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Spectral Impact of Low-Power Laser Radiation on Wheat and Maize Parameters*

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Introduction

The amazing characteristics of the laser radiation, such as monochromatism, polarization, coherence and high density, can be used not only in all spheres of engineering but also in biology and plant growing. The changes that occur in the physiological state of seeds and plants can stimulate or inhibit their development and depend closely on the laser radiation type, its wavelength – λ and intensity [1]. The experiments carried out by the Institute of Physiology (Academy of Sciences, Russia) in 1980s and later as well as by agrobiologists from Italy, Hungary and other countries, including Bulgaria show that non-photosynthesizing cells and material are capable of accumulating sunlight energy. Seeds can absorb photons concentrated sunlight, transform light quantum energy into chemical energy, store and use it during further growth and development of plants. The additionally absorbed light energy accelerates plant growth and increases their productivity [1, 2].

Having got acquainted with the experience of the scientists from countries working in the sphere of increasing the agricultural yield with decreased use of artificial fertilizers, scant irrigation and the boom of nitrates (used mainly in improving soil for growing crops), a group of specialists from the Institute of Optics in Sofia and from Base for Irradiation Application and Development BIAD-AA got in touch with the idea to use lasers in agriculture.

In 1983, when the research, construction and technology stages were over, the production of lasers, according to the National Program for "Development and Implementation of Lasers and Elements for Them" became possible. The development of He-Ne lasers began promptly using a small amount from the total sum of the finances from the same program (45 million BGN, 35 000 rubles and $ 45 000). This had to be done

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as lasers of that type had not yet been offered extensively by the western countries. The ones that could be imported by the USSR were more powerful – up to 25 mW (LG-75 type) but it took more than 3-4 years to import those He-Ne lasers.

Thus, only by the end of 1984, He-Ne lasers with output power of up to 25mW and lifetime (i.e. ability to generate) of more than 5,000 hours had already been constructionally developed and technologically ensured. This allowed us to construct and produce the "SOLAR" 25XH85 installation – a laser processing system for the agriculture with 25 mW He-Ne laser which won a Gold Medal at the Plovdiv Fair in 1985. We got positive comments from specialists from Hungary, some of the Soviet Republics and Japan. But due to economical stagnation things remained as they were.

The He-Ne laser, emitting on λ = 632.8 nm, as we mentioned above, was successfully used in 1980s here in the research of the laser radiation impact on plants aiming at increasing their productivity. It is enormous in size, very sensitive to dynamic loads (the working material is a mixture of gases – He and Ne, captured in a glass pipe with a diameter of 3-5 mm and a length of 80-100 cm) and much more expensive than the contemporary semiconductor (diode) lasers generating on a similar wavelength – 630 nm, 650 nm at room temperature and which cost only tens of $US.

In 1996 we renewed our experiments of laser application in the agriculture. In 1998, a competition was announced by the Ministry of Education, Science and Technology. This put the beginning of our work on the topic "A Laser System for Physiological Influence on Young Plants". Our aim was to use the already famous diode lasers generating on frequencies close to those of He-Ne lasers at room temperatures.

In 1998-2001, to research the laser radiation impact on wheat and maize seeds our team used diode laser with λ = 675 nm (this diode laser type was bought due to the lack of enough finances; the cost of a diode laser, generating on λ = 630 nm which is closest to He-Ne laser – λ = 632.8 nm, was a few times higher). In 2000, we bought a laser generating on λ = 650 nm. Now, after buying a diode laser with money from the contract between the Ministry of Education and Science and IIT- Bulgarian Academy of Science, generating on λ = 630 nm, the same will simultaneously be used with the other diode lasers generating on λ = 650 nm and λ = 670 nm (for comparison).

1. Aim of the research – investigating the laser radiation impact on the development of wheat and maize plants

The main aim of our research was defining the main parameters of the photosynthetic activity in wheat and maize plants under the influence of laser radiation, from the moment of planting, during the period of growing of the very plant till the gathering of crops and the registering of the natural growth, namely:

1. Germinating and germinating energy;
2. Amount of the root system of 10 plants;
3. Amount of chlorophyll in the leaves;
4. Intensity of photosynthesis;
5. Labial resistance;
6. Intensity of transpiration;
7. Density of leaves;
8. Efficiency of used water;
9. Increase of leaf area of a plant;

10. Weight of green mass and absolute dry matter of 10 plants;
11. Structure of the yield;
12. Grain yield per quarter of an acre.

