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THE AMOUNTS OF DRAINAGE WATER AND SOLUTES FROM LYSIMETERS PLANTED WITH EITHER OAK, PINE OR NATURAL DUNE VEGETATION, OR WITHOUT ANY VEGETATION COVER

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I. INTRODUCTION

In biological research of the soil thorough knowledge of the environment is necessary. The nature of the eco-system is largely determined by the available water, and by the reactions of the matter dissolved therein. More information is available on the agriculture rather than on the forestry aspects of this problem.

The large lysimeters of the P.W.N. (Provincial Waterworks of North Holland) near Bakkum made it possible to study certain aspects of the water and salt regime in soil covered with forest. The annual reports of the P.W.N.[2] describe the lysimeter station near Bakkum, which consists of 4 lysimeters, and the director of the P.W.N. put at our disposal the chemical analyses of the drainage water during the period of 1946 to 1966.

From a study of the literature it would seem that this long series of observations provides unique information on the water and salt regime of forest soils. Because of the planning of the station four vegetations can be compared: a bare weeded, sandy plain (I), a natural dune vegetation (II), Oak (*Quercus robur*) with initially some Alder (*Alnus incana*) (III), and black Pine (*Pinus nigra* var. *austriaca*) (IV). The discussion of the results should give an insight into the water and salt regime of growing trees up to an age at which a certain stability in the regime appears.

II. THE LYSIMETERS

The construction of the lysimeters has been described by Van Nievelt [7] and Wind [9]. The situation and the vegetation cover are shown in Fig. 1.

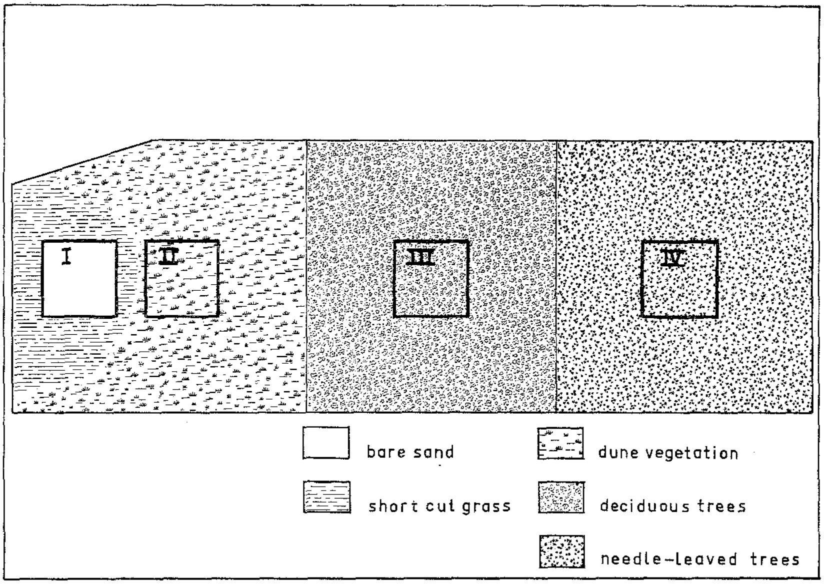


Fig. 1. General outline map of the lysimeter area.

The lysimeter tanks are square, with sides 25 m long and with an effective depth of 2.25 m. The beginning of the vegetation dates from 1940 and 1941, for at that time in and around tanks no. II and IV young trees were planted, while tank III and its surroundings were sown with acorns. In the surrounding comparison areas planting and, later, thinning was similar to that in the tanks. The growth of the vegetation was rather poor during the first years. In order to enhance growth Prof. Ir. J. H. Jager Gerlings advised covering the surface of all the tanks with a layer of black soil of about 1 cm thick, i.e., about $12\frac{1}{2}$ m^3 per tank. This was carried out in 1942 and again in 1943. When in 1945 no result was visible two tons of compost originating from a rubbish dump were deposited on lysimeter II, III and IV. This was followed in 1946 and 1949 by doses of 6.7; 9.5 and 6.9 kg nitrogen. In 1948 growth improved (Fig. 2), either because fertilization had satisfactory results, or because a change in the drainage of water had influenced the water regime of the tanks. Until April 1947 water drainage took place without any resistance. The drainage water freely discharged through the open drains into the storage tank. In dry periods, when the drains were empty, air could penetrate into the soil from below. In the spring of 1947 a valve was constructed in the main drain, so that the drains could not completely empty. The minimum water level in the lysimeters was now as high as the top of the gravel layers at the bottom of the lysimeters. The drains in those gravel layers remained filled with water, and therefore no air penetrated via the drains into the soil, while the pendular water was subjected to a counter pressure of one atmosphere, as is normal in the open field.

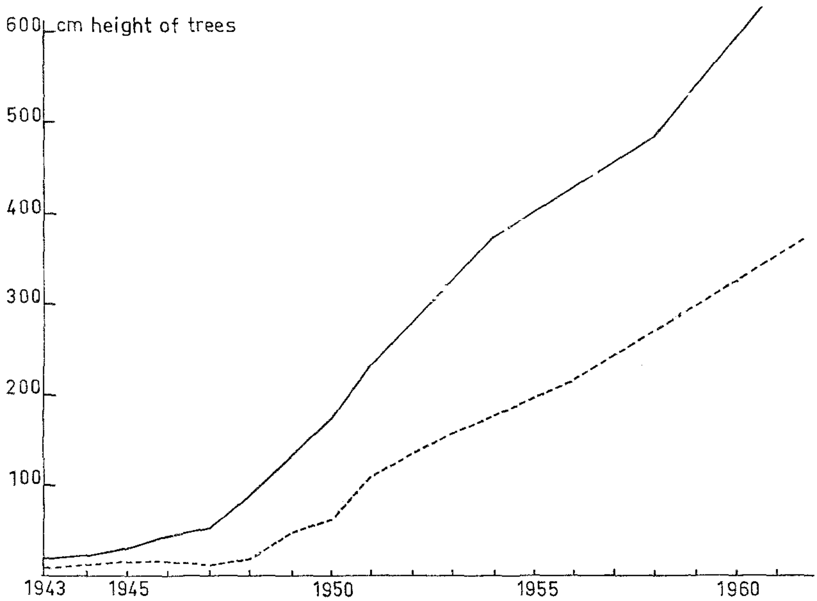


Fig. 2. Growth in length of the forest plantations.
- - - - - - - oak on Lysimeter III
———— pine on Lysimeter IV.

