BIOLOGIA PLANTARUM (PRAHA)

21 (6) : 475—479, 1979

BRIEF COMMUNICATION

The Biological Response to the Forbush Effect

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Abstract. The frequency of nucleus and cell division in prothallia of *Equisetum arvense* L. grown under aseptic, defined conditions shows a considerable stabillity in the course of long-term experiments. This stability can be impaired if germinating spores are afflicted in the period 50 ± 5 h after sowing by the just occurring Forbush effect in the period of decreasing intensity of cosmic radiation but not in the period of its repeated increase.

Frequencies of nucleus and cell divisions have been studied in prothallia of *Equisetum arvense* L. (SOSNA 1953, 1968) in the course of long-term (1947 to 1977) observations of spontaneous mutability. These numerical data have shown a stable extent of variability in all years, except in some cases in which significant differences were observed in a few experiments within the year. These differences could not be explained either by cultivation

TABLE 1

Basic physical characteristics of the Forbush effect which are in relation to the investigations of the biological response. (Extract from the tables by KŘIVSKÝ and RŮŽIČKOVÁ-TOPOLOVÁ 1978)

	Characteristics of the Forbush decreases								
	Start		Maximum of decrease		Start value	Decrease value	T_S [h]	T_D [h]	D [%]
	Day	Hour	Day	Hour					
1969	May 15	01	May 16	02	101.6	95.2		25	6.4
1970	June 17	08	June 17	15	101.3	99.7	43	07	1.6
	Nov. 7	03	Nov. 7	17	105.6	99.4	48	14	6.2
1973	June 18	00	June 18	07	98.6	96.7	34	07	1.9
	July 8	12	July 10	09	102.0	99.0		45	3.0
1974	July 7	06	July 8	08	95.0	92.7		26	2.8
	Sept. 13	19	Sept. 14	13	97.8	95.1	69	18	2.7
1976	July 15	06	July 15	17	102.0	100.3		11	1.7

Received June 4, 1979; accepted June 14, 1979

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conditions or by integral factors of the observed cosmic radiation. New findings in heliophysics, hydromagnetics, and in the investigation of the primary cosmic radiation (CoR) and of variations in the secondary component in Earth magnetosphere enabled an insight into more profound relation-

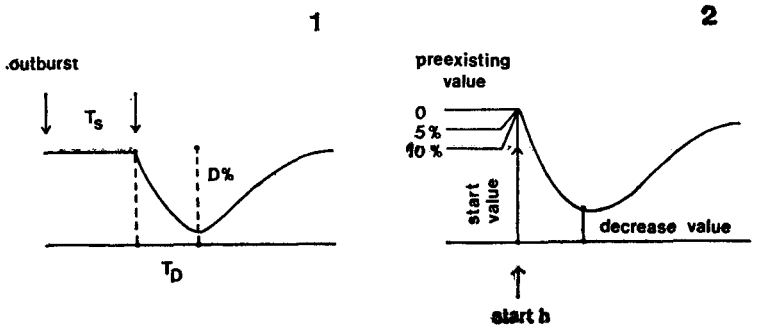

Fig. 1. A diagram of parameters of the Forbush effect representing the course of cosmic radiation in its time course. T_S stands for the delay in the beginning of the Forbush effect after the start of the eruption, T_D stands for the time of the decrease in cosmic radiation, D% for the decrease in cosmic radiation expressed in %.
Fig. 2. A diagram of parameters of the Forbush effect representing the initial value, the value at the start, and the maximum value of the decrease in cosmic radiation in its time course

ships, primarily the Forbush effect. The depressions in the level of recorded cosmic radiation, the so-called Forbush decreases (FD) are due to the Earth getting swathed in "magnetic bottles" with particles of solar origin. The magnetic bottles with their discontinuities form a shield around the

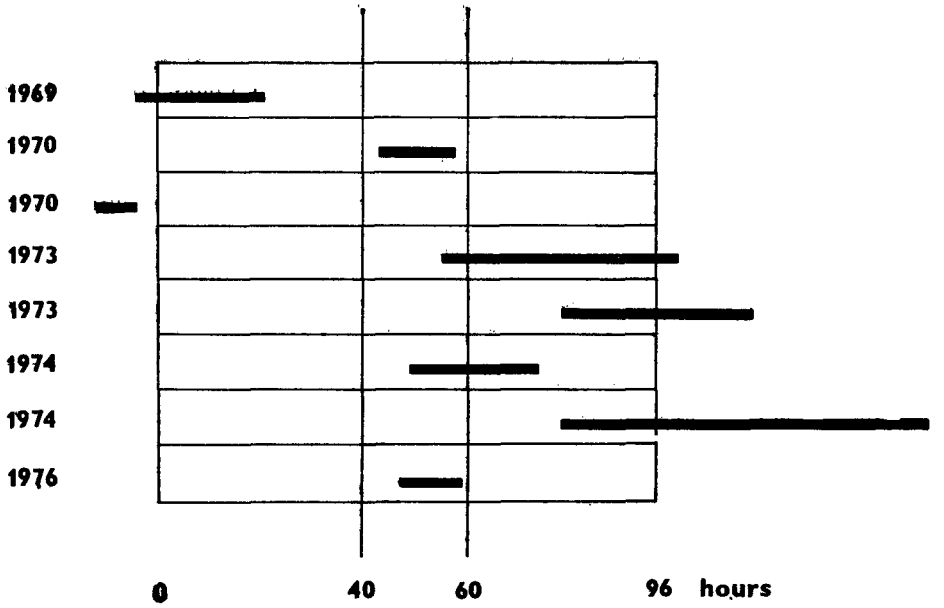

Fig. 3. A diagram representing the time course of the decrease in cosmic radiation during the Forbush effect (T_D) and its biological responses in a period of about 50 h.

