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Characteristics of runoff generating rains on bare loess soil in South-Limbourg (The Netherlands)

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SUMMARY

In 1985 a plot study was started in Dutch South-Limbourg to evaluate the effects of various cropping systems of fodder maize on runoff, erosion and crop yield. Also permanently bare soil was included in the study. In the course of the period of measurement of three years and four months, 73 run-off events were registered on bare soil, 35 in summer and 38 in winter. In this paper the following characteristics of the runoff generating rains are presented : amount, duration, average intensity and max. 5-minute intensity. From an analysis of the collected data it appeared, that the modal runoff generating rain during the period of study was characterised by a rainfall amount of 2-4 mm, a duration of 30-45 minutes, an average intensity of 2-3 mm/hour and a max. 5 minute intensity of 5-10 mm/hour. These are not high values. It is important to note, that runoff generation was not restricted to high intensity summer thunder storms. Runoff was also generated by low intensity winter rainfall. This can be interpreted to mean that Horton overland flow was not the sole or even the dominant form of overland flow at the site of study. Saturation or storage controlled overland flow may have been just as important. This must be given due consideration in devising soil conservation measures, which traditionally aim at increasing the *infiltration capacity* in stead of the *moisture storage capacity* of the soil. Also, in many soil erosion models Hortonian overland flow is postulated or tacitly implied. There seems to be room for erosion models based on soil storage excess overland flow.

RESUME

En 1985, nous avons commencé à étudier des parcelles afin d'envisager les effets de divers systèmes de cultures du maïs sur le ruissellement, l'érosion et le rendement.

Des sols nus ont également été inclus dans notre étude. Sur l'une des parcelles nues a été installé un système de mesures "HS" équipé d'un enregistreur d'eau automatique. Au cours des 3 ans et 4 mois pendant lesquels les mesures ont été effectuées, 73 événements de ruissellement ont été enregistrés sur ces parcelles - 35 pendant l'été et 38 pendant l'hiver. Les précipitations, facteurs de ruissellement, ont été enregistrées à l'aide d'un pluviographe mécanique à siphon de type Lambrecht (taux de transfert sur papier : 1 mm / 3 minutes). Nous présentons ici les caractéristiques des orages générateurs de ruissellement : quantité, durée, intensité moyenne et intensité maximum à 5 minutes. L'analyse des données ainsi recueillies fait apparaître que les orages générateurs de ruissellement se caractérisent par une quantité de pluie de 2 à 4 mm, une durée de 30 à 45 minutes, une intensité moyenne de 2 à 3 mm / heure et une intensité maximum à 5 minutes de 5 à 10 mm / heure. Ces valeurs ne sont pas élevées.

Fullen et Reed ont publié des valeurs comparables en 1986, avec un seuil d'intensité de 2 mm / heure pour un début d'érosion du sol sur des sols à croûte de battance en Angleterre. Il est aussi important de noter que le ruissellement n'est en aucun cas généré uniquement par des orages d'été de haute intensité : il est également produit par des pluies d'hiver de faible intensité. Ceci signifie que le modèle proposé par Horton est insuffisant. Il faut tenir compte d'un tel fait dans l'élaboration de mesures de conservation du sol, mesures qui traditionnellement visent à augmenter la *capacité d'infiltration* du sol au détriment de la capacité de *rétention du sol*. Il semble qu'il y ait place pour des modèles fondés sur un excès de rétention.

1. INTRODUCTION

In hilly Dutch South-Limbourg, rainfall induced accelerated soil erosion of loess soils with associated off-site effects (flooding, sedimentation) occurs (1 - 2 - 3). In 1985 a plot study was started to evaluate the effects of various conservation cropping systems of fodder maize on runoff, soil loss and crop yields (4 - 5 - 6 - 7 - 8). As part of this study, rainfall measurements were carried out. Objectives of the rainfall measurements were : (a) to assess rainfall conditions which give rise to overland flow and erosion on loess soils in South-Limbourg, and (b) to determine the value of the EI_{30} -index or rainfall erosivity index as part of the procedure to establish the K-factor or soil erodibility index from soil loss measurements on permanently bare fallow plots (9). In this paper results regarding the first objective are presented. Not very many data are available for western Europe on rainfall characteristics related to soil erosion. For Belgium data are given by Bollinne (10), Bollinne et al. (11) and Sinzot et al. (12). Data for England were summarised by Evans (13). From these data it appears that rainfall that is excluded from the calculation of the R-factor value of the Universal Soil Loss Equation in the USA (9), contributes to accelerated soil erosion in West-Europe.

2. MATERIALS AND METHODS

In 1985, twelve plots were laid out in a randomized block design with three replications per treatment (14). The plots were located near the village of Wijnandsrade (Fig. 1) on a uniform 6 % slope. Plot length and plot width were 22.00 and 1.80 m resp. (15). Runoff was collected and stored in three storage tanks with divisors per plot (16). Runoff volume and sediment concentration of the runoff was determined with four weekly intervals. For budgetary reasons more frequent visits of the experimental site were not possible. Fodder maize was grown continuously on the plots during 1986, 1987, 1988 and 1989. Cropping systems of fodder maize are described in detail by Geelen (4) and Kwaad (6 - 7). Systematic measurements of runoff and soil loss were carried out from May 1987 until March 1990, both in summer and winter. Precipitation was measured with a standard raingauge and a mechanical recording raingauge with a paper transfer rate of 1 mm per 3 minutes (Lambrecht, type 1509).

Figure 1. Location of Experimental Farm Wijnandsrade in South-Limbourg.