Contemporary methods and technical aids were used in all these activities.

2. Design and production of a laboratory model of a system for pre-sowing diode laser irradiation of seeds

2.1. Selection of laser radiation source

After a thorough analysis, at the beginning of the experiment, it was decided to use semiconductor laser diodes during the experiment. Here are some of the main reasons:

– grain radiation to be possibly done from all sides;

– power density of the laser radiation to be the same all over the seed area;

– the optical system for the introduction of laser radiation into the processing zone to be constructed of minimum optical elements for decreasing losses of reflection and absorption;

– the grain movement speed to be secured by the use of such gravitation which leads to their roll and overall radiation;

– the grain movement speed regulation to be done by adjusting the slope angle;

– the capacity of the seed basket (ready for pre-sowing radiation) to be not less than 10kg maize seeds;

– the debit of the passing seed flow to be regulated by adjustable slot;

– the construction to secure simplified control so that it can be used by a large number of specialists;

– the system to be dust-proof.

At this stage, the selection of a laser diode is based primarily on economical reasons, namely:

– the shorter the wavelength, the higher the cost (the cost of the selected diode is $62.20, while for the same output power but with wavelength λ = 630 nm, the cost rises up to $80-100);

– the cost also rises highly when the output power is more than 20 mW (a 30 mW laser diode costs twice as much as a 20 mW one);

– a laser module, i.e. laser diode plus collimation optics costs more than $120.

As has already been mentioned, in the “SOLAR 25XH 85” device (a laser processing system in agriculture with 25 mW He-Ne laser) [3] the laser beam cross-section is 2 mm which makes the voluminous irradiation of the seeds impossible even if these seeds were wheat or rice. In addition, the density of the laser irradiation power in this case is 2 mW, but only in a cross-section spot of 0.0314 cm^2, which is 31.85 mW per 1 cm^2. This repeatedly surpasses the admissible spectral influence and is definitely close to thermal influence although the time of influence is very short (the tetrahedral prism which reflects the laser beam coming from He-Ne laser rotates at 2300 min^{-1}). As a result, instead of stimulating this may lead to damaging the germ.

The selection of the laser diode depends on the following considerations, too:

– the laser radiation generated by the laser diode has a horizontal beam divergence of 8° and a parallel beam divergence of 24° which is significantly useful from the point of view of the irradiator’s structure;

– the above defines an irradiated area, 200 mm from the laser diode front, with the following dimensions: width 25 mm and height 85 mm, with evenly distributed radiation without the use of any optical devices; this is successfully used later in designing the system's irradiator for the pre-sowing seed irradiation;

– by construction and production of an input stabilizing power supply unit for the generated irradiation with the possibility of regulating it within a certain range limit, a universal laboratory irradiator can be achieved without any optical losses.

2.2. Construction and Production of a Laboratory Irradiator

Due to the above-mentioned reasons for conducting the experiments, we used the laser irradiator developed during the first year [5].

Fig. 1 shows the mechanical structure of this laser irradiator. The laser diode is placed in a special bed in the ribbed part of the module which provide good cooling so that it can operate in a normal mode for an indefinite period of time. The laser diode fixing is provided by a metal screwing ring with M14×0.5 mm grooves. Silicone coating has been applied to the to the front peripheral ring for better thermal contact. A mechanical switch has been mounted to the radiator front for protection against undesirable irradiation at activated voltage and against polluting the optical exit of the laser diode when it is not in use. The plate with the electronic circuit for feeding the laser diode, which is mounted on it, is fixed with bolts and is embedded in a plastic cylinder right behind the radiator. Thus the laser diode, the plate, the cylinder and the radiator together with the mechanical switch form a whole unit – the so called laser laboratory irradiator. The supply voltage comes from an outside adapter – 12 V.