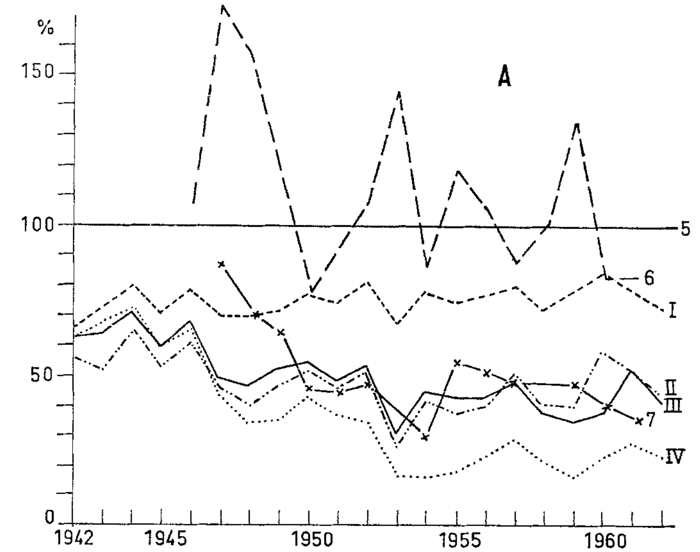
Observations

The P.W.N. made many metereological observations. Information was obtained on daily precipitation, and the quantity of drainage water was recorded daily. Samples of the drainage water from March 1946 to December 1961 were analyzed monthly by the chemical laboratory (director K. W. H. Leeflang) of the P.W.N. at Bloemendaal and the quantities of various ions in the drainage water was calculated.

III. RESULTS

a. *The water in the soil*

Van Nievelt [8] has summarized the data on precipitation and quantity of drainage water during the period from 1942– to 1952.



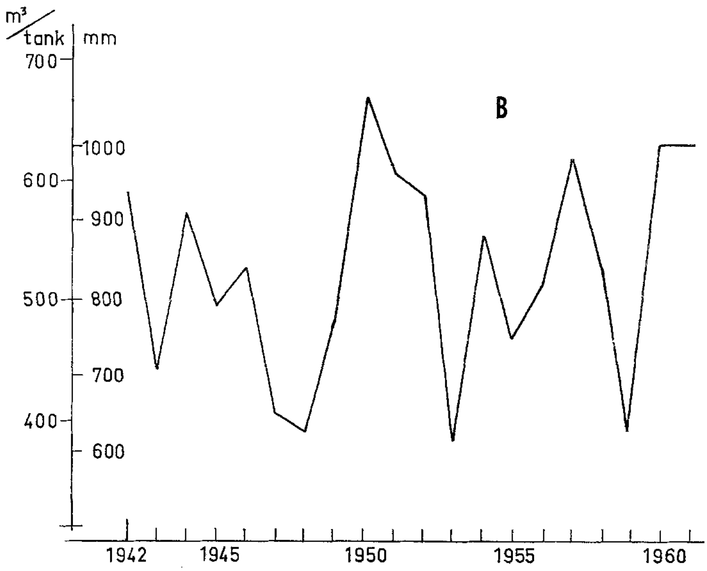


Fig. 3. Precipitation, evaporation and drainage water.

A. Precipitation for every year was put at 100 (line 5) Drainage water of the four lysimeters (curves I–IV), as well as evaporation from a free water surface either next to I (curve 6), or under the pines next to IV (curve 7) are expressed in percentages of the precipitation.

B. The annual precipitation in mm and in m^3 per tank of 625 m^2 surface.

TABLE 1

Precipitation and drainage water from Lysimeters 1942–1961

Year	Precipitation		Drainage water – Lysimeters I		II		III		IV		Ground-water, average level,	Sun-shine, hours
	m³	mm	%	m³	%	m³	%	m³	%	m³	cm +NAP	
1942	602	956	65		56		63		62			—
1943	446	708	73		52		64		68		162	—
1944	579	920	80		65		71		72		138	—
1945	503	798	71		53		59		59		186	—
1946	531	843	78	415	61	361	68	361	65	342	182	1650
	2662	4225	73		57		65		65			
1947	408	648	70	287	46	188	49	200	43	174	129	1995
1948	391	620	70	275	40	155	46	178	34	133	76	1723
1949	487	773	72	373	46	221	52	253	35	170	13	1792
1950	671	1065	77	519	51	345	54	364	42	280	52	1607
1951	609	967	74	451	46	277	48	291	36	222	115	1601
	2566	4073	74	1905	46	1186	50	1286	38	979		8718
1952	590	937	81	475	51	300	53	314	34	202	121	1624
1953	383	607	67	257	26	101	31	117	16	63	64	1523
1954	561	891	77	434	41	232	44	249	15	84	9	1445
1955	471	749	74	347	37	173	42	197	17	81	18	1688
1956	515	816	76	391	39	202	42	219	22	116	16	1505
	2520	3999	76	1904	40	1008	44	1096	22	546		7785
1957	624	991	79	495	50	313	47	291	28	175	8	1570
1958	530	842	71	376	39	207	36	188	20	109	77	1492
1959	397	630	77	305	39	154	34	135	15	59	100	1956
1960	635	1009	83	527	57	364	37	237	22	143	92	1387
1961	636	1010	78	496	50	321	51	328	26	167	159	1544
	2822	4482	78	2199	48	1359	42	1179	23	653		7948

