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Impact of electromagnetic fields on morphogenesis and physiological indices of tomato

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A b s t r a c t. The impact of electromagnetic fields of the power of 1800 Am^{-1} (=H), 1000 Am^{-1} (=H), 800 Am^{-1} (~H), 1500 Am^{-1} (~H), 200 Am^{-1} (~H) on the morphological and physiological parameters of tomato plants which were affected directly during the whole vegetation by these fields, and in the first and second generation after effect, was studied in vegetation trials in the glass greenhouses of the phytotron complex. When tomatoes were affected with electromagnetic fields directly during the whole vegetation period, seedlings developed rapidly, and formed the biggest leaf area and grew up the highest when affected by the electromagnetic field of 1500 Am^{-1} (~H). The leaves of tomatoes affected by electromagnetic fields of 1000 Am^{-1} (=H) and 1500 Am^{-1} (~H) accumulated the highest content of pigments. The most intensive photosynthesis occurred under the effect of electromagnetic fields of 1800 Am^{-1} (=H) and 1500 Am^{-1} (~H). Electromagnetic field of 200 Am^{-1} (~H) mostly impeded the formation of pigments and decreased the yield. The greater negative effect of electromagnetic fields was established for germination energy of seeds chosen from tomatoes which were affected directly during the whole vegetation period. The effect of electromagnetic field of the power of 1000 Am^{-1} (=H) and 200 Am^{-1} (~H) was distinguished most notably.

K e y w o r d s: electromagnetic fields, tomato, growth, yield

INTRODUCTION

The positive effect of electromagnetic fields, depending on their power and frequency, were noticed for the improvement of seed germination and quicker growth and development (Dorošenko *et al*., 1997; Namba *et al*., 1995; Taikomoto *et al*., 2001). Seeds affected by such fields germinated better (Aksyonov *et al*., 2001; Martinez *et al*., 2002; Tučin *et al*., 2001) and later such plants had extra yield (Jerochin, 1999). Meanwhile, mostly, it is an effect of several minutes, hours or weeks on plants at corresponding stages of their development. Such plants produced more fresh weight, had greater leaf area and an increased amount of pigments, especially chlorophyll a and carotenoides, in leaves. Short effect of electromagnetic fields had a positive impact on the formation of generative organs (Bliandur *et al*., 1997; Borodin *et al*., 1998; Celestino *et al*., 1998; Muraji *et al*., 1997; Oturina and Čmil, 1997). According to some authors, a weak effect of such fields can develop a defensive system which decreases the negative effects of stronger stress (Ružič and Jerman, 2002). Not much data was found in scientific literature indicating that plants would be affected through the whole vegetation by electromagnetic fields. Some authors pointed out that electromagnetic fields of high frequency and power, spread by special equipment, impeded plant growth and development, and changed the ultrastructure of their cells (Magone, 1996; Roško and Roman, 1997; Selga and Selga, 1996). Still less data is available on the effect of electromagnetic fields on other generations of plants. It was established that seed germination of such plants decreased markedly (Selga and Selga, 1996).

The aim of this work was to determine the direct and the first and second generations after effect impact of electromagnetic field on the morphological and physiological parameters of tomato.

MATERIALS AND METHODS

Vegetative trials with the tomato variety *Svara* were carried out at the Laboratory of Plant Physiology of the Lithuanian Institute of Horticulture in the greenhouses of the phytotron complex in 1999-2001. In 1999 plants were grown on compost substrate in 58x36x27 cm plastic boxes. Four plants were grown in each box (one plant – one

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replication). Electromagnetic field was produced by a special reel. In such reels both continuous and alternating electromagnetic fields of different power were produced. The trials consisted of the following treatments: control – without artificial electromagnetic field; 1A - 1800 Am^{-1} (=H); 1B - 1000 Am^{-1} (=H); 2A - 800 Am^{-1} (∼H); 2B - 1500 Am^{-1} (∼H); 4_I+4_{II} - 200 Am^{-1} (∼H) (Fig. 1). Boxes with plants were placed inside the reels. The reels were elevated so that the field affected the zone of tomato apical meristem during plant growth. The power of electromagnetic field was measured by Magnetic Field Monitor HI-3550, a meter designed for measurement of continuous (=H) and alternating (~H) electromagnetic fields. The measurement range of the meter was from 80 Am^{-1} to 24000 Am^{-1}.