TABLE 2

Numerical data of biological experiments in individual investigated years. Experiments from the period without corresponding eruptions serve as control

	Start										
	Day	Hour	D [%]	T_D [h]	T_D/ biological start [h]	No. of spores	Non-dividing spores	Four-cell prothallia 72 h	[%]	Four-cell prothallia 96 h	[%]
1969	May 15	01	6.4	25	+ 6	609	57	177	29.1	307	50.4
						604	61	150	24.8	301	49.6
1970	Nov. 7	03	6.2	14	−44	601	66	114	19.0	335	55.7
	June 17	08	1.6	07	+12	595	65	149	25.0	240	40.3
						620	62	148	23.9	252	40.6
1973	July 8	12	3.0	45	−54	605	61	112	18.5	346	57.2
	June 18	00	1.9	34	−78	600	54	150	25.0	261	49.5
						608	55	142	23.3	250	41.1
1974	July 7	06	2.6	26	−48	610	61	105	17.2	360	59.0
	Sept. 13	19	2.7	69	−80	617	71	146	23.7	258	41.8
						613	75	147	24.3	253	41.3
1976	July 15	06	1.7	11	−48	602	62	92	15.2	349	57.9
						599	61	148	24.7	253	48.2

TABLE 3
Correlation between cosmic radiation and the number of four-cell prothallia

Cosmic radiation / 72 h :	$S_d^2 = 312$
	$r_s = 0.1429$
Cosmic radiation / 72 h < four-cell prothallia:	
	$S_d^2 = 412$
	$r_s = -0.13$
Cosmic radiation / 96 h :	$S_d^2 = 566$
	$r_s = <0.1$
Cosmic radiation / 96 h < four-cell prothallia:	
	$S_d^2 = 162$
	$r_s = 0.555$

Earth and prevent primary particles of a certain spectral range of energies to penetrate to it from the Galaxy (DORMAN 1968, HULTQUIST 1968, HAYAKAWA 1969).

Investigations of CoR variations were made possible in the last few years by introducing special neutron monitors with running registration. The first analyses of the Forbush effect are also of recent date (ŠVESTKA and SIMON 1975, KŘIVSKÝ 1977, KŘIVSKÝ and RŮŽIČKOVÁ-TOPOLOVÁ 1978).

In this paper, the possibility of the response of observed aberrations of cell divisions in prothallia is verified in retrospect with the short-term Forbush effect at the period of solar cycle No. 20, *i.e.* in the years 1965 to 1975. Corresponding physical and biological data are presented in the Tables and Figures. Table 1 is an extract from the Tables of the Forbush effects (KŘIVSKÝ 1977). The corresponding parameters presented in the Tables are shown diagramatically in Fig. 1 and Fig. 2.

Spores harvested in the respective year were cultivated aseptically in the same year at certain intervals (10 in total) on agar plates (medium A 41), approx. 200 spores per Petri dish. Cell division was evaluated at fixed intervals (48, 60, 72 and 96 h). Cell division occurs under standard cultivation conditions at an exact time limit. Significant aberrations are always caused by external factors (SOSNA 1953, 1968). Numerical data from the experiments which were coincident in time with or which approached in time to the just occurring Forbush effect, selected from the years 1969 to 1976, are summarized in Table 2. Correlations between the CoR and the number of four-cell prothallia are evaluated in Table 3, and differences in exposure length are tested in Table 4. From these data it follows that there is a statistically significant difference in the number of four-cell prothallia if the spores have

TABLE 4
Testing of differences in exposure length in experiments afflicted by the Forbush effect and control cases

1970	Nov. 7	(−44 h)	and control:	$\chi^2 = 27.857$, $P < 1\%$
1973	July 8	(−54 h)	and control:	$\chi^2 = 22.58$, $P < 1\%$
1976	July 15	(−48 h)	and control:	$\chi^2 = 29.40$, $P < 1\%$

been afflicted in a period of about 50 hours (50 $\pm$ 5 h) by a decrease in CoR intensity due to the just occurring Forbush effect. Most χ^2 of the cases, the beginning of germination of which took place approx. 50 h before the decrease in CoR, are > 20 (Table 4. χ^2 was not calculated for the year 1974 as the difference was larger than in other years.)

$\chi^2_{\text{tab.f}=1} = 6635$ for $\alpha = 1\%$, thus P is smaller than 1% and the differences are highly significant. There is also a correlation between the total magnetic activity and the number of four-cell prothallia after 96 h. This was proved by means of the nonparametric test for correlation with the Spearman's coefficient of serial correlation:

$$r_s = 0.6759,\ n = 13,\ 5\% > P > 1\% .$$

r_s is significant at the 5% level.

The mechanism of the biological response to the Forbush effect will certainly be of complex character. The determining physical parameter is the sudden change in CoR intensity (in the region of the T_D curve), magnetic activity being also of great importance. With regard to purely physical factors, the response in the biological projection can be sought in the transport of solutes across membranes or in the excitation of changes in membrane potentials. Further experiments are being carried out in this respect in simulated conditions as well as in the course of the Forbush effect.

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