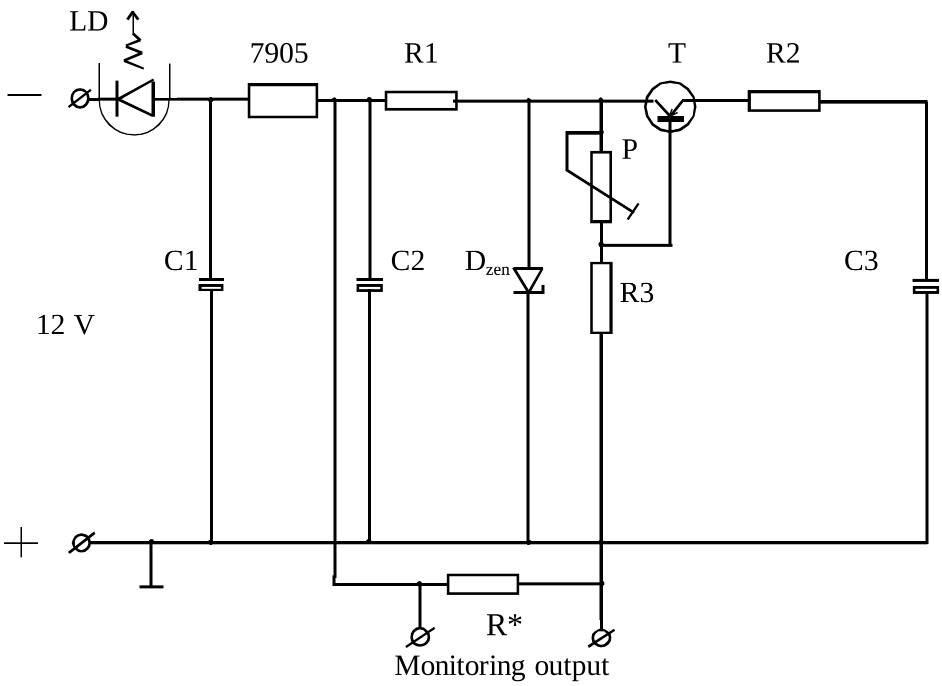

Fig.1. Electronic circuit for diode power supply: D_{zen} – zener diode, selected 5 V

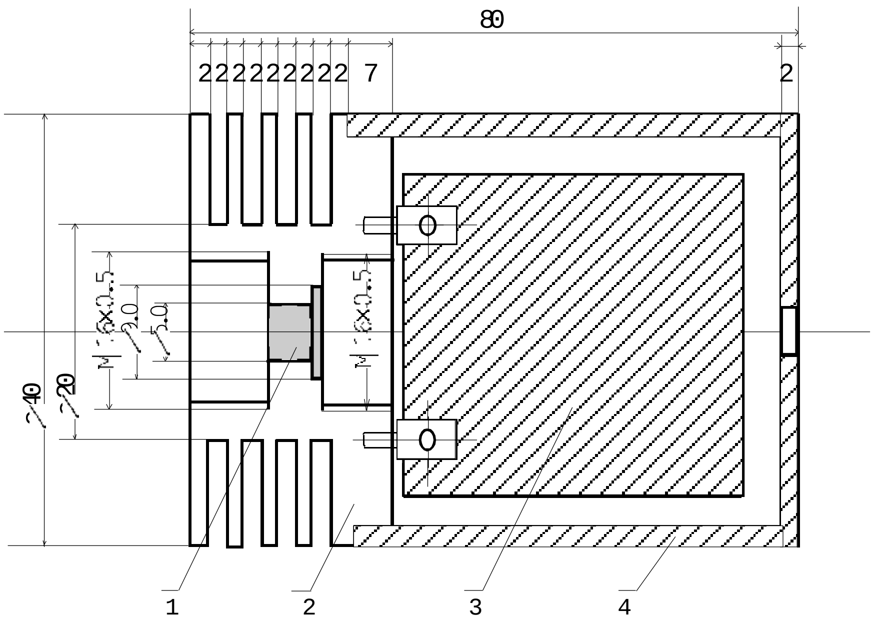

Fig. 2. Mechanical structure of the laser irradiatior: 1 – laser diode, 2 – cooling radiator, 3 – electronic supply driver, 4 – protective plastic cylinder

2.3. Electronic Circuit for Laser Diode Control [5]

We have used the electronic circuit for laser diode control developed during the first stage in 1999. It meets the requirements for long life-time and a wide temperature range performance. It is built on the basis of a current regulator with a few built-in forms of protection of the laser diodes (Fig. 1).