The mutual differences in drainage between the four lysimeters became more pronounced in later years as a result of the differences in vegetation on the four lysimeters. As expected, the percentage of the precipitation that left lysimeter I as drainage water did not change much during the total series of observation (Fig. 3 and Table 1). This figure clearly shows the influence of the different vegetation covers on lysimeter II, III and IV. It also shows that for each lysimeter the ratio between precipitation and drainage water reaches a constant value after a certain time. This occurs around 1948 in lysimeter II and III, but it took until 1952 in lysimeter IV.

The water-storing capacity of the soil layer in which the trees can root and not the quantity of drainage water is important for the growth of vegetation. The trees on the tanks must obtain the necessary water from the pendular water present in the soil layer of 2.25 m above the gravel layers. Water supply by capillary action from the drains need not be considered. In the area around the tanks the average annual water level varies (Fig. 4). From 1943–1961 the average level is 88 cm + N.A.P.* But this level of 88 cm – about 3 m below the surface – can be attained by the tree roots, and according to information from the P.W.N. personnel the roots were able to reach this depth. Consequently in dry years the water quantity available for growth is more favourable for the trees out-

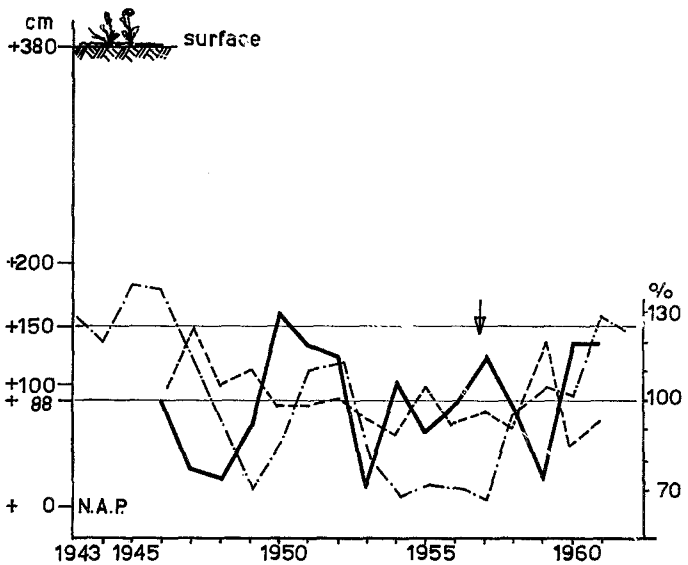


Fig. 4. Precipitation, level of ground water, and hours of sunshine

—.—. = Groundwater outside the lysimeters from 1943–1962. Average level during that period *i.e.* + 88 cm N.A.P.

——— = Annual precipitation in per cents of the average over 1946–1961, *i.e.* 840 mm, or 537 m³ per tank.

- - - - - - - = Hours of sunshine in per cents of the average over 1946–1961 of 1620 hrs/year.

↓ = Beginning of the subirrigation by water from the River Rhine in the dune region.

* N.A.P.: – official standard level in the Netherlands.

side the tanks, than for those on the tanks which can only root to a maximum depth of 2.25 m.

It is remarkable that in the very dry years 1947, 1948, and 1953 the water level was not very low, although it was low one or two years later. In the dry year 1959 there was no question of an immediate or delayed lowering of the water level (Fig. 4). This is unusual, since in the eastern Netherlands (Hackfort) the influence was noticeable until 1961. The abnormal behaviour of the water level around the lysimeters is a result of the sub-irrigation of the dunes with water from the river Rhine since August 1957.

b. *The chlorine-ion in precipitation and drainage water*

Wind [9] drew attention to the interception of great quantities of salt by small pine forests in the dunes. For open dune land he calculated the annual salt-fall to be 78½ kg Cl' or almost 130 kg NaCl per ha. Although he did not calculate or estimate the amount reaching the soil under a pine forest, from his data it is possible to estimate that this must be about 1½ to 2 times as much as the quantity deposited on open dune land.

Fig. 5 shows for each of the lysimeters how much Cl has been

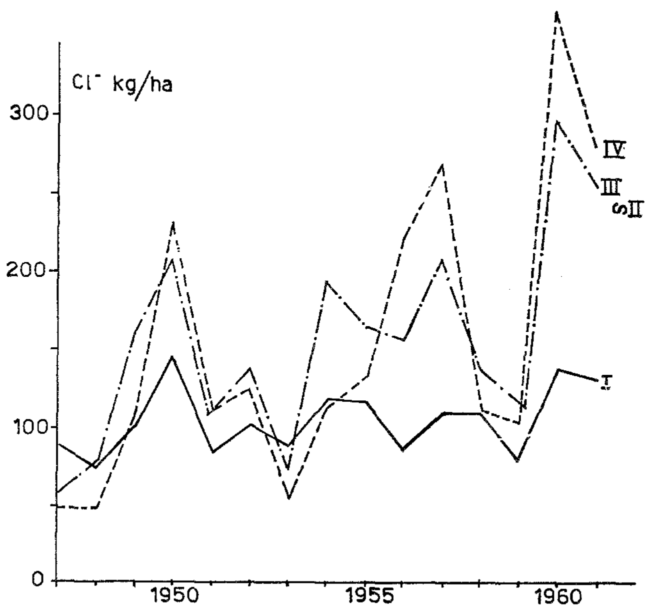


Fig. 5. Chlorine discharge in kg/ha/annum.

discharged annually with the drainage water. In this graph the more or less horizontal line for lysimeter I, and the ascending and fluctuating lines of the other lysimeters are clear. Although the vegetation cover was very different the quantities of discharged ions show only small differences.

