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EFFECTS OF REPRODUCIBLE MAGNETIC FIELDS
ON THE GROWTH OF CELLS IN CULTURE
(Final Report)

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EFFECTS OF REPRODUCIBLE MAGNETIC FIELDS ON THE GROWTH OF CELLS IN CULTURE

This report presents the final results of studies performed in both high and very low magnetic fields. A description of the fields used was presented in a previous report (Q-B2375-3).

The data represent the combined results of all experiments performed during the course of this study. Some of these data had been presented in preliminary form in previous reports. The experiments conducted during this study are summarized as follows:

Very low magnetic fields

- Euglena gracilis
- Colpidium
- P. caudatum
- P. multimicronucleatum
- Chlorella pyrenoidosa
- Clover seeds
- Wheat seeds and seedlings

High magnetic fields

- Euglena
- P. multimicronucleatum

During the entire course of this study, as many of the environmental parameters as feasible were maintained constant. Lighting was maintained uniform by using a bank of 32 fluorescent lamps consisting of 16 40 watt cool white (F40-CWX) and 16 40 watt Gro-Lux (F40-GRO) lamps. The lighting was cycled 14

hours on and 10 hours off. Temperature was remarkably constant. The air temperature was recorded at 21°C on a Honeywell 7-day recorder. No variation was observed. The temperature of the culture medium, however, was noted daily with no daily fluctuation, but the range within the different culture jars was from 23.4° - 23.8°C. Relative humidity was not significant since liquid cultures were used; nevertheless the relative humidity of the chamber was held between 48 - 52% R.H.

With the exception of Euglena and Chlorella which were grown in Knop's solution, the other protozoa were cultured in a rice-milk medium (0.3 g powdered skim milk, 1 liter Aq. dist., 5 grains of boiled white rice).

All cell counts were made with a Model B Coulter Counter. These counts were verified by visual means using the Sedgwick-Rafter method with a Dunn counting chamber. A detailed description of the physical environment and methods used are given in a previous report (Q-B2375-3).

For the high magnetic field studies, control cultures were placed in relation to wooden blocks of the same size, color and configuration as the magnets. In the low field studies, control cultures were maintained in aluminum cylinders of the same dimensions as the high permeability metal shields. Both cylinders, experimental and control, either were painted on their internal surface with flat white paint (3 M Velvet Coating, 101-A10 white) or were lined with white paper toweling. Experimental and control cultures were set up in pairs and were run simultaneously. Any change or modification of the environment that might occur due to factors or events beyond the investigator's control would apply equally to both experimental and control cultures. In

extreme cases, experiments were discontinued and started over again. (This occurred in two instances when there was a power failure over the week end.)

EXPERIMENTAL RESULTS

Very Low Magnetic Fields (less than one milligauss)

Fifty separate cultures of Euglena gracilis were grown for periods up to 21 days, with samples taken every seven days. Each sample consisted of five aliquots which were counted in the Coulter Counter and averaged. The data are shown in Table I.

Twenty-four cultures of Chlorella pyrenoidosa (71105) were grown for eight days in Knop's solution, with 1% CO_2 in air bubbled through the solution continuously at the rate of 500 ml/min. Samples were taken at the end of three, five and eight days, each sample consisting of five aliquots. Cells were counted electronically in the Model B Coulter Counter and averaged. The data are summarized in Table II.

Fifteen cultures of Colpidium were grown in a milk-rice medium for 21 days with samples taken at the end of seven and fourteen days. Each sample consisted of five aliquots which were counted in the Coulter Counter. Since an electrolytic medium is required in making electronic cell counts, the Coulter Counter was set and calibrated for Knop's solution as the electrolyte. In preparing the Colpidium samples for counting, a ten-fold concentration of one part of Knop's solution was diluted with nine parts of the Colpidium culture. The data obtained are presented in Table III.

TABLE I

GROWTH OF EUGLENA IN NEAR-ZERO MAGNETIC FIELDS

Days	7 Days				14 Days				21 Days			
Initial Inoculum Cells/ml	Cell Count* Cells/ml		Growth Ratio**		Cell Count Cells/ml		Growth Ratio		Cell Count Cells/ml		Growth Ratio	
	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.
240[1]	850	580	3.5	2.5	1920	1670	8.0	7.0	2460	1550	10.0	6.5
1000[2]	4880	3930	5.0	4.0	10100	6480	10.0	6.5	23400	27900	23.5	28.0
1000[3]	5980	2660	6.0	2.5	13400	10200	13.5	10.0	22800	16900	23.0	17.0
750[4]	3900	2390	5.0	3.0	8470	6120	11.0	8.0	16200	15500	21.5	22.5