Besides nine plots with three replications of three maize cropping systems, three permanently bare fallow plots were laid out, one in each block. The fallow plots were tilled (ploughed and harrowed) once a year, at the same time as the conventional maize cropping system (around May 1st). One of the fallow plots was equipped with an HS-flume (17) and a Munro water level recorder (type IH 89 with vertical rotating drum). The data obtained with the water level recorder were used to sort out the runoff generating rain storms from the pluviograph recordings. The resolution of the water level recorder (one drum rotation in 28 days, or a paper transfer rate of 1 mm per 96 minutes) did not allow determination of the runoff volume of single runoff events, but only approximate timing of the occurrence of runoff peaks. Due to the low resolution of the stage recording and the fact that soil loss was not determined on a single event basis, but as a four-weekly total, it was not possible to establish the contribution of single storms to total runoff and soil loss. The available data were used to analyse the characteristics of the runoff generating rain storms.

Soils of the experimental site were imperfectly drained, truncated gleyic luvisols with less than 0.80 m colluvium, overlying the (lower part of the) original argillic horizon. Parent material was decalcified loess. A (perched) water table was present within 1.00 m of the soil surface during part of the year.

Average yearly rainfall amount of the site is 750 mm with rain in all seasons. High intensity rains only occur in the summer half of the year ; 30-minute intensity that is exceeded once a year is 24 $mm.h^{-1}$ (18). Average yearly rainfall erosivity (R-factor), as defined by Wischmeier and Smith (9), is 75 (metric units) according to Bergsma (19), resp. 60 (metric units) according to Bollinne et al. (20). These values are relatively low, compared to large parts of the USA (9).

3. RESULTS

Total yearly rainfall amounts of the years 1987, 1988 and 1989 at the site of study were 873.2 mm, 780.4 mm and 695.8 mm resp. These amounts are not far from normal (750 mm). Therefore, the period of study is considered as fairly representative of the rainfall regime of the region. From Fig. 2 and 3 it appears that, on the permanently bare plots, soil losses were higher in summer than in winter, whereas runoff amounts and runoff percentages were (much) higher in winter than in summer.

3.1 Frequency and seasonality of runoff generating rains

During the 40 months period of observation, 73 runoff events were recorded with the HS-flume : 9 in 1986, 17 in 1987, 27 in 1988 and 20 in 1989, or an average number of 22 runoff events per year on permanently bare soil. In fact, a few more events have occurred, which were not recorded due to malfunctioning of the equipment, mostly by sediment clogging the connecting tube between the flume and the stilling well of the stage recorder. Of the total number of runoff events 35 (48%) occurred in summer and 38 (52 %) in winter. Summer is taken here as the period from sowing to harvest of maize, approximately May 1st to November 1st.

3.2 Storm rainfall amount

From Tab. 1 it appears that runoff was generated by rains with rainfall amounts of 1.4 - 33.3 mm. Summer runoff was generated by rains of 2.1 - 33.3 mm and winter runoff by rains of 1.4 - 22.3. Average rainfall amount of all runoff generating storms was 7.6 mm (Tab. 2). Average amounts of summer and winter storms were about equal, 7.9 and 7.4 mm resp. Rainfall amount of the modal rain was 2-4 mm for both summer and winter rains (Fig. 4). In Fig. 5 rainfall amount of all runoff generating rains is compared with the long term frequency distribution of all "rains" occurring in the Netherlands (21). It appears that 12 % of all "rains" fall in the modal class (2-4 mm) of the runoff generating rains.

3.3 Storm duration

Duration of all runoff generating rains ranged from 6 minutes to 22 hours (table 1). Duration of runoff generating summer storms was 6 - 420 minutes and that of winter storms 13.5 - 1320 minutes. Average duration of all runoff generating storms was 3 hours 7 minutes (table 2). Average summer storm duration was about 2 hours and winter storm duration 4 hours. Modal storm duration was 30-45 minutes for all runoff generating storms, with a second modal duration of 1-15 minutes for the summer storms (Fig. 6).