Table 2 summarizes the elution over periods of 5 years.

TABLE 2

Discharged quantities of Cl-ions and salt (in kg/ha) over periods of 5 years

Period	Cl				Total salt			
	Lys. I	Lys. II	Lys. III	Lys. IV	Lys. I	Lys. II	Lys. III	Lys. IV
1947–51	512	615	619	560	844	1012	1020	922
1952–56	512	701	732	644	844	1155	1205	1062
1957–61	566	1023	1008	1128	932	1685	1660	1680
1947–61	1590	2339	2359	2379	2620	3852	3885	3844
	100%	147%	148%	147%				
Average 1947–61 per annum	106	156	157	175	257	259	259	257
Average 1957–61 per annum	113	205	201	225	186	337	332	372

Evidently there is a much stronger discharge from the lysimeters with a vegetation cover. The most likely explanation for this is that the trees and shrubs catch droplets of salty spray carried by winds from the sea. The salt that is caught either drops to the soil as small crystals after evaporation of the water, or it is washed down by rain.

At first sight some relationship would be expected between the interception of precipitation by the canopy, and the interception of salt. However, close examination shows that in the interception of rain by the canopy the total surface of wettable leaves and branches, and the structure of the surface play an important role, whereas in salt interception the surface directly facing the wind determines the amount of interception. The salt crystallizes on the margins and tips of the leaves when the water evaporates by the action of the wind.

Objects under the lee will catch less salt than those on the weatherside. This is borne out by Wind [9] who found that a series of raingauges under the lee caught considerably less salt than the more exposed series in the same small forest. Interception of precipitation on the other hand was highest in the series under the lee.

c. *Organic matter*

The quantity of organic matter in the drainage water has not been determined directly, but it has been calculated from the quantity of $KMnO_4$ required to oxidise the dissolved organic matter. In order to convert the $KMnO_4$ values to quantities of organic matter it is necessary to know the molecular composition of the organic solutes in the drainage water. This analysis proved impracticable, and therefore an estimate of the rations between C, O, and H in the mixture of solutes has been made.

The organic solutes can be considered a soluble fraction of the humus complex, probably as fulvic acids. In an acid environment the following reactions take place:

$$2KMnO_2 + 3H_2SO_4 \rightarrow K_2SO_4 + 2MnSO_4 + 3H_2O + 5O$$

and:

$$\text{Fulvic acids } (C_4H_6O_3)_x + 8O \rightarrow 4CO_2 + 3H_2O$$

From these reactions, and from the molecular weights of 158 for potassium permanganate, and of $(102)_x$ for fulvic acid it can be derived that 1 mg $KMnO_4$ corresponds to 0.202 mg fulvic acid or to 0.095 mg C.

Marked differences exist among the discharges of organic matter in different months, but they are correlated with the quantity of drainage water, and not with a difference in content of organic matter of this water.

Fig. 6 shows the quantity of organic matter discharged by the four lysimeters. It is clear that lysimeter I always discharged more organic matter than the lysimeters III and IV with a vegetation cover. The application in 1945 of a layer of compost on lysimeter II, III and IV did not affect the discharge figures of the following years. Not until 1950 did the discharge increase. But then it ran parallel to that from I which did not receive compost.

Despite the vegetation on three lysimeters the discharged quantity of organic matter is very small. It is curious that since 1950 considerable agreement exists between tanks I and II as to the quantity of discharge. The cause of the abnormal behaviour of II, in comparison to III and IV, might be sought in the soil of tanks I and II, which might have been of a different composition in relation to III and IV. Alternatively perhaps the vegetation on tank II produced a greater percentage of organic matter than tanks III

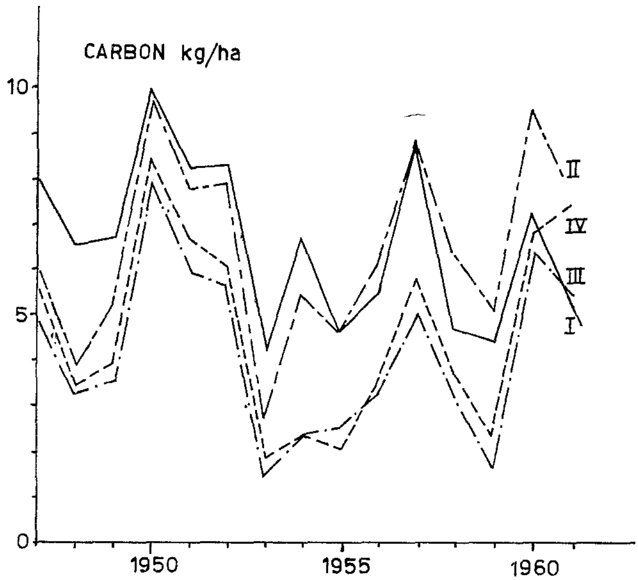


Fig. 6. Carbon discharge via drainage water in kg/ha/annum.

and IV, which in the presence of free $CaCO_3$ is soluble in water. Table 3 shows that the annual discharge of organic matter dissolved in the drainage water is, in practice, small.