The electronic circuit consists of a voltage regulator, a few condensers, resistors, a transistor, a potentiometer, an adapter, Zener and light-emitting diodes. After connecting to the 12 V adapter, the charging of the filter condensers is slow and provides a slow start for the laser diode. The voltage stabilizer is selected for exactly 5.001 V. If, for any reasons, it fails to function or if the output voltage has been increased to more than 5.1 V the Zener diode cuts in and limits the voltage towards the laser diode. If burst, this Zener diode will get into a short circuit. The indicator diode is lit only when the laser diode is properly functioning. The voltage regulator is voltage of $U_{sh.c\ min}$ = 0.5 V. The total voltage drop of the working current flowing through the laser diode is 60 mA and is equal to:

$$U_{sh.c} + U_{a.c.\ (indicator)} + U_{r=10}W + U_{LD} = 5\ V.$$

This means that the current flowing through the laser diode can't be bigger than 60 mA. The resistor R* for easy indication is selected to be compatible with the photodiode monitoring current. The laser diode output power is directly dependent on the monitoring current. For an output power of 20 mW the necessary monitoring current is within the range from 0.32 to 0.34 mA.

Finally, we have to point out that the constructed supply unit can be used for other laser diodes generating on other wavelengths.

2.4. Production of the New SOLAR-2 Laser System for Pre-Sowing Seed Irradiation

The experience of the members of the team M.Antonov, PhD, Associate Professor and Stoyan Dinoev, PhD, Associate Professor and the cooperation between Gorublyane and Sofia in 1985, brought to the preliminary results showing 5-25% increase in the crop yield (depending on the type of crop). But, due to the financial freezing this interesting project *was not carried out in three consecutive years* so that these positive results could be accepted as valid. Due to the lack of adequate financial support during the first year of the project, the team used the SOLAR with some alterations and additional changes. Because of this, it was not the generating He-Ne laser and the rotating prism that were taken out of the body. But the operating neon glow (red) lamps were kept. Two laser irradiators were mounted in the corporate body. There were placed parallel one against the other and the distance between them was 75 mm. Thus the two laser irradiators were irradiating over double surface. In fixing the two laser irradiators a mechanism was designed to secure the co-axing of the laser irradiation. They were fixed to a steady stand in specially designed beds in such a way that the total laser spot remained fixed. As already explained, no *collimation optics has been mounted on the laboratory laser irradiators*. The laser irradiation energy necessary for the pre-sowing seed irradiation is evenly distributed in compliance with the law of the semiconductor laser irradiation with a total spot of 150×25 mm at a distance of 200 mm from the laser fronts. In the total irradiated surface the germ seeds can make 2 to 3 rotations thus they are irradiated from all sides while rolling down the sloping plane of the laser system body.

Fig. 3 shows the mechanical design of the laboratory “Laser system for pre-sowing seed irradiation” – SOLAR-2. The body of the laser irradiator is fixed to the main corpus by three bolts, thus directing the laser beams to the sloping plane zone of the passage of the rolling germ seeds. The mechanism regulating the amount of the seeds let out allows the operator to regulate this amount. The mechanism for adjusting the slope of the system allows him to regulate the speed of the seed flowing through the zone of irradiation, including the time of irradiation of the seeds rolling down the sloping plane.

From the above mentioned, it is clearly seen that the laser irradiation processing does not require any additional use of chemical substances – fertilizers, etc. The laser irradiation processing for pre-sowing seed irradiation is characterized by high productivity, low production cost. Because of its simplicity of control and operation, it does not require a highly qualified operator.

Of course, the research team will think about the construction of the final structure of this Laser System for Pre-sowing Seed Irradiation only during or after the third year, according to the project plan of the Contract, and only after the real financing of the project and the expected and *proven three-year yield increase*.

3. Germs and Methods of operation

During the period 1999-2002 the research was conducted in the laboratories of BIAD-AA, the greenhouses of IPE N. Pushkarov and research fields of KOS, Pazardjik and IPS General Toshevo. The object of research was sowing material (germs) of the maize sort “Knezha-530” and “Knezha-613”and of the wheat sort “Aglika” and “Teodora”.