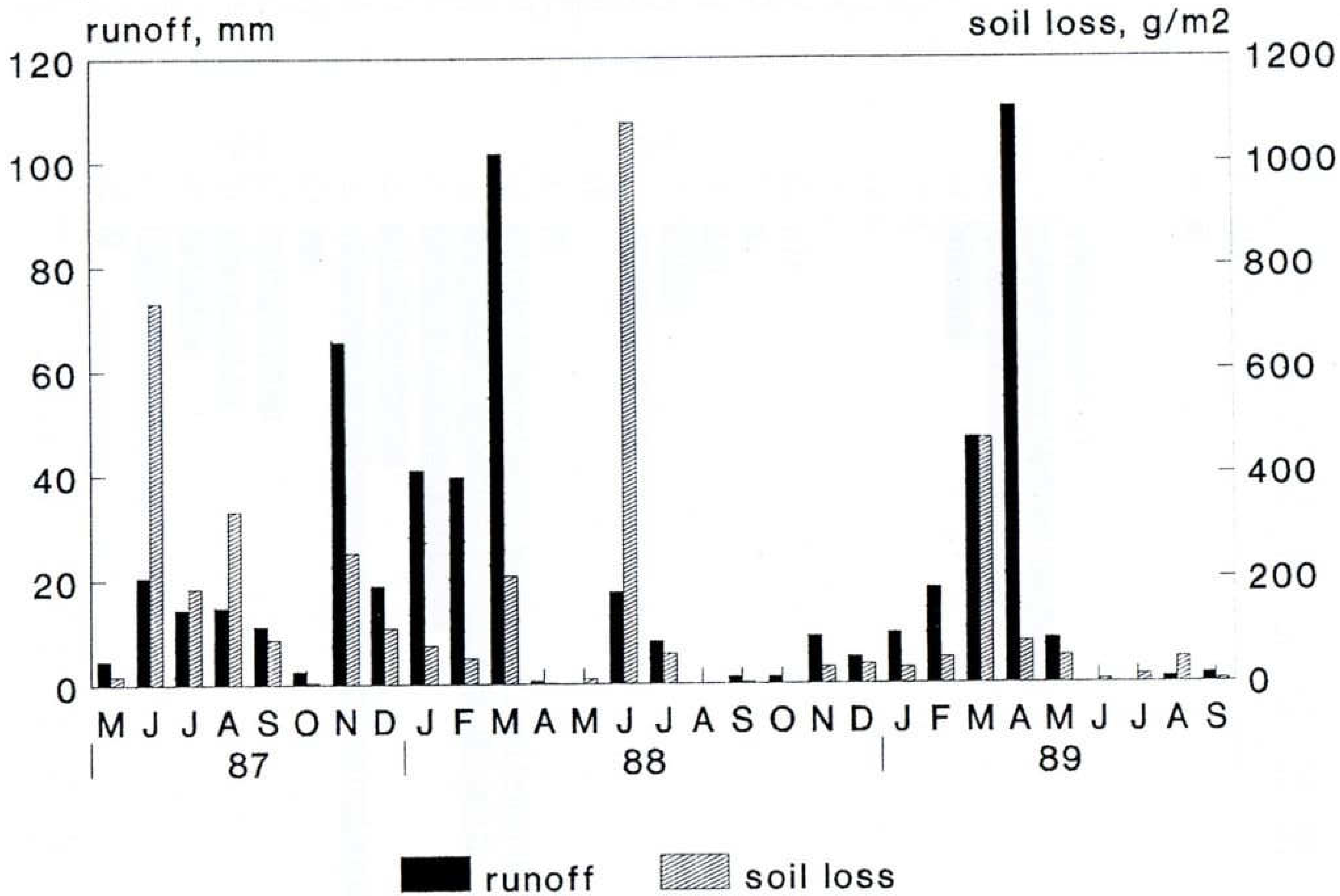

Figure 2. Monthly runoff and soil loss of permanently bare soil (average of three fallow plots).

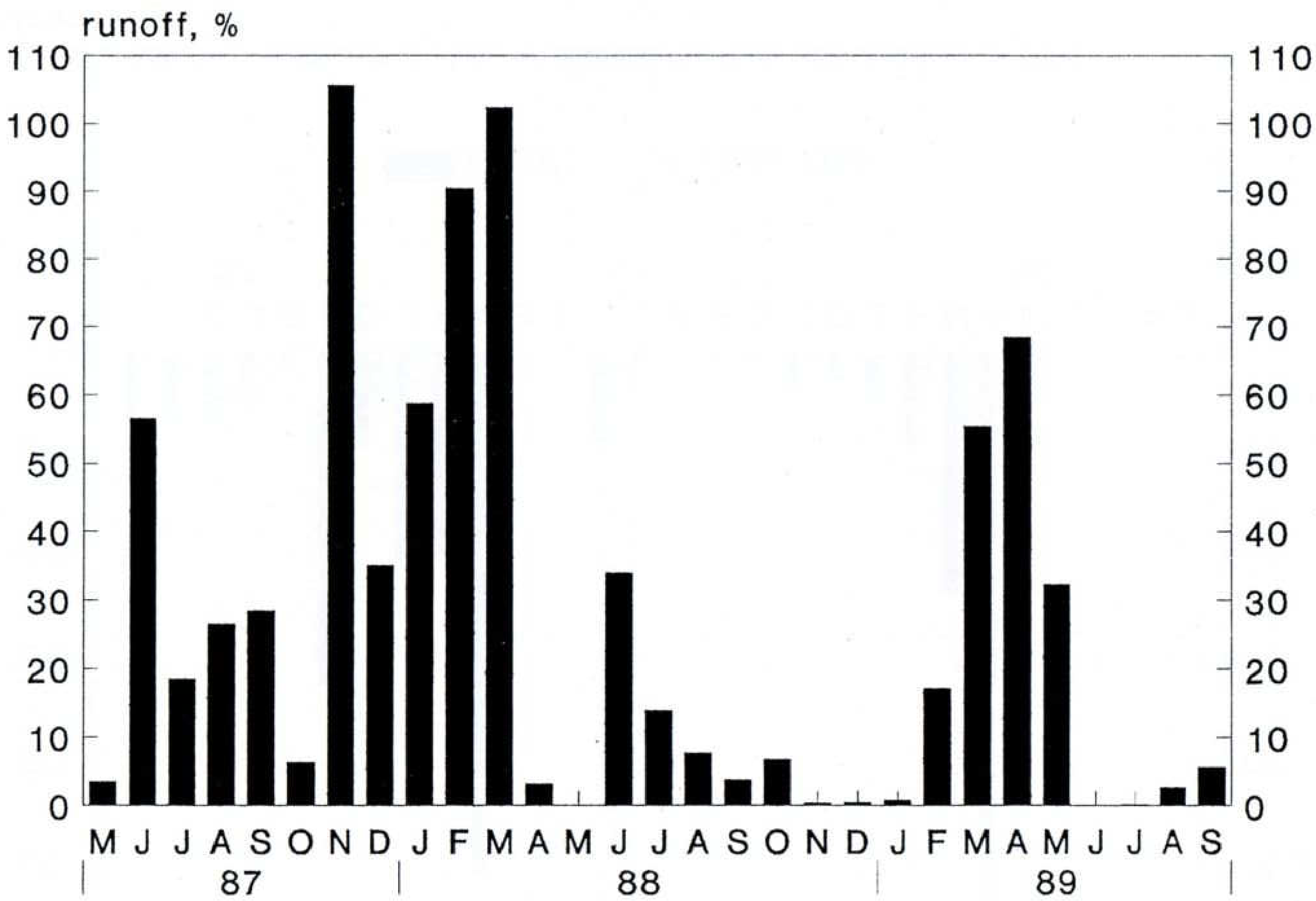

Figure 3. Monthly runoff percentages of fallow plot, equipped with HS-flume.