TABLE 3

Carbon discharge from the four lysimeters in kg/ha/year (average over periods of 5 years)

Period	Lysimeters			
	I	II	III	IV
1947–51	7.8	6.7	5.1	5.6
1952–56	5.8	5.2	3.1	3.2
1957–61	6.0	5.4	4.3	5.2

The quantity of organic matter deposited by precipitation is of the order of 5–10 kg/ha (Leeflang [3]).

The amount of organic matter leached, including root excretions, is extremely small under a high and permanent vegetation. In the construction of an organic matter chain this discharge may be neglected, for a quantity of 5 to 10 kg carbon per ha per annum is well within the mean error of the measurements of the annual production of organic matter of 12 to 13 tons (Minderman [6]).

d. *Nitrogen in precipitation and drainage water*

In precipitation nitrogen occurs in a variety of compounds. Mostly ammonia compounds predominate, but sometimes there are more nitrates. It is not clear which compound must be considered as pollution originating from human society. For instance, the inversion of the proportions of ammonia compounds and nitrates during the series of observations at Groningen [4] in the years 1924 and 1938 (Table 4), is of special interest.

Leeflang, working in the centre of Holland, near the coast and in the interior during the period from 1932 to 1937 found predominantly NH_4-compounds in precipitation, while at the same time at Groningen, nitrates predominated. In 1964 Leeflang at Bakkum

TABLE 4

Nitrogen contents and quantities in precipitation at various places and times

Places	mg N per liter water as:				Total kg
	NO'_3	NO'_2	NH'_4	NH'_4-org	N/ha/annum
Middle part of the Netherlands* 1932–37					
Distance from shore 440 m	.068	.004	.24	.09	3.4
2280 m	.045	.002	.29	.05	3.3
3000 m	.045	.002	.24	.07	3.0
5600 m	.023	.002	.39	.06	4.0
48000 m	.023	.0045	.43	.08	4.5
Bakkum 1964 (Report Leeflang)					
2000 m	.105	.03	.75	.12	10.7
Groningen**					
1920–1924	.24			2.12	15.6
1924–1938	1.36			.50	13.0
1938	.70			1.3	14.0
Ruigelandsterpolder*	.00			.6	*ca* 4.2
Uithuizermeeden 1901–1910**	.24			.72	*ca* 6.7
Rothamsted 1880–1916**	.203			.405	4.7
Flevoland March-November 1963†	2.13 mg tot N/l				
Emmeloord N.O.P. March-November 1963†	.75 mg tot N/l				
According to Virtanen (1962):					
Within the arctic circle					1.0
Central Scandinavia					1 à 2
Southern Sweden					2 à 5
Denmark					5 à 7
Giessen (Germany)					28.2

* Leeflang[3]
** Maschhaupt[4]
† Board of the Wieringermeer (report)

(Lysimeter area) found an increase in nitrates. It is very difficult to decide whether it is the proportion of nitrates, or of ammonium compounds of nitrogen that is influenced by the proximity of industry. The increase in the percentage of nitrogen compounds in the samples from drainage water in 1964 cannot be related to transport by wind from the industrial areas IJmond and Zaan. In precipitation from western or north western direction, *i.e.*, from areas without any industry, and from the sea, the N-content also appears to be higher than that in the period 1932 to 1937. The high values found at Groningen can be ascribed to the very unfavourable situation of the lysimeters at the outskirts of the town near the

TABLE 5

Nitrogen in kg/ha/5 years discharged with drainage water

Period	Ion	Lysimeter			
		I	II	III	IV
1947–1951	NO_3'	52.70	4.40	55.70	4.8
	NO_2'	.05	.04	.05	.02
	NH_4^+	.88	.65	.64	.86
	NH_4^+-org.	1.41	1.34	1.82	1.35
		55.04	6.43	58.21	7.04
1952–1956	NO_3'	68.40	24.80	3.22	1.37
	NO_2'	.04	.02	.02	.01
	NH_4^+	.66	.29	.53	.19
	NH_4^+-org.	2.12	1.32	1.98	.85
		71.22	26.43	5.75	2.42
1957–1961	NO_3'	65.00	51.55	3.50	.93
	NO_2'	—	—	—	—
	NH_4^+	.53	.39	.40	.24
	NH_4^+-org.	1.87	2.35	2.66	1.25
		67.40	54.29	6.56	2.42
Total over:					
1947–1961	NO_3'	186.10	80.75	62.42	7.11
	NO_2'	.09	.06	.07	.03
	NH_4^+	2.07	1.33	1.57	1.29
	NH_4^+-org.	5.40	5.01	6.46	3.45
		193.66	87.15	70.52	11.88

Note: In the reports of the chemical analyses the quantities of nitrite are given as units of 0.001 mg/l until 1956, but from 1957 onwards as 'zero', or as units of 0.030 mg/l. Because the quantities found were generally less than 0.030 mg/l, data over the later period cannot be compared with those from the first period. However, omitting the quantities of nitrite hardly influences the total nitrogen figures.

railway yard and near large factories. The residue was also high, mainly because of much SiO_2 and SO_3 from steam engines.

