	Plantation	5	33.3	105.4	162.4	64.2	154.8	29.6	549.7
		6	33.9	105.8	164.3	63.4	150.7	28.3	546.4
	Average	(5 + 6)/2	33.6	105.6	163.9	63.8	152.8	29.0	548.7
	Precipitation in the station rain-gauge		34.7	118.1	175.7	62.9	161.9	41.0	594.3
	Forest	7	13.2	61.3	102.6	29.7	105.3	15.4	326.3
		8	19.2	47.6	53.5	37.0	93.1	11.8	292.2
		9	21.9	85.4	162.1	52.2	132.9	25.2	479.7
		10	26.5	66.6	129.1	51.1	129.8	23.7	426.8
	Average	(7-10)/4	20.2	65.2	119.3	42.5	114.9	19.0	381.1
	Percentage of forest share	(7/10)/(5/6)	60.0	61.7	72.8	66.6	75.3	65.5	69.5

Furthermore, the 4 forest rain-gauges 7-10 show among each other the expected very considerable differences, based on their different set-up under the spruce crowns.

In both years rain-gauge 9 shows the largest, rain-gauge 8 the lowest quantities of precipitation water. As will be seen, the differences are very considerable for the period observed, amounting, with reference to the open country precipitation of the plantation, to 83.0 or 58.1% for the year 1930, to 87.4 or 53.3% for the year 1931.

In 1930, the average precipitation in all forest rain-gauges during the observation period amounts to 68.2% in the forest as compared with the plantation, and to 69.5% in 1931. For the different months, table 1 gives the basic data.

To these figures there would have to be added the precipitation water flowing down the tree stems. In the spruce forest (in contrast to the beech forest) it amounts to only a few percent, which may be safely neglected. For the forest share the above percentage figures of precipitation per observation period appear small if compared with the data of Schubert and, especially with those of Linke, whose stations were under similar conditions.

Thus Schubert gives, for the summer months at the Karlsberg station, a forest share of 83%, at the Sonnenberg station a forest share of 75%, whereas for the whole year the corresponding figures are 89% and 85%. According to Linke, only the forest share in the months of June, July and August, amounting to 87%, 99%, and 88%, fall below the precipitation in the open.

According to the investigations of Hoppe 1/ (cf. the instructive graph of Geiger, Das Klima der bodennahen Luftschichten, "The climate of the atmospheric layers near the soil", 1927, fig. 50), the size of the forest share in precipitation depends not only upon the forest species and the season, but in large part also upon the amount of the precipitation. In the case of rains of less than 5 mm. only 1/4 to 1/3 is allowed to pass through the crowns of the spruce stands. In the case of precipitation of 20 mm. and above, approximately 2/3 reach the soil of the spruce stand. Precipitation of less than 1 mm., according to Bühler, never reaches the forest soil.

These conditions also hold for our observations; the month of July of 1931 especially offered opportunities for such observations, since in its first half it had eight rainy days, four of which show-

1/ Regenmessung unter Baumkronen, "Rain measurements under tree canopy", Mitt. aus dem forstl. Versuchswesen Österreichs XXI.

ed precipitation of more than 10 mm. (daily maximum 54.3 mm.), whereas in the second half, with 11 rainy days, there was no precipitation of more than 10 mm., though eight had a precipitation of less than 5 mm. Upon the whole, in the first half of July the average of rain-gauges 5/6 was 130.7 mm., in the second half 32.6 mm.

In the first half of July, the average of rain-gauges 7-10 was 117.1 mm. (between 71.6 and 139.7 mm.)

The forest proportion of the precipitation in the first half of July then amounts to 82, in the second half of July to only 47%. It is further to be noticed that in the first half of July there were two days with a continuous fog and two with a temporary fog; but in the second half of this month there was not a single foggy day. Precipitation in the forest has thereby no doubt been increased as will be seen in the discussion later. An error for the first half of July exists insofar as on July 5, as a result of very strong rain, the gauges overflowed, so that the determination of the water quantity caught in the four vessels had to be obtained by percentage calculation on the basis of the distribution on other days of heavy precipitation. Nevertheless, no serious error is likely to have occurred. It is possible that the percentage of 82 had been somewhat reduced with normal measurements.

The main question still remains to be cleared up: the relation of fog precipitation to total precipitation in the forest. The answer is made difficult by the fact that on foggy days generally also a vertical precipitation is caught by the gauges underneath the tree crowns. If such were not the case, one might simply give the total of the water caught in the forest on foggy days.