Table 1.
Characteristics of runoff generating rains.

date	rainfall amount, mm	duration, mm	average int., mm/h	max. 5'-int., mm/h
05/07/86	18.3	420	2.6	
06/07/86	4.8			
07/07/86	3.9			
08/07/86	4.2	6	42.0	42.0
04/08/86	6.7	10.0	40.2	40.2
23/08/86	4.8	36.0	8.0	20.0
03/09/86	6.5	157.0	2.5	16.8
15/12/86	5.3			
18/12/86	5.6			
27/02/87	16.4			
18/07/87	5.0	33.0	9.1	24.0
21/07/87	10.3	45.0	13.7	45.0
30/07/87	2.1	11.0	11.5	11.5
31/07/87	3.3	225.0	0.9	2.5
04/08/87	5.0			
23/08/87	10.0	27.0	22.0	48.0
23/08/87	7.9	10.5	45.0	54.0
04/09/87	12.1	144.0	5.0	20.0
22/09/87	8.8	73.0	7.2	32.6
22/09/87	10.0	102.0	5.9	43.2
24/09/87	4.4	87.0	3.0	21.0
12/11/87	12.4	438.0	1.7	33.0
16/11/87	4.0	60.0	4.0	13.3
16/11/87	3.8	34.5	6.6	25.0
19/11/87	11.6	225.0	3.1	13.2
20/11/87	8.6	174.0	3.0	15.6
02/01/88	4.2	108.0	2.3	13.2
04/01/88	3.0	24.0	7.5	40.0
12/03/88	21.7	1320.0	1.0	6.0
13/03/88	16.8	768.0	1.3	9.0
15/03/88	5.1	210.0	1.5	10.0
16/03/88	3.9	282.0	0.8	4.5
21/03/88	6.8	411.0	1.0	3.0
23/03/88	12.4	216.0	3.4	25.0
23/03/88	2.5	78.0	1.9	3.0
25/03/88	9.1	213.0	2.6	6.3
25/03/88	2.9	39.0	4.5	9.3
25/03/88	2.7	72.0	2.3	18.0
25/03/88	2.6	22.5	6.9	15.6
26/03/88	4.2	150.0	1.7	8.4
26/03/88	3.8	108.0	2.1	12.0
21/06/88	33.3	46.5	43.0	94.0
05/07/88	14.5	354.0	2.5	7.6
05/07/88	3.9	153.0	1.5	6.4
14/07/88	5.0	90.0	3.3	12.8
16/07/88	9.8	367.0	1.6	8.0
16/07/88	3.3	72.0	2.8	15.0
23/07/88	9.5	63.0	9.0	38.0
26/07/88	3.3	126.0	1.6	8.0
28/09/88	5.1	57.0	5.4	12.4
06/10/88	6.9	354.0	1.2	2.5
06/10/88	8.6	189.0	2.7	39.0
10/10/88	3.8	24.0	9.5	27.0
15/02/89	5.7			

Table 1. (suite)
Characteristics of runoff generating rains.

08/03/89	17.9	828.0	1.3	5.0
15/03/89	3.1	177.0	1.0	2.4
15/03/89	1.6	45.0	2.1	10.0
16/03/89	4.8	13.5	21.3	49.2
16/03/89	4.1	90.0	2.7	12.0
22/03/89	2.1	33.0	3.8	10.8
24/03/89	6.7	396.0	1.0	2.0
24/03/89	14.1	108.0	7.8	31.2
12/04/89	6.6	462.0	0.9	7.0
13/04/89	22.3	489.0	2.7	9.1
19/04/89	2.8	37.5	4.5	10.0
19/04/89	1.4	16.5	5.1	10.0
21/04/89	16.5	663.0	1.5	15.0
25/04/89	2.1	97.5	1.3	9.6
11/05/89	18.1	231.0	4.7	42.0
30/07/89	6.2	21.0	17.7	52.0
07/08/89	4.0			
27/08/89	3.2	33.0	5.8	10.8
14/09/89	9.7			17.0

Table 2.
Average values of characteristics of runoff generating rains.

	amount, mm	duration, min.	intensity, mm/hour	max.5'-int., mm/hour
all rains	7.6 ± 5.9	187.1 ± 232.3	7.0 ± 10.2	20.0 ± 17.1
summer rains	7.9 ± 5.9	118.9 ± 117.7	11.0 ± 13.3	27.1 ± 19.9
winter rains	7.4 ± 5.8	247.3 ± 285.7	3.4 ± 3.7	13.7 ± 10.7

3.4 Average storm intensity

Table 1 shows that average intensity of the runoff generating rains ranged from 0.8 to 45.0 mm/hour. Average intensity was 0.9-45.0 mm/hour for the individual summer storms and 0.8-21.3 mm/hour for the individual winter storms. Collective average intensity of the runoff generating summer storms was 11.0 mm/hour and that of the winter storms 3.4 mm/hour (table 2). Modal average intensity of all storms was 2-3 mm/hour, with a second modal class of 1-2 mm/hour for the winter storms (Fig. 7).

3.5 Max. 5 min. storm intensity

Max. 5'-intensity of all runoff generating rains ranged from 2.0 to 94.0 mm/hour (table 1). Summer range was 2.5-94.0 mm/hour and winter range 2.0-49.2 mm/hour. Average max. 5'-intensity of the runoff generating summer storms was twice that of the winter storms, 27.1 and 13.7 mm/hour resp. (table 2). Modal max. 5'-intensity was 10-15 and 40-45 mm/hour for the summer storms and 5-10 mm/hour for the winter storms (Fig. 8).