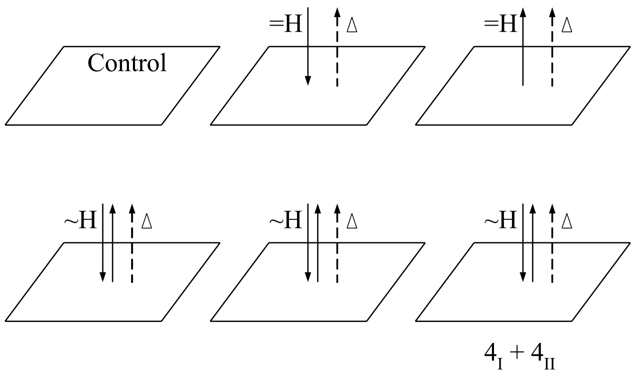


Fig. 1. Schematic presentation of the effect of electromagnetic fields. (Control variant – without effect of electromagnetic fields. 1B variant – direction of the vector of electromagnetic field power is opposite to the direction of plant growth. 1A variant - direction of the vector of electromagnetic field power coincides with the direction of plant growth. 2A, 2B, 4_I+4_{II} variants – direction of the vector of electromagnetic field power is alternating, f = 50 Hz.)

The gradient of electromagnetic field $H = H(x, y, z)$ was measured and calculated according to $\Delta H_X, \Delta H_Y, \Delta H_Z$;

$$\frac{\partial H}{\partial X} = \lim \Delta X = 0 \frac{\Delta H}{\Delta X} \quad (1)$$

$$\text{grad. } H = \frac{\partial H}{\partial X}\vec{i} + \frac{\partial H}{\partial Y}\vec{j} + \frac{\partial H}{\partial Z}\vec{k} \quad (2)$$

$$|\text{grad. } H| = \sqrt{\left(\frac{\partial H}{\partial X}\right)^2 + \left(\frac{\partial H}{\partial Y}\right)^2 + \left(\frac{\partial H}{\partial Z}\right)^2}. \quad (3)$$

Because the gradient H was measured only in the Z axis, *ie* according to the direction of plant growth, so:

$$|\text{grad. } H| = \left|\frac{\partial H}{\partial Z}\right|. \quad (4)$$

The gradient of electromagnetic field was: 1B (ΔH= 15 $A(m\ cm)^{-1}$), 1A (ΔH= 23 $A(m\ cm)^{-1}$), 2A (ΔH= 13 $A(m\ cm)^{-1}$), 2B (ΔH= 19 $A(m\ cm)^{-1}$) and 4_I+4_{II} (ΔH= 3 $A(m\ cm)^{-1}$).

In 1999 tomatoes were affected by electromagnetic fields during the whole vegetation period. Seeds were chosen from the first and the second trusses of the tomatoes. These seeds were sown in 2000 (further on these plants are called ‘tomato of the first generation’). Analogically, seeds were also chosen from these plants of the first generation after the effect of electromagnetic fields. In 2001 plants were grown from those seeds (further on these plants are called ‘tomato of the second generation’). In 2000-2001 tomatoes were grown on compost substrate in 58x36x27 cm plastic boxes. Two plants were grown in each box. There were three boxes in each variant. One plant was one replication.

Tomatoes were sown in January-February in all the years of the investigations. Till April, plants were provided with 14 h photoperiod in the greenhouses. Additionally they were irradiated by SON-T Agro lamps. During vegetation, the day/night air temperature was 15-20/22-27°C. Tomatoes were fertilized 3 times per week with 0.3% complex fertilizers ‘Kemira Combi’ (NPK 14:11:25 plus magnesium (1.4%) and microelements). Germinative energy (determined 6 days after sowing at temperatures of 20-30°C) and germinating capacity (determined 10 days after sowing at temperatures of 20-30°C) of tomato seeds, height and green mass of tomato seedlings, the amount of chlorophylls in their leaves in 100% acetone extraction (acc. to Wettstein (Gavrilenko *et al*., 1975)) and yield were determined. Morphological analyses of tomato seedlings were made according to Kuperman *et al.* (1982).