The quantities of nitrogen discharged with the drainage water of the PWN lysimeters are summarized in Table 5 and Fig. 7. There are considerable differences between the lysimeters. Lysimeter I discharged the greatest quantity of nitrogen and Lysimeter IV the smallest. The schematic Fig. 8, which is partly hypothetical, gives information on the initial N-discharge by the soil. Nitrogen may have been leached from a possible nitrogen reserve in the soil. The initial phase would then have been high, just as in the carbon curve of lysimeter I (Fig. 7). After the initial period in lysimeter I,

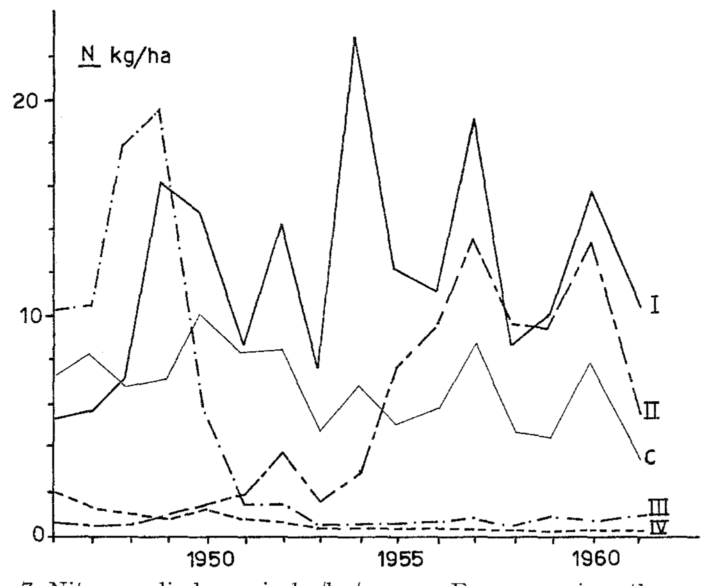


Fig. 7. Nitrogen discharge in kg/ha/annum. For comparison the carbon discharge (C) from I.

the annually discharged quantity of nitrogen appears to be fairly constant, which suggests a rather even process in the soil. It is possible that nitrogen was fixed from the air by, for example, Cyanophycae in the upper layers of the soil. However, the figures per month over the period of 1964 to 1961 relating to lysimeter I give no indication that any fixation took place. N-fixation is more likely to have place in the warm and wet months of early and late summer, and this would have been visible by a double peak of the nitrogen discharge in the drainage water during winter. No such information was recorded for the 16 successive years of the experiment. At present it is recorded as more probable that the discharge curve of lysimeter I reflects the differences in the percentages of nitrogen in precipitation as found by Leeflang in two series. Perhaps some elution took place from earlier available organic matter in the way described by Gadet and Soubies [1]. The curves for the discharge of drainage water, nitrogen and chlorine show distinct synchronization with a phase-shifting of less than one month if compared with the precipitation curve. This synchronization is a remarkable phenomenon, because the percolation speed of water in the four lysimeters varied from a few months to more than a year.

The N-content of the drainage water of lysimeter II showed peaks at different times from those in the remaining three. The highest concentrations for tank II after 1951 alternate with the highest concentrations for the remaining tanks. In tank II these maxima in concentration fell in the period February to July and those of the other tanks in the period September until February. The retention period before precipitation became drainage water is 8 to 11 months in tank II, which strongly suggests that the discharged nitrogen from the peak periods originated from nitrogen fixed by sea buckthorn during the vegetation period, and was partly excreted from its roots. This shifting of phase shows faintly, and at low level in 1952, and it becomes quite distinct and constant from 1955 onwards. Sea buckthorn has grown better since 1948 and it reached maturity in 1952 (Fig. 7).

On lysimeter III there were several alders during the first year. In those years, *i.e.*, before 1950, peaks in nitrogen occurred both in summer and winter, but the level as a whole was so high that comparison with I is not possible. In every month throughout the year a high nitrogen content was found in the drainage water.

The lysimeters showed considerable differences in the amount of nitrogen that was annually discharged. The quantity discharged by lysimeter IV was small throughout, and it decreased to a very low value. A similar phenomenon was apparent in lysimeter III after the alders had been pruned in 1950, and after 1948 when the growth of the oaks improved. Since the last alders (58 trees) were removed in 1961, nitrogen discharge has been low. The decrease of nitrogen in this tank can probably be explained as follows: 1) The oaks in the tank began to grow better in 1948. This improvement was continued and in 1949 growth was very good. The trees had at their disposal considerable amounts of nitrogen as a result of nitrogen fixation from the air by the alders, and consequently developed so strongly that they attempted to utilise all the nitrogen compounds liberated by the alders. 2) In 1950 the alders were pruned strongly. This restricted their growth and nitrogen fixation, while at the same time the oaks grew vigorously and had a high requirement for nitrogen. As a result of these two factors the nitrogen discharge in the drainage water suddenly diminished. If the alders had not been pruned, the reduction of the N-discharge would probably have been more gradual, since the oaks would have experienced more difficulty in competing with the alders.

The dune vegetation, which in addition to sea buckthorn grows on tank II, was also able to use very efficiently the nitrogen produced in excess by the sea buckthorn. The higher nitrogen discharge in the drainage water may be considered as excess-N not utilized by the vegetation, either because the plants could not absorb it, because the nitrogen became available out of the growing season, or because the discharge by the sea buckthorn roots took place deeper in the soil than the depth reached by the other roots requiring nitrogen. It is not possible to deduce from the available

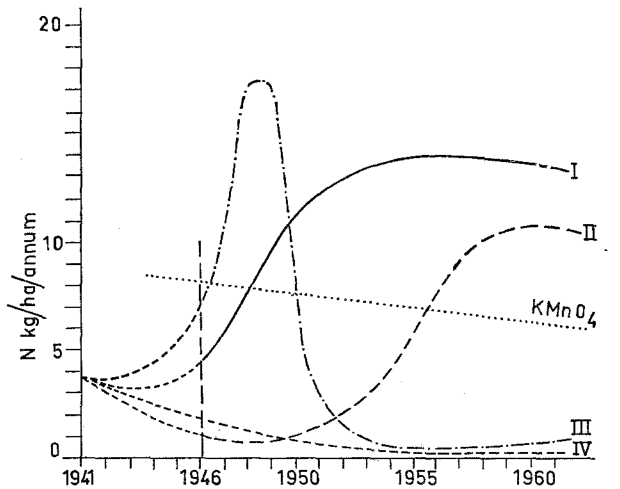


Fig. 8. Schematic discharge curves from Figure 7.

data the actual production by alder or sea buckthorn of nitrogen compounds available for other plants. To do this it would be necessary to know the amount of nitrogen that is fixed in the whole tank, and the amount removed with thinnings. It appeared to be impracticable to sample so intensively that reasonably reliable results could be obtained about the total nitrogen fixation. However, it is clear that more nitrogen is brought into the soil than was present in precipitation only, and also that this surplus of nitrogen is associated with the growth of alder or sea buckthorn.