1. Average of eight experimental cultures and eight control cultures
2. Average of twenty-one experimental cultures and six control cultures
3. Average of twenty-one experimental cultures and seven control cultures
4. Total average of fifty experimental cultures and twenty-one control cultures

* Variation in cell counts did not exceed 10%

** Growth Ratio = $\frac{\text{final cell count}}{\text{initial inoculum}}$

TABLE II

GROWTH OF CHLORELLA IN NEAR ZERO-MAGNETIC FIELDS

Days	3 Days				5 Days				8 Days			
Initial Inoculum Cells/ml	Cell Count* Cells/ml		Growth Ratio**		Cell Count Cells/ml		Growth Ratio		Cell Count Cells/ml		Growth Ratio	
	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.
10100[1]	24100	32700	2.5	3.0	25500	30400	2.5	3.0	30800	26600	3.0	2.5
6800[2]	14800	15000	2.0	2.0	9140	9040	1.5	1.5	-	-	-	-
8450[3]	19500	23900	2.0	2.5	17300	19700	2.0	2.5			3.0	2.5

1. Average of 12 experimental and 6 control cultures
2. Average of 12 experimental and 6 control cultures
3. Total average of 24 experimental and 12 control cultures

* Variation in cell count did not exceed 3%

** Growth Ratio = $\frac{\text{final cell count}}{\text{initial inoculum}}$

TABLE III

GROWTH OF COLPIDIUM IN NEAR ZERO-MAGNETIC FIELDS

Days	7 Days				14 Days				21 Days			
Initial Inoculum Cells/ml	Cell Count* Cells/ml Exp.	Contl.	Growth Ratio Exp.	Contl.	Cell Count Cells/ml Exp.	Contl.	Growth Ratio Exp.	Contl.	Cell Count Cells/ml Exp.	Contl.	Growth Ratio Exp.	Contl.
260[1]	1350	1400	5.0	5.5	2030	1320	8.0	5.0	5550	2160	21.0	8.5
8550[1]	7060	7800	1.0	1.0	22100	10600	2.5	1.5	7320	4990	8.5	6.0
2220[1+]	2460	3390	1.0	1.5	2370	2860	1.0	1.5	2570	2540	1.0	1.0
1370[2]	3620	3610	2.5	2.5	14300	9400	10.0	6.5	19100	10800	13.5	7.5
3100[3]	3620	4050	1.0	1.5	11000	6050	3.5	2.0	10700	5120	3.5	1.5

1. Average of 3 experimental cultures and 2 controls
2. Average of 6 experimental and 2 control cultures
3. Average of 15 experimental and 8 control cultures

* Variation in cell counts did not exceed 10%

\+ Cultures failed to grow, bacterial contamination

Twenty-four cultures of Paramecium were grown on the milk-rice medium for 21 days in the very low magnetic field. These cultures were divided between Paramecium caudatum and Paramecium multimicronucleatum as follows: P. caudatum - 12 cultures, P. multimicronucleatum - 12 cultures.

The same procedure was followed as that used with Colpidium (see above). The experimental results are summarized in Table IV.

A total of 3500 white clover seeds were used in experiments to determine the effect of a magnetically field-free environment on seed germination. The seeds were germinated on a weighed quantity of white, ashless filter paper pulp to which was added a measured volume of water. Three experiments were conducted: (1) germination of seeds in the experimental environment, (2) germination of seeds in experimental and control environment after one month pre-storage under experimental conditions, (3) same as (2) above but after three months pre-storage under the experimental conditions.

The germination percentage for this batch of clover seeds, as stated by the seed packer, as of July 1964 was 70% with an analysis of 98% pure white clover containing 20% hard seeds.

The experimental results are presented in Tables V, VI and VII.

As an extension of the clover seed study, 750 wheat seeds were allowed to germinate and develop to the seedling stage in the low magnetic environment. The wheat seeds were germinated and grown on a mixture of equal parts by volume of perlite, silica, and white ashless filter paper pulp. Weighed quantities of this mixture were moistened with measured amounts of tap water. After seven days, the growing shoots and roots were measured and compared with the controls. The results are summarized in Table VIII.