RESULTS

The direct impact of electromagnetic fields stimulated the development of plants (Table 1). Seedlings formed more leaves, grew up higher and had more fresh weight. The highest tomato seedlings grew up when affected with electromagnetic field of the power of 1500 Am^{-1} (∼H). This tendency was noticed through the whole development period. Tomato affected by this electromagnetic field reach the 8th organogenesis stage faster, *ie* they were good for transplanting. They had the most developed inflorescence according to apex height and formed the greatest number of leaves, though during the whole growth period their speed of development was undistinguished.

The development of the first generation tomato differed in various growth stages (Table 2). According to measurements of 29 February, tomato plants grown in 1A, 1B and 2A variants were in organogenesis stage II. At that time, these tomato plants had the smallest apex. Tomatoes which were grown from seeds of plants affected by electromagnetic fields of the power of 1000 Am^{-1} (=H) formed the smallest number of leaves till the 1st truss. The

T a b l e 1. Morphological and biometric characteristics of tomato seedlings grown under the effect of different electromagnetic fields

Variants	Development of apex		Leaves number	Plant height (cm)	Fresh weight (g)
	Stage	Height (mm)			
			2.01		
Control	II	0.10±0.000	6.3±0.58	5.6±0.72	0.2±0.03
1A	II	0.10±0.000	7.3±0.58	6.9±0.98	0.3±0.11
1B	II	0.10±0.000	7.0±0.00	7.4±0.79	0.3±0.02
2A	II	0.10±0.000	7.0±1.00	7.1±0.67	0.3±0.09
2B	II	0.11±0.014	7.7±0.58	7.8±0.76	0.4±0.02
4_I+4_{II}	II	0.11±0.014	7.3±0.58	7.1±0.58	0.3±0.05
			02.11		
Control	IV.V_a	0.32±0.076	10.0±0.00	8.0±0.67	0.7±0.04
1A	V_a.V_b	0.50±0.100	9.3±0.58	12.0±1.03	1.5±0.14
1B	IV.V_a	0.35±0.500	10.0±0.00	11.8±0.97	1.7±0.28
2A	IV.V_a	0.33±0.580	10.3±0.58	12.1±0.91	1.7±0.24
2B	IV	0.32±0.029	10.0±0.00	12.5±1.00	2.2±0.45
4_I+4_{II}	V_b	0.28±0.029	10.0±0.00	10.8±0.86	1.3±0.18
			02.21		
Control	V_d	0.87±0.058	10.3±0.58	16.7±1.29	5.3±1.50
1A	V_d. VI	1.20±0.300	12.3±0.58	24.7±1.95	8.4±2.68
1B	VI.VII	2.27±1.514	12.7±1.53	27.0±3.60	7.5±0.06
2A	V_d.VI	1.57±0.603	13.3±0.58	28.4±1.77	8.9±1.95
2B	VI	1.73±0.115	13.0±1.00	29.4±2.12	10.8±0.93
4_I+4_{II}	V_d.VI	1.63±0.551	13.0±1.00	25.4±2.32	13.6±2.55
			03.04		
Control	VII.VIII	7.07±3.602	13.3±1.55	43.6±3.41	26.4±1.69
1A	VII	7.27±1.966	14.3±0.58	50.6±3.41	25.0±5.04
1B	VII.VIII	9.70±6.366	14.3±1.16	56.1±2.18	39.6±7.70
2A	VII.VIII	15.77±12.400	15.0±1.00	54.4±5.83	32.6±2.48
2B	VIII	22.17±10.596	16.0±0.00	60.9±3.41	37.8±1.70
4_I+4_{II}	VII.VIII	10.67±2.887	15.0±1.00	52.1±4.41	33.9±1.43

depressing impact of this electromagnetic field also persisted in later organogenesis stages. Seedlings had the shortest first truss and formed the smallest number of leaves. Plants which grew in the control and the 4_I+4_{II} variants developed faster till the 7th organogenesis stage. Later, only tomato seedlings in the control variant formed more leaves and plants in variant 4_I+4_{II} practically did not differ from others. In different variants the height of the first generation tomato depended on the organogenesis stages. In organogenesis stages 2-3rd the smallest were the plants which grew in variants 1A and 1B, in stages 5-7th – in variants 1B and 2B. The height difference between plants of various variants decreased as the tomatoes grew and developed. At the initial organogenesis stages, the highest seedlings grew up in variant 4_I+4_{II}, but in organogenesis stages 7-8th they did not differ from other plants. Tomato seedlings of variant 1B produced the smallest amount of green mass in all the organogenesis stages. Till the 8th organogenesis stage, tomato seedlings of the control and 4_I+4_{II} variants produced more green mass, though the plants of this last variant differed little from plants of variant 1B before transplanting.