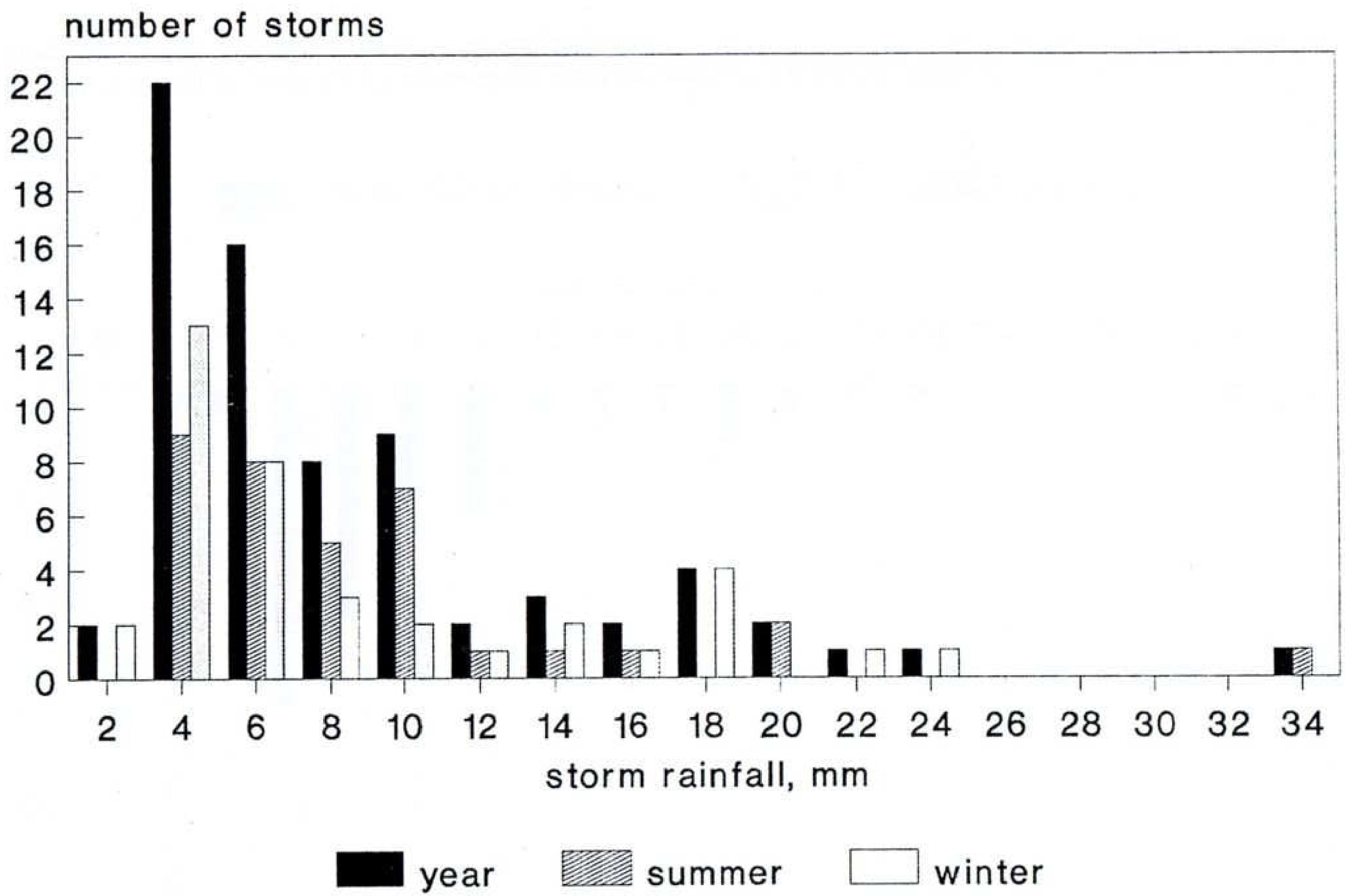

Figure 4. Frequency of runoff generating rains by rainfall amount.