TABLE IV

Paramecium caudatum

Days	7 Days				14 Days				21 Days			
Initial Inoculum Cells/ml	Cell Count* Cells/ml		Growth Ratio		Cell Count Cells/ml		Growth Ratio		Cell Count Cells/ml		Growth Ratio	
	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.
240[1]	93	120	0	0.5	770	860	3.0	3.5	120	120	0.5	0.5
16[1]	7	7	0.5	0.5	7	7	0.5	0.5	12	4	1.0	0
15[2]	31	29	2.0	2.0	26	0	1.5	0	0	0	0	0
90[3]	44	52	0.5	0.5	270	290	3.0	3.0	44	41	0.5	0.5

Paramecium multimicronucleatum

180[1]	63	30	0.5	0	650	290	3.5	1.5	130	190	0.5	1.0
26[1]	3	4	0	0	12	11	0.5	0.5	7	7	0	0
21[2]	65	79	3.0	4.0	52	39	2.5	2.0	31	29	1.0	1.0
76[3]	44	40	0.5	0.5	240	110	3.0	1.5	56	75	0.5	1.0

1. Average of 3 experimental cultures and 2 controls
2. Average of 6 experimental cultures and 2 controls
3. Average of 12 experimental and 6 control cultures

* Variation in cell counts did not exceed 20%

TABLE V

Percent Seed Germination in a "Zero" Magnetic Field (1750 seeds)

Hours	Experimental	Control
24	32%	33%
31	52%	50%
48	84%	69%

TABLE VI

Percent Seed Germination after 1 Month Pre-Storage in a "Zero" Magnetic Field (1500 seeds)

	Experimental		Control	
Time in Hours	A[1]	E[2]	A[1]	E[2]
24	35%	17%	32%	19%
31	53%	32%	51%	30%
48	89%	74%	69%	67%

1. A - seeds stored under ambient conditions
2. E - seeds stored under experimental conditions

TABLE VII

Percent Seed Germination after 3 Months Pre-Storage in a "Zero" Magnetic Field (1250 seeds)

	Experimental		Control	
Time in Hours	A[1]	E[2]	A[1]	E[2]
24	29%	27%	35%	34%
31	51%	41%	49%	50%
48	79%	62%	69%	69%

1. A - seeds stored under ambient conditions
2. E - seeds stored under experimental conditions

TABLE VIII

Growth of Wheat Seeds (750 seeds) after One Week Exposure to a "Zero" Magnetic Field

	Percentage Germination[1]	Root Length[2]	Growth Difference[2]	Shoot Length[2]	Growth Difference[2]
Experimental	78%	42 ± 12 mm		73 ± 31 mm	
			5 ± 3 mm		8 ± 5 mm
Control	79%	37 ± 11 mm		65 ± 30 mm	

1. Based on 750 experimental and 750 control seeds
2. These values represent the mean of the parameter under consideration with the variation representing the average difference from the mean.

High Magnetic Fields

The fields used in this portion of the study were generated by large permanent magnets (surplus magnetron magnets). Various gap distances were used in the several magnets to give the desired field strengths. These may be listed as follows:

Magnet	Field Strength
1	400 - 800 oersteds
1A	400 - 800 "
2	550 -1100 "
2A	90 - 120 "
3	250 - 375 "
3A	550 -1100 "
4	250 - 400 "
4A	100 - 125 "
5	80 - 100 "
5A	80 - 90 "
6	90 - 120 "
6A	400 - 800 "

In the magnetic field studies, each experimental configuration consisted of a magnet and its control. In each case the control was a wooden dummy of the magnet, same size, shape, gap, color, etc. The magnet and its control were placed under the same bank of lights and each experimental-control pair was treated as a unit.

Euglena gracilis cultures were exposed to six different magnetic fields continuously for 28 days, samples were taken every seven days and counted on the Coulter counter. Four such replicates were made over a 4-month period. The resultant data are summarized in Table IX.

The effect of exposure to magnetic fields greater than ambient as compared to controls is summarized in Table X. These data represent the total average of all experiments in all magnetic fields (combined).

A similar series of experiments was performed over a 21 day period using Paramecium multimicronucleatum. Six additional magnets were used, but each was of the same field intensity, gap dimensions, and configuration as those used in the Euglena experiments. This series was repeated twice over a 2-month period. The resulting data are summarized in Table XI.

DISCUSSION

In examining the data, it may be noted that four cell-systems were used in the low field studies. These included Euglena, Colpidium, Paramecium, and Chlorella. This choice represents two simple animals and two simple plants of different cell size ranges.