In the second tomato generation it was determined that plants of variant 4_I+4_{II} developed slowly (Table 3). Before transplanting, those seedlings had the shortest first truss and formed the smallest number of leaves. Meanwhile, tomato seedlings of variants 1A and 1B developed faster, though plants of the first generation, on the contrary, developed slowly. The height of the second generation tomato differed more only at the initial organogenesis stages. Higher plants were observed in variant 1B at the time of seedling growth, though they grew up the least in the first generation. Contrary to tomatoes of the first generation, in variant 1B seedlings of the second generation produced the highest amount of fresh weight. This tendency remained till the transplanting of seedlings. Tomatoes of variant 1A differed little from others at the initial organogenesis stages, but they produced the highest amount of fresh weight in organogenesis stage 8. Tomato seedlings of variant 4_I+4_{II} produced the smallest amount of fresh weight at this stage.

The direct impact of electromagnetic fields had a positive effect on chlorophylls synthesis, except for the electro-magnetic field of the power of 200 Am^{-1} (~H) (Fig. 2A).

T a b l e 2. Morphological and biometric characteristics of the first generation tomato seedlings after the effect of electromagnetic fields

Variants	Development of apex		Leaves number	Plant height (cm)	Fresh weight (g)
	Stage	Height (mm)			
Control	III	0.20 0	10.3 0.58	5.5 0.46	1.0 0.04
1A	II	0.10 0	9.0 1.73	4.1 0.95	0.6 0.22
1B	II	0.10 0	8.3 0.58	3.9 0.79	0.5 0.12
2A	II	0.10 0	9.0 0	4.4 0.12	0.6 0.12
2B	II,III	0.12 0.029	8.7 1.16	5.1 0.12	0.6 0.11
4I+4II	II,III	0.17 0.076	9.7 1.53	5.9 0.98	0.9 0.27
Control	V_b, V_d	1.57 0.666	13.7 0.58	18.7 1.26	12.3 0.97
1A	V_c, V_d	1.13 0.252	13.3 0.58	16.5 1.32	10.0 0.86
1B	V_a, V_b	0.83 0.351	12.0 1.00	11.8 1.89	7.0 1.54
2A	V_c, V_d	1.30 0.557	12.7 0.56	13.2 1.76	8.9 2.31
2B	V_b, V_c	1.03 0.115	13.0 0.00	12.0 0.50	6.6 0.59
4I+4II	V_c, V_d	1.43 0.577	13.7 0.58	19.1 1.15	11.7 1.85
Control	VII,VIII	9.17 1.258	17.3 0.58	46.8 1.61	48.8 0.82
1A	VIII	12.17 0.764	16.0 0	40.7 2.52	45.5 0.44
1B	VII,VIII	7.50 2.291	15.0 0	37.5 4.27	34.6 5.00
2A	VII,VIII	13.83 5.508	15.7 0.58	39.8 0.58	45.1 2.22
2B	VII,VIII	12.33 6.292	15.7 0.58	34.8 0.29	37.7 4.54
4I+4II	VII,VIII	8.00 3.464	15.7 1.53	39.7 0.76	35.4 1.63

T a b l e 3. Morphological and biometric characteristics of the second generation tomato seedlings after the effect of electromagnetic fields