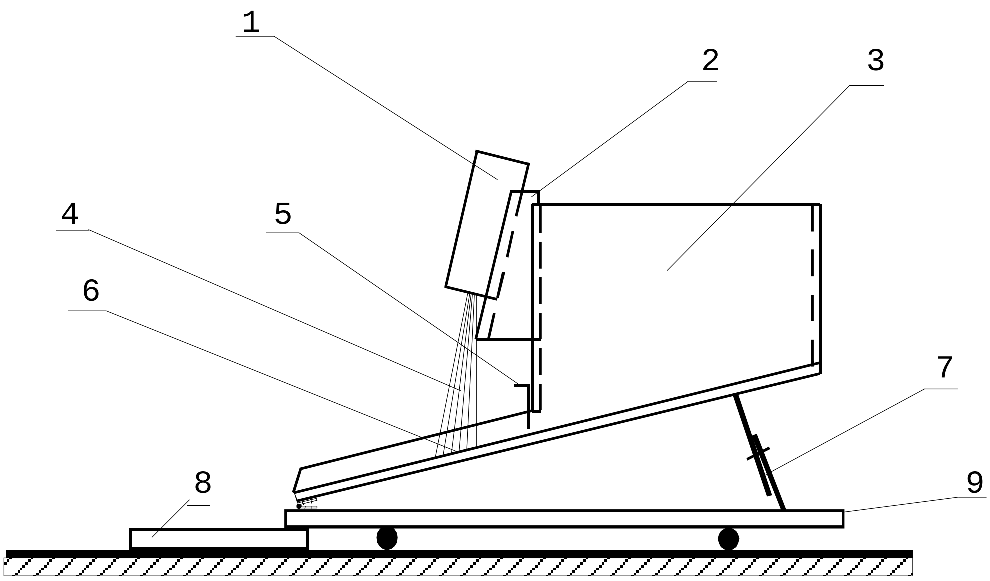

Fig.3. General mechanical pattern of "SOLAR-2" Laser system for pre-sowing grain irradiation:
1 – laser irradiatior comprising a semi-conductor laser, mounted in a cooling radiator with an attached power supply driver;
2 – suppord unit at a fixed angle of the laser diode;
3 – non-radiated grain tank;
4 – laser radiation;
5 – hatch regulating the amount of grains flowing out of the tank;
6 – grain irradiation zone;
7 – mechanism regulating the slope of the system;
8 – irradiated grain collecting container;
9 – foundation of the system

3.1. Research of the influence of the laser irradiation of the laser diode on the maize seeds during the first year

During the first year of the contract we conducted laboratory experiments with maize seeds of “Knezha-530” sort in the greenhouses and laboratories of BIAD-AA and IPE N. Pushkarov, Sofia. We used a laser diode CQL806/20 generating on λ = 675 nm with output power of 20 mW. We carried out two experiments with three repetitions in two vessels each for the one plant variant.

Experiment 1. the maize seeds have been irradiated by the above-mentioned laser in exposure of 10.s, 30.s and 1min.

Experiment 2. the maize seeds have been irradiated by the above-mentioned laser by a single-, double- and triplerolling of the seeds through the laser irradiation zone.

The sowing has been carried out on 08.06.1999.

The plants have been grown till the seventh leaf in plastic buckets filled with 6 kg of soil, fertilized with 1.5 g of ammonium nitre. The soil humidity was kept within the boundaries of 60-70%. Details of the experiments and the researched parameters were shown in the contract account report.

3.2. Research of the influence of the laser irradiation of the laser diode on the wheat seeds during the first year

During the first year we also carried out a vegetation experiment in containers filled with 5 kg of soil leached chernozem from the East Dobrudzha region. Two sorts of winter wheat – “Aglika” and “Teodora” have been researched. The experiment began on 19.10.1999. We had additionally fed in NPK on 10.11.1999 as follows: 200 mg of Nitrogen per 1 kg of soil, 200 mg of Phosphorus per 1kg of soil and 250 mg of Potassium per 1 kg of soil. Details of the experiments and the researched parameters were shown in the contract account report.