This cell size range is represented as follows:

Table IX

Growth of Euglena in Magnetic Fields Greater than Ambient

Days		7 Days				14 Days				21 Days				28 days			
Magnet number	Initial[1] Inoculum Cells/ml	Cell Count[1] Cells/ml		Growth Ratio		Cell Count Cells/ml		Growth Ratio		Cell Count Cells/ml		Growth Ratio		Cell Count Cells/ml		Growth Ratio	
		Experiment	Control	Experiment	Control	Experiment	Control	Experiment	Control	Experiment	Control	Experiment	Control	Experiment	Control	Experiment	Control
1A	1060	3350	3740	3.0	3.5	4700	4360	4.5	4.0	8520	8370	8.0	8.0	11800	12900	11.0	12.0
2A	1060	2960	3460	3.0	3.0	4270	5390	4.0	5.0	8500	9560	8.0	9.0	13300	15800	12.5	15.0
3A	1060	3320	3240	3.0	3.0	4490	4520	4.0	4.0	8170	9380	8.0	9.0	11900	15500	11.0	14.5
3	1060	3130	3380	3.0	3.0	4860	5770	4.5	5.5	9310	9370	9.0	9.0	14200	14900	13.5	14.0
4A	1060	3020	3320	3.0	3.0	4630	5340	4.5	5.0	8980	10100	8.5	9.5	14200	16300	13.5	15.5
5	1060	2930	3350	3.0	3.0	4420	5280	4.0	5.0	8690	10200	8.0	9.5	14300	13100	13.5	12.5

1. Average of 24 cultures, covering six different magnetic field intensities

TABLE X

Combined Data Representing Total Average of All Experiments in All Magnetic Fields

Days	7 Days			14 Days			21 Days			28 Days		
	Cell Count		Growth Ratio	Cell Count		Growth Ratio	Cell Count		Growth Ratio	Cell Count		Growth Ratio
Initial[1] Inoculum	Experiment	Control	Experiment Control	Experiment	Control	Experiment Control	Experiment	Control	Experiment Control	Experiment	Control	Experiment Control
1060	3120	3420	3.0 3.0	4560	5110	4.0 5.0	8700	9500	8.0 9.0	13300	14800	12.5 14.0

1. Average of 24 cultures, covering six different magnetic field intensities

TABLE XI

Growth of P. multimicronucleatum in Magnetic Fields Greater than Ambient

Days		7 Days				14 Days				21 Days			
Magnet Number	Initial Inoculum Cells/ml	Cell Count Cells/ml		Growth Ratio		Cell Count Cells/ml		Growth Ratio		Cell Count Cells/ml		Growth Ratio	
		Exp.[1]	Contl.[2]	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.	Exp.	Contl.
1	81	100		1.0		170		2.0		80		1.0	
2	81	120		1.5		160		2.0		26		0	
4	81	270		3.4		170		2.0		37		0.5	
5A	81	86		1.0		170		2.0		75		1.0	
6	81	66		0.5		130		1.5		32		0	
6A	81	58		0.5		140		1.5		24		0	
Combined Average	81	120	230	1.5	3.0	160	85	2.0	1.0	46	110	0.5	1.0

1. Average of two cultures for each magnet
2. Separate controls did not accompany each magnet. Each experiment consisted of six magnets and two controls. This figure represents the average of the four controls (two replicates of two each).

Euglena	- 50 - 100 microns
Chlorella	- 20 - 30 microns
Colpidium	- 50 - 100 microns
Paramecium	500 - 1000 microns

The original intent was to determine whether cell size has any relationship to the biological effect induced by the very low magnetic field and whether any cell-size differences could be observed between experimental and control cultures after exposure to the low field.

Biological effects that are represented by the reduced data presented in the previous section will be discussed below. However, at this time, any differences in cell size between control and experimental cultures may be dispensed with by noting that none were observed. At the time cell counts were made, cell size distribution was automatically plotted (using the Model B Coulter Counter and Automatic Size Distribution Plotter). In no case could any difference be detected for cell size and size distribution plot between the experimental and control cultures.

Examination of the low magnetic field data shows a response in the same direction for the various cell cultures used. This response is summarized in Table XII.

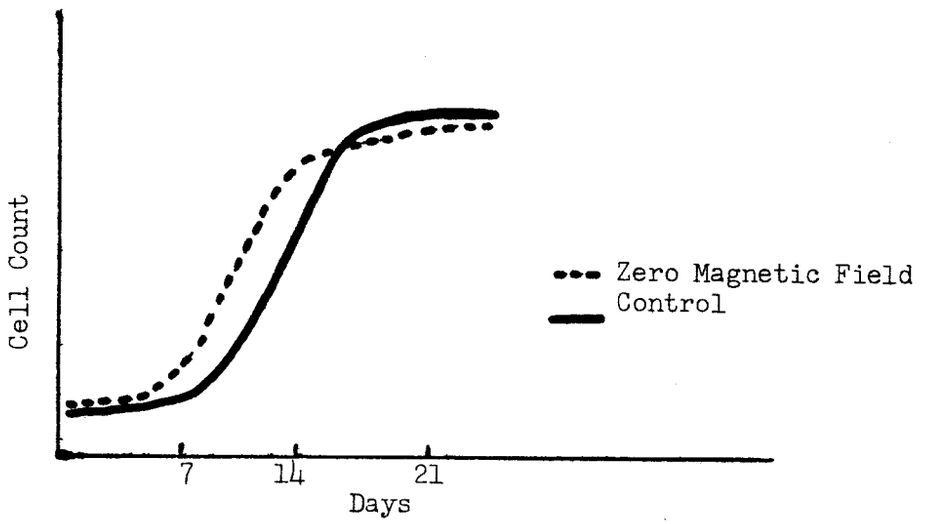
The cultures of Euglena showed a definite increase in growth rate when maintained under conditions where the magnetic field is lacking. This increased growth rate, as compared to control cultures, continued through 14 days, but then the growth rate of controls increased so that by 21 days both the experimental and control groups showed essentially similar growth ratios. This would seem to indicate that the logarithmic phase of the growth curve is reached sooner