Variants	Development of apex		Leaves number	Plant height (cm)	Fresh weight (g)
	Stage	Height (mm)			
Control	III,IV	0.22 0.021	10.0 0	5.9 0.62	0.8 0.09
1A	III,IV	0.20 0.041	9.3 0.47	5.0 0.21	0.6 0.16
1B	III,IV	0.22 0.024	10.0 0	6.7 0.57	1.2 0.36
2A	III	0.17 0.047	10.0 0	5.3 0.29	0.7 0.03
2B	III	0.20 0	10.0 0	5.0 0.25	0.1 40.7
4I+4II	II	0.12 0.024	9.3 0.47	5.7 0.19	0.6 0.07
Control	V_c	1.13 0.125	12.7 0.47	11.8 0.76	4.6 0.21
1A	V_a-V_c	0.70 0.245	12.0 1.41	11.5 0.78	4.2 0.71
1B	V_c,VI	1.73 1.040	13.7 0.47	13.2 1.31	6.8 1.86
2A	V_b,V_d	1.00 0.294	13.3 0.94	12.7 1.04	6.1 1.20
2B	V_c,V_d	1.33 0.189	13.3 0.47	11.3 0.56	6.1 0.45
4I+4II	V_a,V_d	0.67 0.249	13.0 0	11.5 1.23	5.0 0.71
Control	VII,VIII	12.23 4.055	17.0 0	40.0 3.74	38.2 2.50
1A	VIII	21.33 4.190	17.7 0.47	39.7 1.25	54.9 2.81
1B	VIII	22.27 1.543	16.7 0.47	43.3 1.70	49.2 4.92
2A	VII,VIII	11.00 6.377	16.3 0.94	37.2 2.25	35.0 6.06
2B	VII,VIII	13.53 7.722	16.3 0.47	35.7 0.47	34.1 9.60
4I+4II	VII,VIII	9.33 3.091	15.7 0.47	33.0 5.89	30.3 3.37

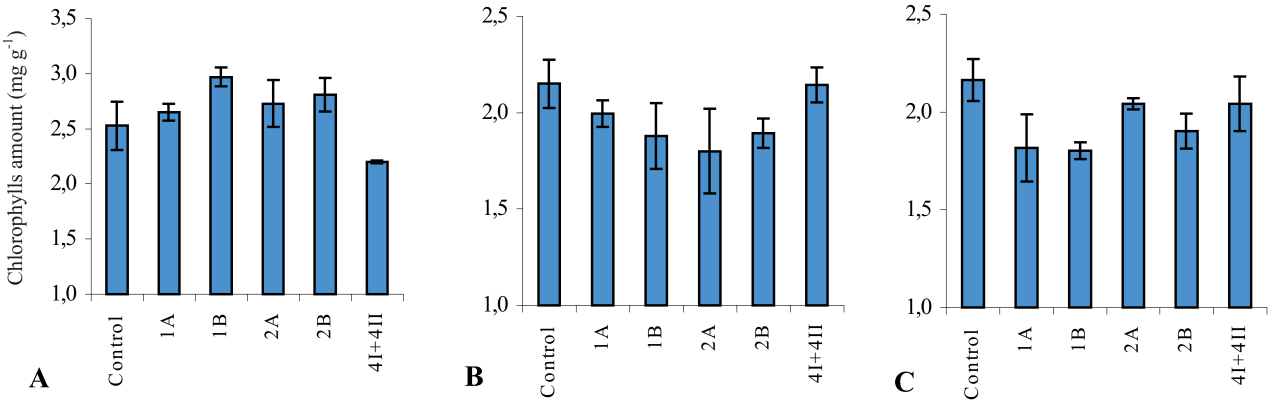


Fig. 2. Chlorophylls amount of tomato seedlings (A - direct impact of electromagnetic fields, B - the first generation of tomato after the effect of electromagnetic fields, C - the second generation tomato after the effect of electromagnetic fields).

Greater chlorophyll content was determined in leaves of tomato affected by electromagnetic fields of the power of 1000 Am^{-1} (=H) and 1500 Am^{-1} (~H). In the first generation, this index was a little lower in leaves of variants 1B, 2A and 2B (Fig. 2B) and in the second generation – in variants 1A and 1B (Fig. 2C). After the effect of electromagnetic fields, the amount of chlorophylls in tomato leaves did not exceed the control in none of the generations.

Total yield of tomato affected by electromagnetic fields of the power of 1000 Am^{-1} (=H), 1500Am^{-1} (~H) and 200 Am^{-1} (~H) was significantly lower in comparison with the control (Fig. 3A). No significant differences in total yield in the various variants after the effect of electromagnetic fields were established in any year (Fig. 3B,C).

Seeds of tomatoes which grew under the direct effect of electromagnetic fields of the power of 1000 Am^{-1} (=H) and 800 Am^{-1} (~H), had the least germination energy (7.3 and 8.3%, respectively) (Fig. 4A). Seed germination of the latter tomato was the poorest (84.3%) as well. Seed germination of tomatoes which grew under the effect of electromagnetic fields of the power of 1000 Am^{-1} (=H) was similar to that of the control (93.0%) and was 93.3%. Electromagnetic field of the power of 200 Am^{-1} (=H) had practically no impact on the germination of the first generation tomato seeds after the effect. Electromagnetic fields had no impact on the germinative energy and germinating capacity of the first generation tomato seeds after the effect (Fig. 4B). In variant 4_I+4_{II} these indices of the first generation tomato seeds after the effect were a little lower.