Since this is not possible, the precipitation was determined on foggy and fog-free days during 1931. Table 2 gives the data unexpectedly resulting in the fact that on the monthly average the forest share in precipitation on foggy days in the gauge which in each case contained the maximum quantity of water in most cases exceeds the precipitation in rain-gauge 5/6 or at least approaches it 100%. If we consider, on the other hand, the precipitation quantities on fog-free days, we notice that they all remain considerably below 100%, lying in general between 70% and 80%. Even the supposition that the rain-gauge containing as a rule a maximum of precipitation water had a particularly favorable location within reach of the drops of a spruce crown, cannot explain this excess: fog precipitation must be called in to explain the matter satisfactorily.

Table 2

Forest share in precipitation on foggy and fog-free days

Time	No. of days with precipitation	Share of the forest precip. in % of prec. in the open	No. of foggy days with precipitation	Fog precipitation in the free fogmeter mm. per m² of vert. catchment plane	Precipitation in the free rain-gauge mm.	Maximum forest precip. in mm.	Share of the maximum forest precipitation %	No. of fog-free precipitation days	Precipitation in a free rain-gauge, mm.	Maximum forest precipitation %	Share of the maximum forest precipitation %
1	2	3	4	5	6	7	8	9	10	11	12
1930											
July	18	75.1	3	0.27	29.4	30.5	104.7	15	94.7	91.1	96.4
August	13	76.0	6	0.60	84.2	92.1	109.3	12	57.5	45.2	78.4
September	22	60.8	10	1.02	30.8	25.4(1)	82.5	12	39.0	30.0	76.9
Oct.1 to 25	16	66.0	7	1.41	59.4	57.3	96.4	9	78.3	68.1	86.9
1931											
May 7 to 31	13	60.0	5	1.44	10.5	9.9	94.3	8	22.7	19.7	86.8
June	16	61.7	5	0.51	51.6	49.4	95.9	11	54.3	39.0	61.2
July	20	72.8	3	0.33	93.7	114.6(2)	122.4	17	69.7	49.7	71.1
August	23	66.6	6	0.48	21.1	24.2	114.7	17	43.0	31.8	73.9
September	24	75.3	10	1.68	74.5	85.5	114.8	14	79.8	65.9	82.6
Oct.1 to 27	9	65.5	2	0.78	12.4	14.7	118.6	7	16.7	12.5	74.9

(1) In this month, on the ten foggy days very slight precipitation occurred with rare exceptions, namely in the free rain-gauge: 1.3, 5.0, 2.9, 0.2, 0.5, 0.2, 7.4, 3.0, 0.8, 9.5 mm.

(2) This percentage is not trustworthy since in one day with 54.2 mm. precipitation in the open the gauges in the forest had run over and since the forest share had to be estimated on the basis of other observation days.

Comparing the average figures of the four gauges standing under the spruce crowns with the above-mentioned maximum figures, we recognize the importance of the manner of the set-up of the gauges under trees and the care to be used in the interpretation of the result obtained with only one, and this a small, rain-gauge. The forest soil receives quite different quantities of precipitation water, the quantity depending upon the coverage afforded by the tree crowns. The average can be obtained with the required exactitude only by the use of a large number of small or a small number of large gauges.

On a few days, amounting altogether to three during the two observation periods of 1930 and 1931, the free rain-gauges showed no precipitation whereas in the gauges set up in the forest we found precipitation water. When on these days all fogmeters registered precipitation, there was a possibility of establishing a comparison between the precipitation shown by the fogmeters and those benefiting the forest soil. Thus, computed for one m^2, some indication was obtained for the size of the catchment surface of the spruce crowns as compared with the catchment areas of the fogmeters.

If in the three cases referred to (Oct. 16 and 17, 1930, July 6, 1931) the average quantity of water caught is compared with the average quantity found in fogmeters 1 and 3, set up in the open, 3.5 or 5.7, or 10.4 times as much water is caught per m^2 of forest soil from horizontal precipitation as the amount registered by the fogmeters. The reason evidently is that in the spruce forest, above one m^2 of horizontal catchment surface, there stands not $1/3$ m^2 of vertical catchment plane as in the fogmeter, but much more, in our case about six times as much.

but on p. 5 [illegible] $1/3$ m^2 of vertical catch[illegible] are shown $1/20$ m^2 of fog collector here!

A direct comparison between the precipitation measured by the fogmeter and the precipitation in the forest is evidently quite impossible.

If of small rains, below 5 mm., 2/3 to 3/4 is retained by the spruce crowns, it goes without saying that the percentage is much higher in the case of dense fog. Of the latter hardly more than 10% probably reaches the forest soil. On the other hand, the fogmeter, as a result of the drops gliding easily down the aluminum rods, can suffer only slight loss, the estimation of which is possible only with great difficulty, for which reason we have assumed an elimination free from loss in the fogmeter.