TABLE XII

Growth Response of Organisms to a "Zero" Magnetic Field

Days		7 Days		14 Days		21 Days	
Organism	Cell Size in Microns	Growth Ratio		Growth Ratio		Growth Ratio	
		Exp.	Contl.	Exp.	Contl.	Exp.	Contl.
Euglena	75	5.0	3.0	11.0	8.0	21.5	22.5
Colpidium	75	1.0	1.5	3.5	2.0	3.5	1.5
P. caudatum	750	0.5	0.5	3.0	3.0	0.5	0.5
P. multimicronucleatum	750	0.5	0.5	3.0	3.0	0.5	0.5
		3 Days		5 Days		8 Days	
Chlorella	25	2.0	2.5	2.0	2.5	3.0	2.5

in the very low magnetic field than it is under control conditions. The following graph indicates a possible growth reaction of cells in the very low field.



A similar patternof effect has been observed in cultures of Colpidium. It is interesting to note, however, that both Euglena and Colpidium are about the same size organism. Also, it should be pointed out that the growth requirements are different for these two organisms: Euglena may be classified as a plant since it contains chlorophyll and photosynthesizes whereas Colpidium is an animal deriving its growth requirements from its nutrient medium.

Both species of Paramecium showed the same response. Population size decreased from the original inoculum during the first week. After the culture became established, growth progressed during the second week, and as the nutrients in the medium became exhausted and metabolic end products accumulated, growth diminished again in the third week. The same growth ratios occurred in experimental and control groups indicating that, in this instance, the environmental differences had no effect. A similar type of response was observed in the

algae, Chlorella, over a period of eight days. During this period no growth differences were observed. Perhaps, if the cultures of Chlorella were continued for 21 days an effect might have been seen.

The failure of Paramecium to follow the patterns established by Euglena and Colpidium might be due to two possible factors:

(1) There is a cell-size sensitivity which affects the response to the magnetic environment.

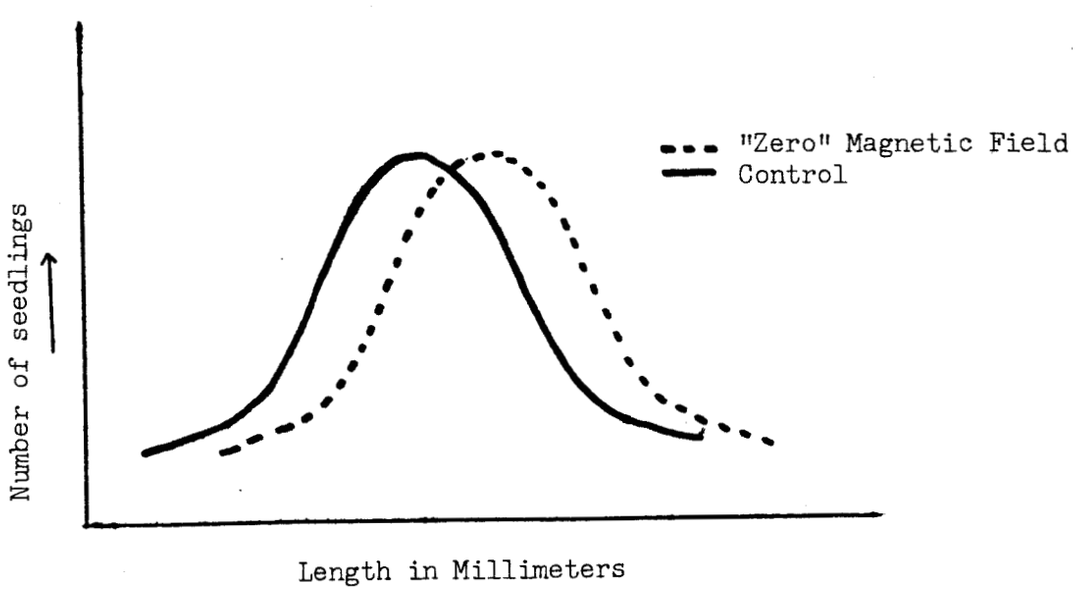
(2) Other factors in the environment beyond the range of experimental control.