DISCUSSION

In the first stage of research, tomato apical meristem zones were affected by electromagnetic fields during the whole vegetation period. The investigated electromagnetic fields stimulated the development of plants, but their impact depended on the organogenesis stages. Seedlings developed rapidly and grew up the highest when they were affected by the electromagnetic field of the power of 1500 Am^{-1} (~H) (Table 1). Such plants, also, formed the biggest leaf area (Stašelis *et al.*, 2000a). According to other data, such electromagnetic fields did not have any impact on the

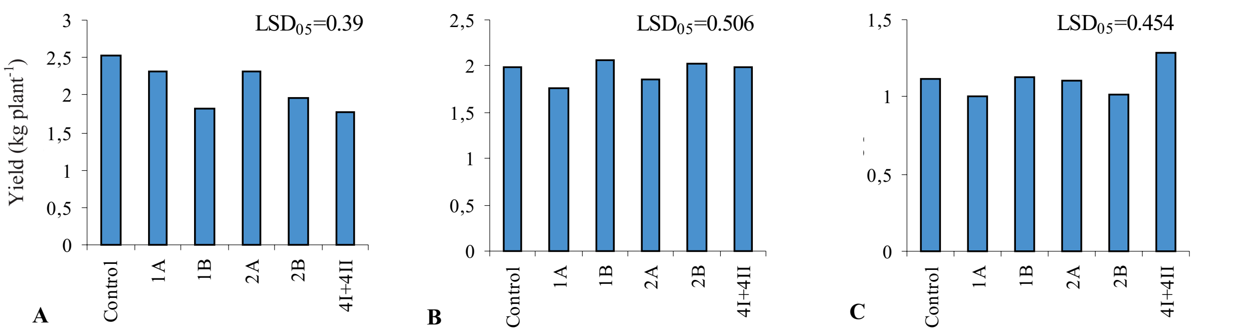
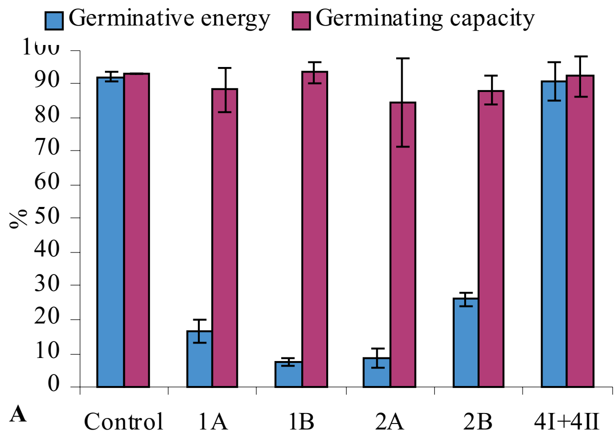


Fig. 3. Yield of tomato (A - direct impact of electromagnetic fields, B - the first generation of tomato after the effect of electromagnetic fields, C - the second generation tomato after the effect of electromagnetic fields).



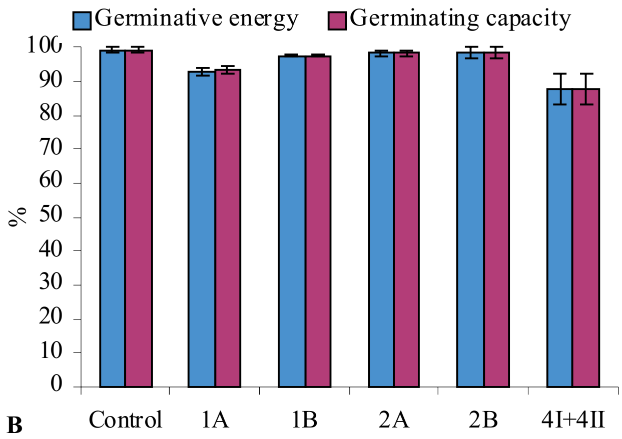


Fig. 4. Germinative energy and germinating capacity of tomato seeds (A - seeds chosen from tomatoes which were affected by electromagnetic fields during the whole vegetation, B - seeds chosen from the first generation tomatoes after the effect of electromagnetic fields).