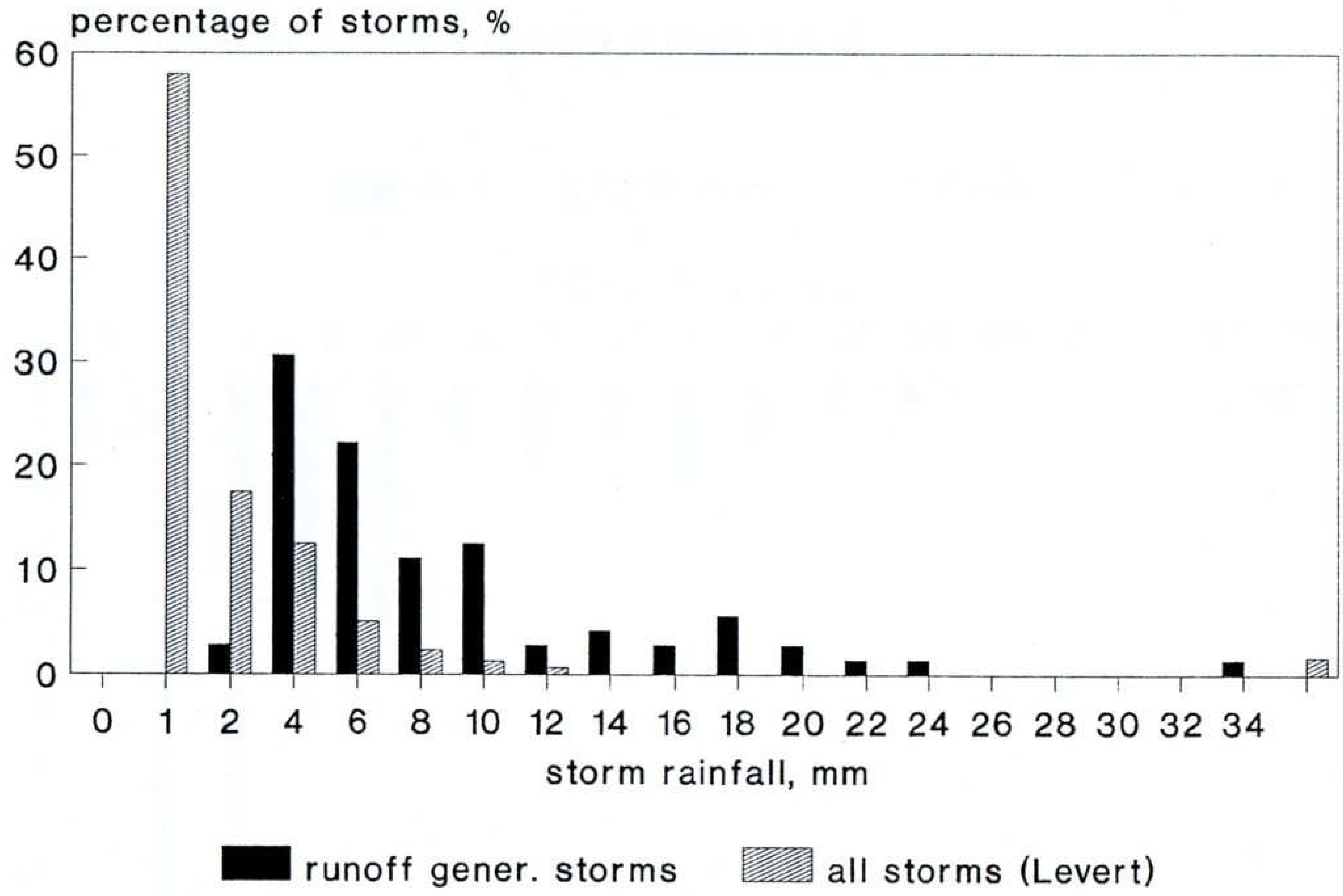

Figure 5. Frequency of runoff generating rains by amount, as compared to long term frequency of all rains in the Netherlands (21).

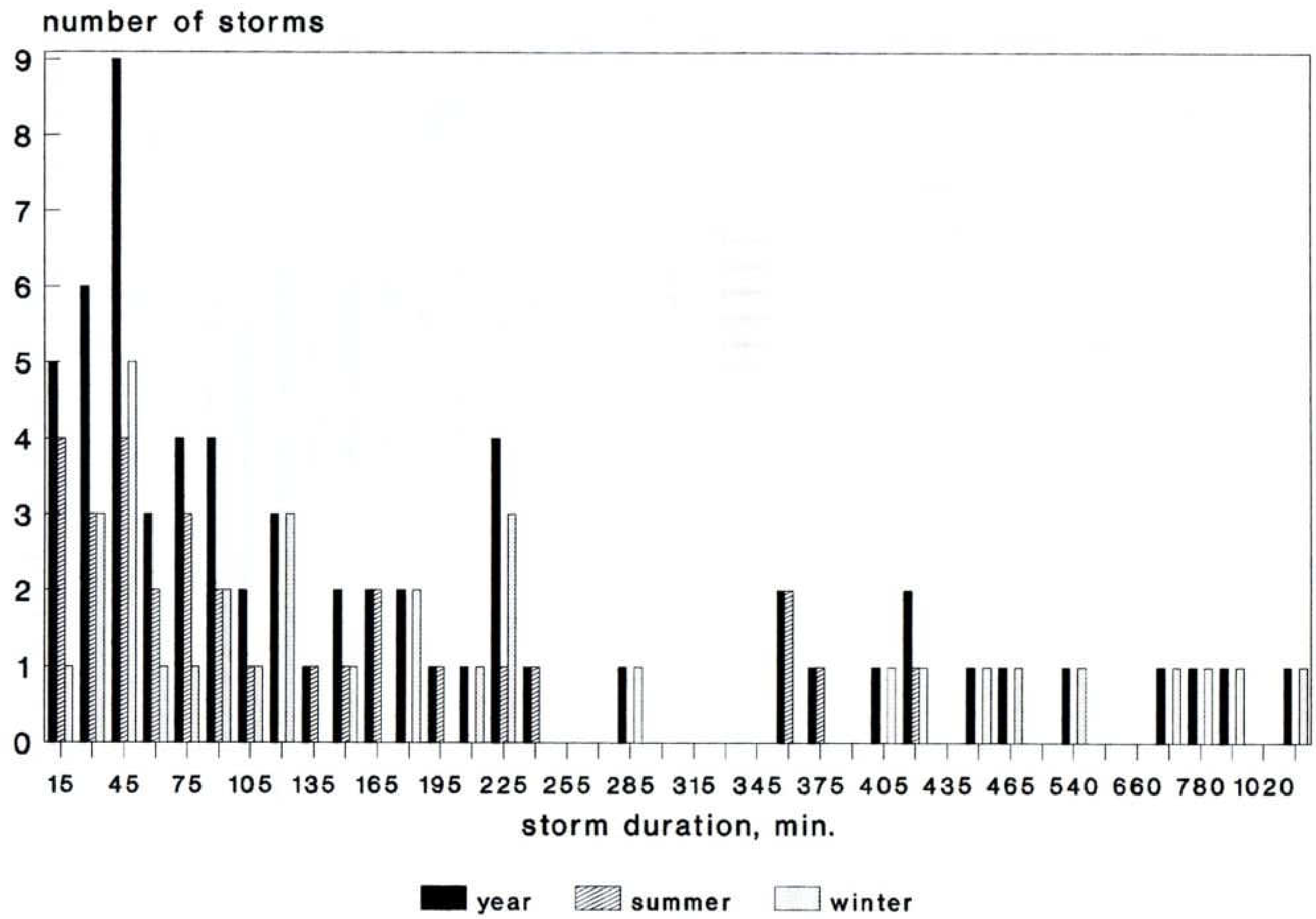

Figure 6. Frequency of runoff generating rains by duration of rain.