Although this first premise looks inviting, it appears unlikely in light of the results obtained with the clover and wheat seeds. After 48 hours, a higher percentage of clover seeds germinated in the "zero" magnetic field than in the ambient. Again this seems to indicate that the developmental process is apparently accelerated in the absence of a magnetic field. Tables VI and VII present data on the effect of pre-storage of seeds in the very low magnetic field prior to germination. Those seeds pre-stored in the "zero" magnetic environment for one month and then subsequently germinated in the same environment showed a lower percentage germination (74%) than those seeds not pre-stored (ambient stored seeds), then germinated in the low magnetic environment (89%). When germinated under control conditions, pre-storage made no difference in percent germination (69% not pre-stored vs. 67% pre-stored). Similarly pre-storage for three months made no difference in germination in the control environment (Table VII). However, in the low magnetic field, the pre-stored seeds had a lower percentage germinating than in the control environment, and still less than the number of ambient stored seeds germinating in the magnetic-field free environment (Table VII). These results seem to indicate that

pre-storage of seeds has little consequence upon subsequent germination. This might be expected since a plant seed is in a dormant state and therefore tends to react more slowly, if at all, to its environment. (Conditions of humidity and temperature which are important in maintaining seed viability during storage are not being considered since these have been maintained constant.)

Because of the noted differences in numbers of seeds germinating, further studies were initiated to determine the low magnetic field effects upon the growth of seedlings. For this purpose wheat was used and wheat seeds germinated and seedlings maintained for seven days under the conditions of the experiment. After seven days, no difference in germination percentage between experimental and control batches was observed.

A consistent difference was observed in the length of the growing shoots and roots of the experimental plants compared to controls. The seedlings grown in the low magnetic field were larger and more robust than the controls. The differences noted may be graphically demonstrated in the following curves which represent the size distribution of the seedlings.



These curves show a similar displacement toward greater growth in the very low magnetic field grown seedlings as was seen in the growth curves for Euglena.

From these data, there is more than just a general trend toward growth enhancement in the very low fields. In those cases where close control was exercised over the environmental variables (within limits of feasibility), a reproducible pattern of increased growth in very low magnetic fields (less than 1 milligauss) was observed. However, these data are considered inconclusive at this time because exposure was of a relatively short duration. In none of our previous studies have we ever found an effect due to acute exposure. This lack of effect in short term experiments had been previously reported for tissue culture cell lines. In order to get the full impact of the low magnetic field effect, plant studies must be done over a time period long enough to allow the plants to mature and develop seeds and then these seeds germinated and grown in the very low magnetic field. However, it should be pointed out that when a size distribution of the wheat seedlings was made, the resultant plot was a bimodal curve indicating that these wheat seeds were not from a homogeneous population. This heterogeneity may explain the failure to get similar data to that obtained from the clover seed study.

Examination of the data obtained from magnetic fields greater than ambient, results in a more complex situation. Complicating factors are introduced by differences in magnetic field strength and gradients within the field (field homogeneity).

TABLE XIII

Growth Response of Euglena to Magnetic Fields Greater than Ambient

Days		7 Days		14 Days		21 Days		28 Days	
Magnetic Field Strength (Oersteds)		Growth Ratio		Growth Ratio		Growth Ratio		Growth Ratio	
		Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control
400 - 800	1A	3.0	3.5	4.5	4.0	8.0	8.0	11.0	12.0
90 - 120	2A	3.0	3.0	4.0	5.0	8.0	9.0	12.5	15.0
550 - 1100	3A	3.0	3.0	4.0	4.0	8.0	9.0	11.0	14.5
250 - 375	3	3.0	3.0	4.5	5.5	9.0	9.0	13.5	14.0
100 - 125	4A	3.0	3.0	4.5	5.0	8.5	9.5	13.5	15.5
80 - 100	5	3.0	3.0	4.0	5.0	8.0	9.5	13.5	12.5

Referring to Table X, examination of the growth ratios indicates that magnetic fields greater than ambient tend to have an inhibiting effect upon the population growth of cultures of Euglena over a period of 28 days. However, examining the data in terms of field strength and homogeneity, a similar pattern of effect still emerges but with some interesting overtones. These data are summarized and presented in Table XIII.