3.3. Research of the influence of the laser irradiation of the laser diode on the maize seeds during the second year

During the second year the experiments were carried out with maize seeds of the Knezha – 613 hybrid on 5-dekare areas in KOS-Pazardjik fields.

During the second year the experiments with wheat seeds were not carried out due to the lack of financing, including the travel allowances to IPS General Toshevo.

The maize seeds were irradiated in BIAD-AA, where the good old SOLAR, constructed in the Institute of Optics in 1986, with parameters for servicing the existing Co-operative farms, was stored and kept. We used the irradiators which were constructed during the first contract year. They had two mounted semi-conducting laser diodes generating on λ = 675 nm and with output power of 15 mW each and gamma rays with a source of Cs137 with dose power of 200 rad/min, Due to the minimal financing by the Ministry of Education and Science (out of the well grounded request for 2500 BGN, we got only 650 BGN), we could not buy another laser diode generating on a second close wavelength, λ = 650 nm or λ = 630 nm for example, closest to the one of the He-Ne laser. The research group decided to expand the range of the field experiment to prove the influence of the electromagnetic field over the plants using the available gamma irradiator.

The experiment was carried out using the following pattern in 4 repeating cycles:

– non-irradiated seeds (controls);
– single-roll laser irradiated seeds;
– triple-roll laser irradiated seeds;
– five-fold-roll laser irradiated seeds;
– seeds irradiated with an exposure of 10 s;
– gamma-ray irradiated seeds with a dose of 10 Gy (Gray).

The sowing was carried out exactly 7 days after the irradiation – on 17.04.2000.

The agro-technical operations connected with the maize seeds growing were as follows:

– deep autumn ploughing with two consecutive spring cultivations and N20P15KO nitrogen fertilizing; a third of the fertilizer was dispersed before the sowing and the two thirds – during the feed-up;

– during the vegetation period, the crop was treated with the anti-weeding agent “Guardian” (250 g/dka);

– the experiment moved to a watering regime with a pre-sowing humidity of 75% during the vegetation of ultimate field specific humidity;

– phenological observations, biometric and physiological measurements were regularly carried out; physiological data were taken by Li-6000Cor computer system.

The experiments were carried out using the same parameters as was done during the first year of the contract. In addition, we registered:

– the height (the growth rate) of the plants;

– the absolute and hectolitre number of 1000 grains.

4. Results and analysis

4.1. Results from the experiments with maize seeds carried out in laboratories during the first year

The data for the germination and germination energy, given in the respective tables in the reports from the first year, show that, despite of being insignificant, they are beneficial for the irradiated seeds. In both experiments this is best expressed in the penta-fold irradiation and the irradiation with exposure of 1 min.

The amount of hlorophyll per a unit of an area in the separate variants is insignificant in the sixth leaf and in irradiation multiplicity, ant the amount is increased 7-8% in both experiments in the seventh leaf. The amount of hlorophyll (a+b) per 1kg in the variants with exposure irradiation and in the 6th and 7th leaf is less stable. This might be due to the highly reduced leaf mass of these plants. No additional stimulating or inhibiting effect was observed. We suppose this might be due to the different doses of absorbed radiant energy and the different climatic conditions of the experiments as a result of which the plants leaves had different water-intake capabilities.

The results for the photosynthesis intensity received after the laser irradiation in the first and second experiments respectively, showed that in both measurements on the 34th and 41st day there was an increase in this intensity. The intensity of the treated plants in the next measurement, on the 48th day, in some of the variants, showed a decrease of the photosynthesis compared with the control sample, i.e. the data are varied.

The influence of the laser irradiation on the labial resistance is expressed better in the initial period. The labial resistance is lower compared to the control sample in almost all the variants of treatment in both experiments. The treatment with duration of laser radiation of 10 s, 30 s and 1min leads to its further decrease. At the end of the period the labial resistance of the treated plants is higher, which is probably due to their fast aging.

The influence of the laser radiation on the density of the leaf mass of the plants shows that it is in reciprocal correlative relationship with the labial resistance. In accordance with this, at the beginning of the vegetation period there is an increase in this parameter, while in the case of the plants' aging, there is a decrease. The laser irradiation has brought to a change in the leaf density in both experiments.