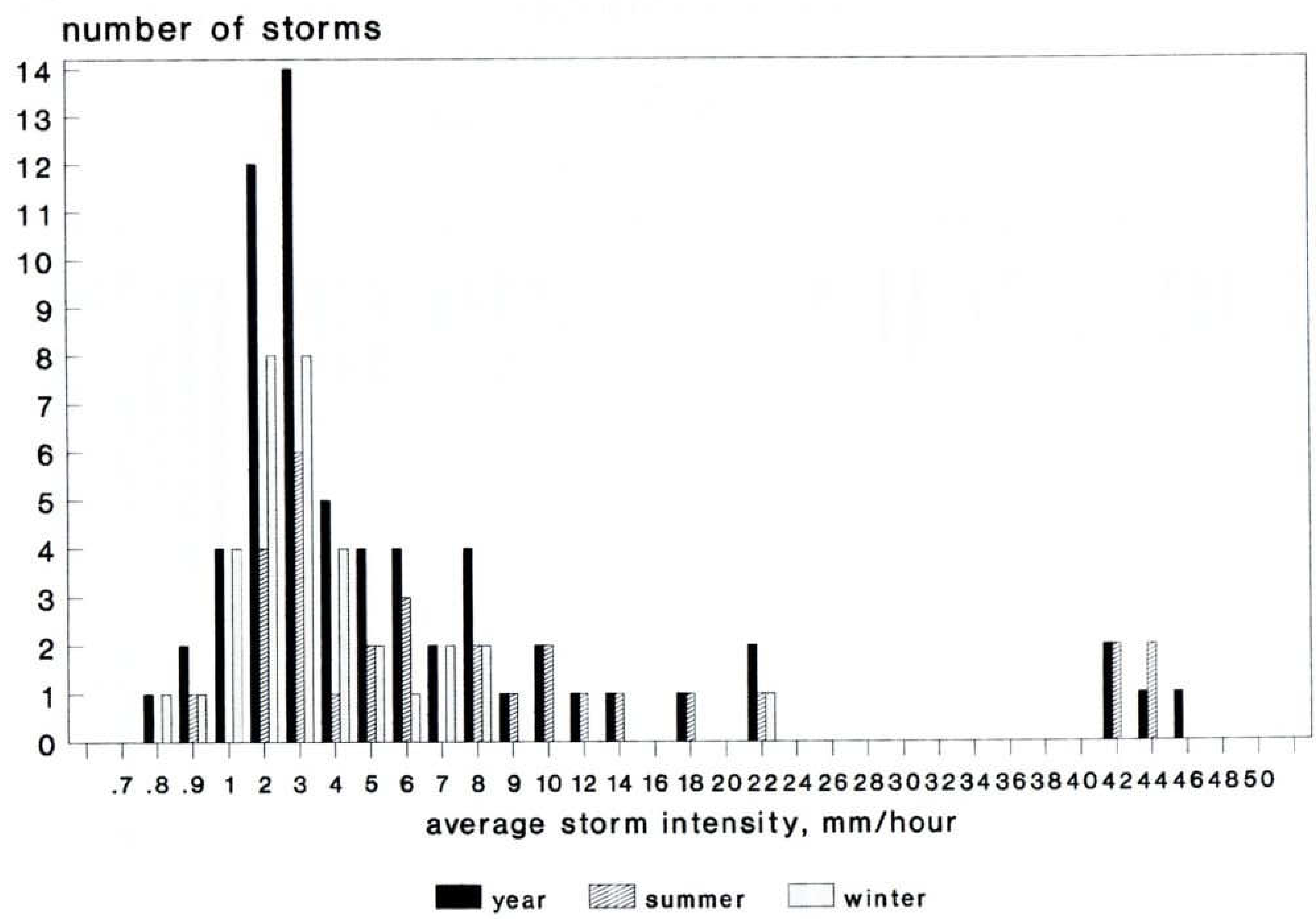

Figure 7. Frequency of runoff generating rains by average intensity.