The nitrogen added with compost and fertilizer was probably used completely by the plants, with perhaps the exception of a small part that volatilized from the effect of the slightly alkaline environment on ammonia compounds. No increased discharge of nitrogen of the drainage water was observed.

e. *The remaining ions*

The mutually different fluctuations of some of the remaining ions and their relations to the drainage water in lysimeters I and IV have been summarized in Figs. 9a and b, and in Table 6.

The figures show that on the whole the discharge of the ions is in phase with the fluctuations in the discharge of drainage water. The pattern strongly suggests a regular leaching of the soil by water from precipitation.

Table 6 illustrates some abnormalities which occured and which cannot be easily explained. Since information on the preceding period is not available e.q. a marked discharge of sulphate and magnesium from lysimeter III in the period from 1947 to 1951.

The quantities of calcium discharged are interesting when related to the total quantity of calcium which is mainly present in the soil as $CaCO_3$. If the annual discharge, and the total content in the soil are known, it is possible to calculate how long it would take for all the $CaCO_3$ to be leached out, or in other words how long it takes for the depletion of bases to be completed. Table 6 shows that there is little difference between the Ca discharge of the lysimeters, although the discharge of IV might be expected to be higher, because of the influence of the acid humus of the pines. This is not the cause. Apparently the quantity of drainage water plays a larger part in the discharge of Ca, than that of the vegatation.

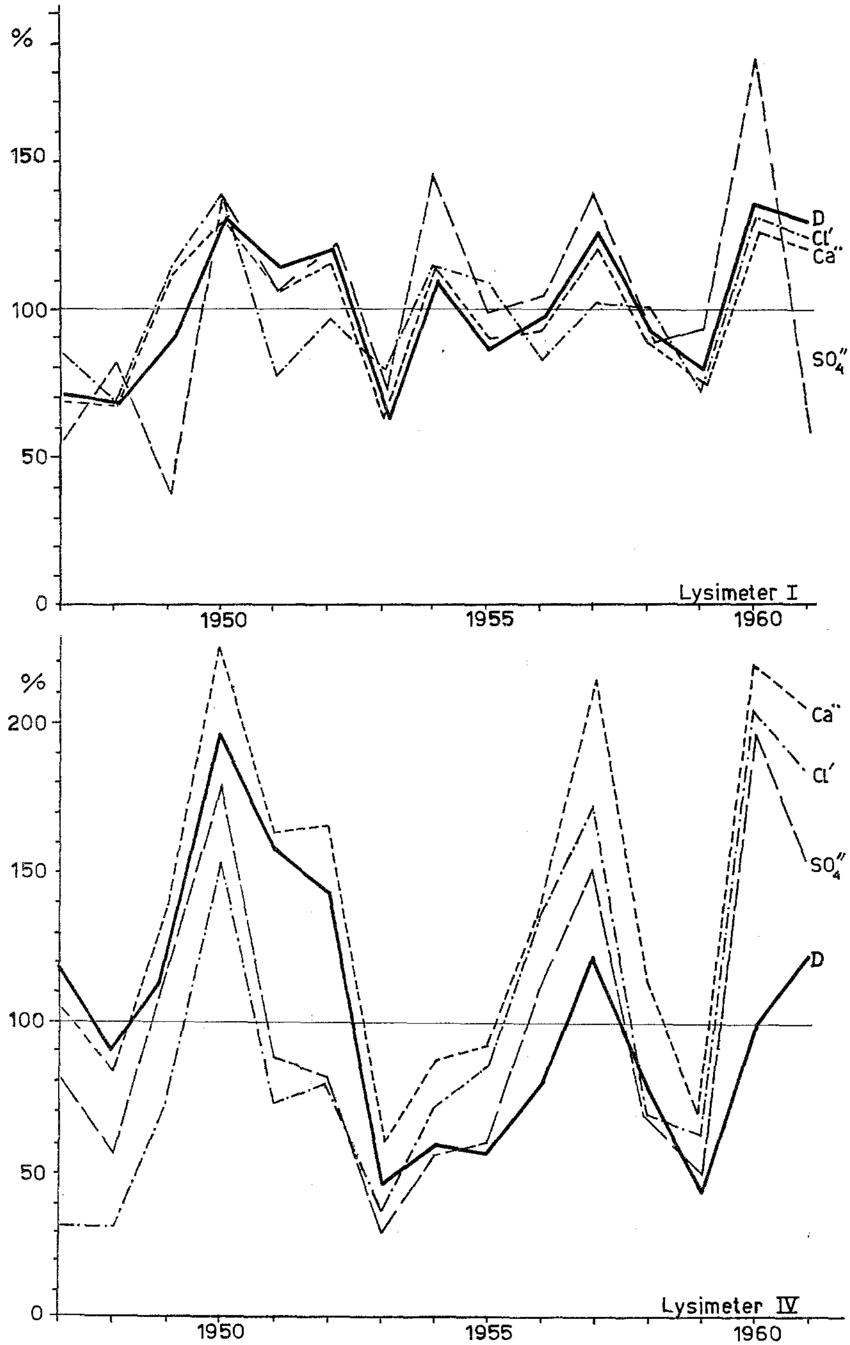


Fig. 9. The inter-relation of some ions, and their relation to the drainage water of lysimeters I and IV. For each ion, and for the drainage water (D) the quantities discharged in every year have been expressed in percents of the average over the complete period of observation.