number of flowers and fruits (Stašelis *et al.*, 2000b). The leaves of tomatoes affected by electromagnetic fields of the power of 1000 Am^{-1} (=H) and 1500 Am^{-1} (~H) accumulated the highest amount of chlorophylls (Fig. 2A). The most intensive photosynthesis occurred under the effect of electromagnetic fields of the power of 1800 Am^{-1} (=H) and 1500 Am^{-1} (~H) (Gavrilenko *et al.*, 1975). The effect of all the electromagnetic fields decreased the tomato yield. The electromagnetic field of the power of 200 Am^{-1} (~H) impeded most strongly the formation of chlorophylls (Fig. 3A) and photosynthesis intensity in tomato leaves (Stašelis *et al.*, 2000b), and decreased the yield.

Electromagnetic field had an impact on subsequent tomato generations after the effect. The greatest negative effect established was that on the germinative energy of seeds chosen from tomatoes which were affected by electromagnetic fields during the whole vegetation (Fig. 4). In scientific literature we found references that electromagnetic field of high power decreased seed germination of pines which grew under their effect for a long time (Selga and Selga, 1996). In the first and second generations, the effect of electromagnetic field on growth and development was mostly observable in the initial organogenesis stages (Tables 2 and 3). Later on the differences between the various variants were inconsiderable. The effect of electromagnetic field of the power of 1000 Am^{-1} (=H) (variant 1B) and 200 Am^{-1} (~H) (variant 4_I+4_{II}) was eminent. The first field, whose direction of vector was contrary to the direction of plant growth, depressed germination energy of seeds most strongly. Tomatoes of the first generation grew and developed slowly in this variant. Opposite results were obtained in the second generation. They grew and developed rapidly, but the synthesis of chlorophylls was a little lower. Contrary to this, the first generation tomatoes from variant 4_I+4_{II} did not lag behind the control in the initial organogenesis stages. Later, their rate of growth and development slowed down. In the second generation, the germination energy and seed germination of these tomatoes were the least. They grew and developed slowly, though this field had not depressing impact on the amount of chlorophylls and on yield. Meanwhile, when tomatoes grew under the effect of electromagnetic field of the power of 200 Am^{-1} (~H) during the whole vegetation, lower amount of chlorophylls in leaves (Fig. 2A) and yield (Fig. 3A) were determined as compared with others. Maybe it is possible to assume that electromagnetic fields not only change the cell ultrastructure (Selga and Selga, 1996), but also influence gene expression and that this influence could be expressed not only in the first, but in the second generation after the effect as well.

CONCLUSIONS

1. The direct effect of electromagnetic fields stimulated the development of plants, but their impact depended on the organogenesis stages.

2. Tomato seedlings developed rapidly and grew up the highest when directly affected by the electromagnetic field of the power of 1500 Am^{-1} (~H).

3. The direct impact of electromagnetic fields had a positive effect on chlorophyll synthesis, except for the electromagnetic field of the power of 200 Am^{-1} (~H). After the effect of electromagnetic fields, the amount of chlorophylls in tomato leaves did not exceed the control in none of the generations.

4. The direct effect of electromagnetic fields decreased tomato yield. No significant differences in total yield in the various variants after effect of electromagnetic fields were determined in any year.

5. The greatest negative effect of electromagnetic fields was established for the germinative energy of seeds chosen from tomatoes which were affected directly during the whole vegetation period.

6. In the first and second tomato generations after the effect of electromagnetic field, differences in growth and development appeared mostly in the initial organogenesis stages.

7. The effect of electromagnetic field of the power of 1000 Am^{-1} (=H) and 200 Am^{-1}(~H) was the most pronounced. The first field, whose direction of vector was opposite to the direction of plant growth, depressed the germinative energy of seeds the most. They grew and developed the most slowly. In the second generation they grew and developed rapidly and formed a greater leaf area. Tomatoes of the first generation after the effect of electromagnetic field of 200 Am^{-1} (~H) grew and developed similarly as in the control only in the initial organogenesis stages. In the second generation, the germinative energy and seed germinating capacity of these tomatoes were the least. They grew and developed slowly and formed the smallest leaf area.

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