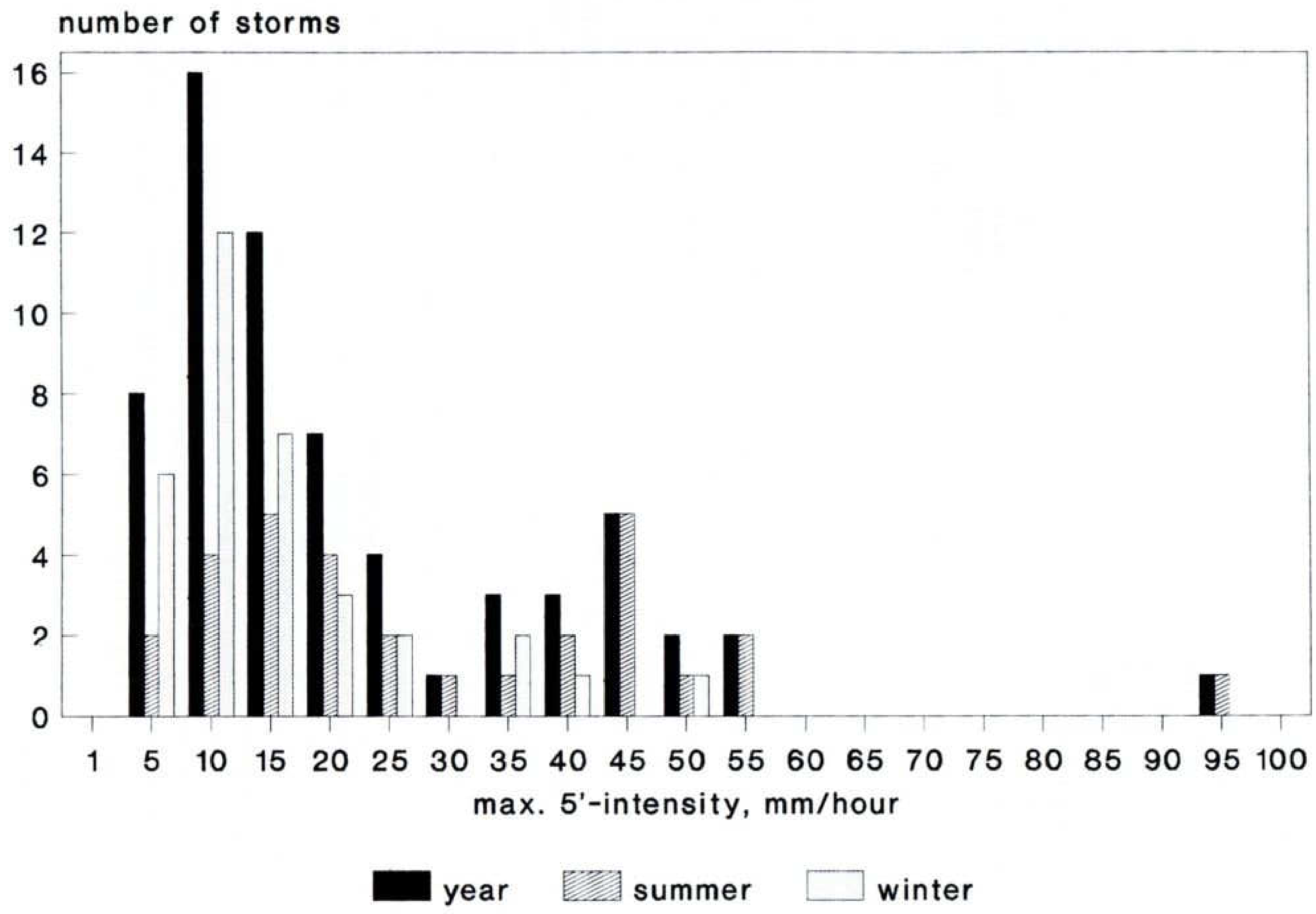

Figure 8. Frequency of runoff generating rains by max. 5 min. intensity.

4. DISCUSSION

The rather high number of 73 runoff events in 40 months, as inferred from the HS-flume recordings, corresponds with the fact that runoff and erosion has occurred on the permanently bare plots during 31 (or 58.5 %) of the total number of 53 four-weekly intervals of measurement (4 - 22 - 23 - 24). A comparable frequency of potentially erosive rains was found by Fullen and Reed (25). They observed erosion on 50 occasions during an 18 month plot study in Shropshire (England) with 125 field visits. Unexpected was the finding that about half of the runoff events occurred in winter. Before the start of the plot study it was supposed that only summer storms on slaked loess soils would cause overland flow and erosion. The fact that 16 (51.6 %) of the 31 four-weekly periods with runoff and erosion occurred in summer and 15 (48.4 %) in winter, fully confirms the runoff event recording. Evidently, not only summer but also winter conditions were conducive to runoff generation (see also fig. 3). Summer and winter regimes of runoff generation and soil erosion on the bare experimental plots have been discussed in some detail by Kwaad (5). Different modes of runoff generation are envisaged for the experimental site in summer and winter, viz. Hortonian overland flow dominating in summer, and saturation overland flow or storage controlled overland flow (26), with a perched water table reaching the soil surface, coming into play in winter and early spring.

Rainfall amount of only 11 (15 %) of the 73 runoff generating rains was more than 12.7 mm, the lower limit for inclusion of a storm in the R-factor of the USLE (9). Therefore, the results of this plot study seem to support the recommendation of Sinzot et al. (12) to set a lower limit for the inclusion of a storm in the calculation of an erosivity index for West-Europe. They recommend a rainfall amount of 8 mm as lower limit. This would include 25 (34 %) of the 73 runoff generating rains of this study. Fullen and Reed (25) found that 3.25 mm of rain can be sufficient to initiate plot erosion. This would include 62 (85 %) of the 73 runoff generating rains of the present study.

Duration of runoff generating winter rains was on average twice that of the runoff generating summer rains. No literature data are available to verify this. The difference fits in with the idea of Hortonian overland flow dominating in summer and saturation overland flow being important in winter. Summer runoff was caused by higher intensity rainfall than winter runoff. Average and max. 5'-intensity of the summer rains was 3 resp. 2 times higher than that of the winter rains. This also is in agreement with Horton overland flow generation in summer. Fullen and Reed (25) found that an intensity of 2.08 mm/hour is necessary for soil erosion to begin. This would include 54 (74 %) of the 73 rains of the present study.

5. CONCLUSIONS

The results of the runoff and rainfall recording on the experimental site indicate that : (a) overland flow generating events occur quite frequently, 22 per year in the period of study, (b) the most frequent (or modal) runoff event during the period of study was characterized by a rainfall amount of 2-4 mm, a duration of 30-45 min., an average intensity of 2-3 mm/hour and a max. 5'-intensity of 5-10 mm/hour, (c) overland flow events occur just as frequently in winter as in summer, (d) seasonal characteristics of the runoff generating rains are in agreement with the hypothesis of a dominance of Horton overland flow in summer and of saturation overland flow in winter.

Because of the different modes of runoff generation that can occur, soil conservation measures should not be directed exclusively at the key variable of the Horton model of overland flow generation, viz. the infiltration capacity of the soil surface, but also at the key variables of the saturation model of overland flow generation, viz. the presence of an impeding layer in the soil and the moisture storage capacity of the zone above this layer.

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