Further, it is to be considered that in the fogmeters set up in the open little filtered fog, or fog not filtered at all is received, whereas in the stand, the greater the distance from the margin, the more the fog precipitation will be reduced; but even here no absolute comparison is permissible.

Finally, it goes without saying that the duration of the fog plays an important role in forest precipitation. Only when branches and needles are completely moistened, drop formation and hence precipitation will be noticed. This duration of the moistening again is very much dependent upon the density of the fog.

All the same, we may sum up our findings for the given conditions by saying that in connection with the above figures on the average six times the amount registered in the fogmeter set up freely, with 1/3 m^2 of vertical catchment plane, reaches the forest soil; this means only 1/10 of the horizontal precipitation received by the canopy. Such a computation in our spruce forest would result in 1/3 x 6 x 10 = 20 m^2 of vertical catchment plane above one m^2 of horizontal catchment plane.

On the basis of a completed counting on an experiment area, one may figure upon approximately 550 trunks per hectare, that is, with a crown projection area of approximately 18 m^2 per stem, given a density of 1.0. The actual density was however estimated to be 0.75, so that this crown projection area would amount to only 14 m^2 per stem. But this figure signifies only half the surface of the canopy since the other half lies in the 'fog shade'.

The computation may be carried out on still another basis.

According to Burger [1] one may compute on the average, per kg.

[1] Burger, Holz-, Laub- und Nadeluntersuchungen "Wood, foliage and needle investigations" Schweiz. Zeitschrift für Forstwesen, 1925.

of spruce needles, a needle surface of 5.5 m^2. If these figures are applied to the thin parts of the tree, that is, needles and thin twigs, and if we further assume that there are about 100 kg. of such small parts per average stem, we obtain a surface per spruce crown of 550 m^2. The fog-catching area would then amount to 275 m^2.

From this follows that our canopy surface, computed in a roundabout way from the fog precipitation in the forest, is correct, at all events in the order of sizes.

Summing up now the most important results of our investigations and comparing them with the investigations quoted at the outset, we may consider the following facts as established:

(1) The fogmeter set up by us has proven in principle a usable measuring instrument and makes possible comparative measurements of horizontal precipitation. In localities protected

from storm (e.g. deep in the interior of a stand) it can be used without restriction. Since in the open the fogmeter must not be set up in the wind shade (evidently the lee side, Tr.), the lateral blowing in of rain and snow cannot be entirely prevented by roofs. This circumstance may considerably reduce the accuracy of the measurements; for this reason the construction of a fogmeter not having these disadvantages would be very valuable.

(2) A comparison of the water received by a given vertical catchment surface in the fogmeter with the precipitation obtained on rain-free fog days under tree canopy permits a conclusion from the water quantity obtained in the fogmeter as to the quantity caught by the tree canopy and gliding down the stems. But in this one must always remember that the result is valid only for the forest locality in question and for the predominating weather. Furthermore, it is to be noted that only a very small percentage of fog precipitation actually reaches the forest soil.

(3) The water quantities originating in horizontal precipitation in the forest are small in the order of their sizes during the vegetation months from May to September inclusive, amounting on the monthly average to only a few mm. in 1929-1931. They do not appear to exceed 5 mm. The autumns of 1928 and 1929 show much higher figures; so does April 1929.

(4) The fact that the forest share in precipitation on foggy days may lie considerably above the precipitation on fog-free days permits the general conclusion that on foggy days in special parts of the forest the amount of precipitation may exceed the amount in the open. But I am unable to give figures since these depend upon the duration, density and movement of the fog.

(5) Linke's very high figures for the Taunus station are to be used with caution and cannot be regarded as an average of forest precipitation in foggy mountain regions, for the reason that only one gauge was used in the forest. They are however valuable because they show the very large increase in the forest share in precipitation by horizontal precipitation, the number of foggy days being large. Furthermore, Linke has proven the water-catching effect of the forest border standing in the way of the driving fog, a fact of general silvicultural interest.

(6) Schubert's figures for the stations of Karlsberg and Sonnenberg favor the assumption that the high forest share in precipitation is due also to horizontal precipitation, of

which, as was seen above, a larger percentage reaches the forest soil only in connection with a stronger vertical precipitation. For the winter months with their especially high forest share in precipitation it must however be remembered that of snow precipitation alone about 9/10 may reach the forest soil.

(7) The statements of Descombes, that the precipitation produced by fog in mountainous regions is many times the ordinary amount of precipitation, in one case amounting to fifteen times as much, is improbable on general grounds; for our conditions it is absolutely impossible.

(8) It would finally be desirable that similar observations should be made in several foggy regions in the German Central Mountains, thus furnishing further possibilities for comparisons.

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