Practically no effect was observed for magnets 1A and 3 which represent fields of 400 - 800 and of 250 - 375 oersteds respectively. The greatest effect was seen for magnets 2A, 3A, 4A, and 5 which represent fields of 90 -120, 550 - 1100, 100 - 125, and 80 - 100 oersteds respectively. However, these various field intensities represent a rather wide range of gradients. Contour plots of these magnetic fields were drawn and presented in a previous report (Q-B2375-3). For convenience at this time, the magnetic field intensities and their gradients are summarized below:

Magnet No.	Field Intensity	Field Gradient
1	400 - 800 oersteds	30 - 70 oersteds/cm
1A	400 - 800 oersteds	40 - 70 oersteds/cm
2	550 - 1100 oersteds	50 - 80 oersteds/cm
2A	90 - 120 oersteds	3 - 4 oersteds/cm
3	250 - 375 oersteds	10 - 18 oersteds/cm
3A	550 - 1100 oersteds	50 - 90 oersteds/cm
4	250 - 400 oersteds	10 - 25 oersteds/cm
4A	100 - 125 oersteds	2 - 6 oersteds/cm
5	80 - 100 oersteds	1 - 2 oersteds/cm
5A	80 - 90 oersteds	1 - 2 oersteds/cm
6	90 - 120 oersteds	2 - 4 oersteds/cm
6A	400 - 800 oersteds	25 - 75 oersteds/cm

With the exception of magnet 3A which represents the highest field intensity used, the magnetic fields that showed the greatest biological response were those with the most homogeneity (Magnet 2A, 90 - 120 oersteds, gradient 3 - 4 oersteds/cm; Magnet 4A, 100 - 125 oersteds, gradient 2 - 6 oersteds/cm; Magnet 5, 80 - 100 oersteds, gradient 1 - 2 oersteds/cm). Is there a relationship between field homogeneity and biological response? Based on these data, no definite conclusions can be drawn. The response to the magnetic fields of various field strengths and various gradients are less clear cut and more difficult to explain than the effects observed in the very low fields.

Nevertheless, if the combined magnetic field data are used (Table X), then there is a clear indication of growth inhibition in higher than ambient magnetic fields.

For purposes of discussion, the growth ratios for cultures of Euglena exposed to high and very low magnetic fields are compared in Table XIV (data from Table X and Table XII).

These data may be represented pictorially in the following graph.