TABLE 6

Discharge of various ions in kg/ha/5 years
Period A = 1947–1951
Period B = 1952–1956
Period C = 1957–1961

Ion	Period	Lysimeter I	II	III	IV
HCO_3'	A	4162	4275	3770	3326
	B	3850	3855	3796	2368
	C	4278	4918	4496	3250
Cl'	A	511	615	619	559
	B	512	701	732	649
	C	566	1023	1008	1128
Ca^{++}	A	1467	1478	1773	1261
	B	1417	1383	1352	928
	C	1574	1899	1684	1364
SO_4''	A	422	854	2038	871
	B	511	475	563	564
	C	563	767	764	1033
K^+	A	—	—	—	—
	B	174	146	179	122
	C	153	151	160	152
Na^+	A	—	—	—	—
	B	305	368	375	326
	C	346	578	563	673
Mg^+	A	89	85	115	76
	B	80	72	77	58
	C	92	92	71	83
PO_4'''	A	1.4	1.5	3.9	2.8
	B	1.4	.8	3.6	1.6
	C	2.3	1.4	2.8	2.1
NO_3'	A	234	19	247	21
	B	303	110	14	6
	C	288	229	16	3
NH_4^+-org.	A	1.8	1.7	2.3	1.7
	B	2.1	1.7	2.5	1.1
	C	2.4	3.0	3.4	1.6
NH_4^+	A	1.1	.8	.8	1.1
	B	.9	.4	.7	.3
	C	.7	.5	.5	.3
SiO_2''	A	182	166	199	142
	B	178	150	177	89
	C	196	178	198	124
Carbon in H_2CO_3	A	819	841	752	654
	B	757	758	747	466
	C	841	967	884	639

The total amount of Ca present in each tank appears to be 378000 kg at a $CaCO_3$ level of 3.5%.

Discharge during the last 5 years was about 300 kg/ha/annum. If this is considered as a problem in a compound interest calculation, then the annual decrease of p. % is given by:

$$1 - \frac{378000 - 300}{378000} = 0.00078 \text{ or } p = 0.078\%$$

Depletion of bases upto 99% would take

$$\frac{\text{Ln. } 0.01}{0.00078} = \frac{-4.6}{0.00078} = -5900 \text{ years}$$

A reduction to half the original amount could occur after a period of approximately:

$$\frac{\text{Ln } 0.5}{0.00078} = \frac{-0.6931}{0.00078} = -890 \text{ years}$$

According to the above data the total discharge during 20 years can be put at about 6000 kg Ca per ha, which in only 0.16% of the total quantity available in the soil of the tanks. This is a lower percentage than Maschhaupt[5] found for the top soil of Dollard polders. He found a reduction of 1% $CaCO_3$, or 0.4% Ca in the top soil after 23 to 34 years, while no decrease could be demonstrated below the top soil.

In the lysimeters of the PWN we could not find after 20 years a difference between the $CaCO_3$ content of the upper layer and that of the rest of the profile. Apparently leaching was equally strong throughout the depth of the sand.

SUMMARY

From 1946–1961 the amounts of drainage water, salts and carbon were determined from four adjacent lysimeters (1 with bare sand, 3 with a vegetation cover of natural dune vegetation, oak with some alder until 1950, and Black pine respectively) situated about 2 km from the North Sea shore, in the Netherlands.

The quantity of drainage water is strongly dependent on the nature of the vegetation cover. From 1952–1961 the four lysimeters discharged, 77; 44; 43 and 22% of the total precipitation for bare sand, natural dune vegetation oak and Black pine respectively.

From 1947–1951 for bare sand, natural dune vegetation, oak and Black pine respectively 102, 123, 124 and 122 kg/ha chlorine were discharged. From 1957–1961 in the same sequence: 113, 205, 201 and 225 kg/ha were discharged. The increase of the discharge is closely related to increase in height of the vegetation cover, which leads to increasing interception of salty spray from the sea. The difference between the bare lysimeter and those with a vegetation cover is considered to be the result of interception of salt by the vegetation.

The quantity of carbon discharged was determined from the $KMnO_4$ values of the drainage water. The discharge was small: 3–8 kg C/ha/annum.

The nitrogen supply by precipitation varied from 3–10.7 kg/ha/annum. The average N-discharge over 15 years for bare sand, natural dune vegetation, oak originally mixed with some alder and black pine respectively was 12.7; 5.7; 4.7; and 0.8 kg/ha/annum. From 1947–1951 the quantities were 11.0; 1.3; 11.6; and 1.4 kg/ha/annum and from 1957–1961 13.5; 10.8; 1.3 and 0.5 kg/ha/annum. The difference between the two periods in nitrogen discharge from the lysimeters with a cover of natural dune vegetation and that with oak and some alder must be ascribed to the N-fixation by sea buckthorn and alder. Sea buckthorn did not grow well until 1948–1952, while alder disappeared after 1950.

As to the remaining ions Ca, Mg, K, Na en SO_4 the discharged quantities appeared to be only proportional to the discharged quantity of drainage water. There is no question of a strong depletion of bases by the Pines, for the drainage discharge under this vegetation cover is much lower than that of the other tanks. The total discharge during 15 years was 4458, 4760, 4809 and 3553 kg/ha for bare sand, natural dune vegetation, oak and black pine respectively.

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