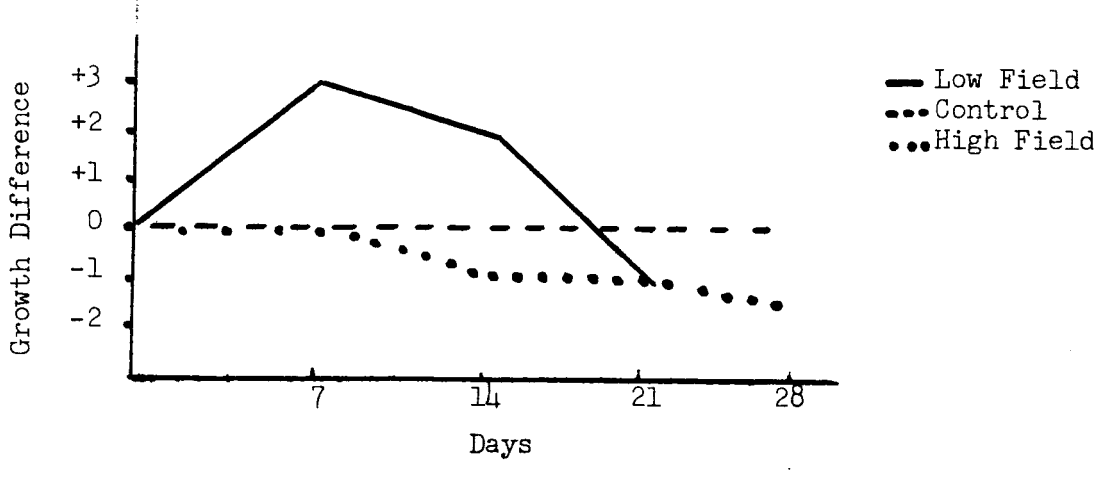


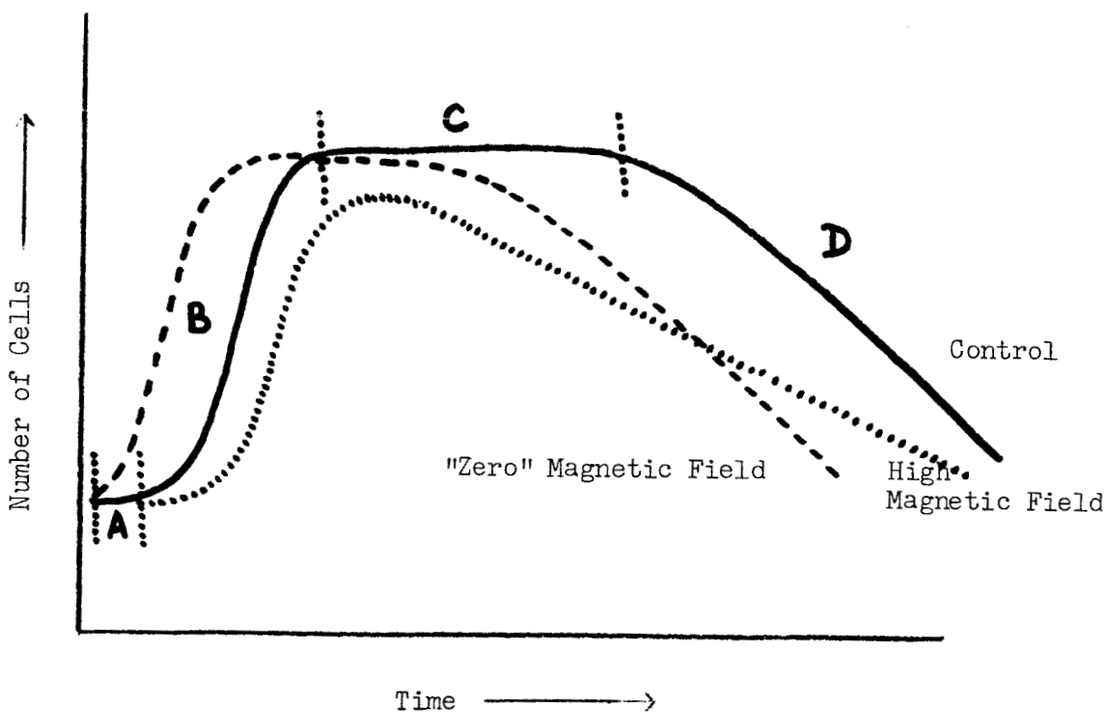
TABLE XIV

Response of Euglena to High and Very Low Magnetic Fields

Days	7 Days		14 Days		21 Days		28 Days	
Magnetic Field	Growth Ratio Exp.	Control	Growth Ratio Exp.	Control	Growth Ratio Exp.	Control	Growth Ratio Exp.	Control
Very Low	5.0	3.0	11.0	8.0	21.5	22.5	-	-
Higher than Ambient	3.0	3.0	4.0	5.0	8.0	9.0	12.5	14.0
	Growth Difference[1]		Growth Difference		Growth Difference		Growth Difference	
Very Low	+ 2.0		+ 3.0		- 1.0		-	
Higher than Ambient	0.0		- 1.0		- 1.0		- 1.5	

1. Growth Difference = Experimental Growth Ratio - Control Growth Ratio
+ Sign indicates acceleration of growth in the experimental culture over the control.
- Sign indicates inhibition of growth in the experimental cultures over the control.

This graph may be interpreted by saying that removal of the normal magnetic field results in a sudden increase in growth activity which may be the result of either the elimination of the lag phase of a normal growth curve or a time shift of the growth curve so that the logarithmic phase occurs earlier. The stationary phase may be abbreviated with the death phase occurring sooner. Thus by 21 days, the population of Euglena in the very low magnetic field shows a lower growth ratio than the controls. On the other hand, in a higher than ambient magnetic field, the growth curve proceeds at a normal rate, but since there is an inhibition of growth after seven days, it might be conjectured that the logarithmic phase of growth is shortened, the stationary phase begins earlier and is abbreviated with a slowly developing death stage ensuing. This entire process may be schematically represented in the following diagram.



A = lag phase of growth
B = logarithmic phase of growth
C = stationary phase
D = death phase

This explanation of the results reconciles the differences observed between "zero" magnetic field and control cultures and between higher than ambient magnetic field and control cultures. Unfortunately, however, based on these data, no mechanistic explanation may be offered at this time. To relate these results to a functional process would require another series of studies probing the biochemical and biophysical properties of the cells under the experimental environmental conditions.

SUMMARY

A series of biological specimens, both plant and animal, simple and complex, have been exposed to magnetic fields of varying intensities varying from near zero (less than one milligauss) to higher than ambient (1100 oersteds maximum). The general effect seems to be one of growth acceleration in the very low field; in the higher than ambient fields, there is an indication of growth inhibition. The high magnetic field results compare favorably with those reported by other investigators. Since this is the first study done in the near "zero" field, the results are interesting in that growth acceleration seems to be induced as a result of relatively long-term exposure. A possible explanation for these effects is presented.

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