In the experiments for defining the influence of laser irradiation on efficiency of water use in young crops, there was an increase of the leaf density in the first experiment, while in the second – it's just the opposite. As we have mentioned above, the different doses of laser radiation and the meteorological conditions caused different influence on this parameter.

The coefficient of the used water is an important indicator for the ability of the plants to accumulate bio-mass and be resistant to adverse meteorological conditions.

This coefficient is determined by the ratio between the photosynthesis intensity and the transpiration intensity. As a ration between two dynamically changing parameters (in most cases in parallel), it shows a greater stability in is less dependent on meteorological conditions. In both variants, the results in the initial period show an increase in this parameter, and then – a decrease compared to the control sample. With the aging of the crops this coefficient increases in all the variants. As a result of the decreased intensity of the photosynthesis and the decreased efficiency of the use of water, the leaf mass accumulated by the crops, also decreases.

In both experiments there was an increase in the accumulated dry substance, both in the crop's average day growth rate and the accumulated dry substance during the period of the experiment. This definitely shows that the laser radiation leads, to a certain extent, to changes in the growth and development of the crop and the accumulation of dry substance.

4.2. Results from the experiments with wheat seeds carried out in laboratories during the first year

For the "Aglika" sort, the stimulating doses for the quantity of stalks/container and the length of the stalk, the stimulating effect of the laser radiation is noticed in the variants where the laser irradiation is triple, penta-fold and sexta-fold, and for the "Teodora" sort, this is noticed in the variants where the laser irradiation is single and double.

The results of the fenological (height at 3-4 leaf and in 4-5 leaf) and the physiological (light intensity, temperature, transpiration, labial resistance, photosynthesis rate) measurements both for the "Aglika" and "Teodora" sorts are presented in separate tables.

Although the measurements have been taken only once, these parameters support the tendency shown by the fenological observations. These measurements are time-consuming and very expensive, but during the second and third year it is recommended that they be carried out in dynamics so that they can show the development and fluctuation of processes in time.

The concluding measurements for the length of the stalk in cm, the quantity of the stalks in every container and crop yield in gr in wax maturity for every container were systematized in separate tables for the two sorts. Due to sparrows attacks on the crops, the results are not very dependable!

4.3. Results from the experiments with maize seeds carried out in the field during the second year

The experiment was carried out for the second year. In contrast to the first year, when many of the parameters were measured in closed controlled conditions of the vegetation house, this time it was carried out in the fields. That's why, in a separate table, we present the meteorological data during the vegetation for the rainfall, average month temperatures, relative humidity and sunshine. These data were compared to other periods and years. It can be seen that during the maize growing period the rainfall was inadequate, the temperature was higher, the relative humidity – lower and the sunshine – of greater amount.

Due to the lack of adequate financing and its delayed issuing (after 20.05.2000), we missed the favorable deadline for sowing the wheat seeds. That's why during the second year no field experiments with wheat was carried out.

Under the controlled conditions (in the greenhouse) of the maize growing in 1999, the data are more precise and the alteration- smaller.

The year 2000 was favorable for maize growing. But the six-time-watering (which was not requested by us but done by our colleagues from KOS, Pazardjik), the fertilizing and the good argo-engineering brought to the elimination of the laser radiation, despite of the certain advantage of the irradiated variants in the initial phases of the maize growth.

The dynamics of the increase in height is shown in a separate table. There are no significant differences compared to the control sample. The growth rate is constant and is insignificantly regulated by fertilizing and watering rather than the irradiation.

Separate tables show the structure of the crop yield – number of corncobs, height of plants and height up to the corncob, quantity of seeds. All the variants are similar to one another. The situation is the same in determining the absolute and hectoliter number in 1000 seeds.

The crop yield is within the range of 858.4 kg/dka and 941.6 kg/dka. It is the highest in the variant of the penta-fold laser irradiation – 13.3 kg/dka more. In this way our colleagues from Pazardjik compensated for their expenses as we didn't provide any financing!

A mathematical simulation of the data, which were not proved, was done.

If we compare the experiment from the previous year when most of the parameters showed positive values but under the controlled conditions (in green-houses), we'll see that in the experiment during the second year (in the fields), they are almost equal.

Last but not least, we would like to point out the economical parameters as well. According to the accounting papers from KOS-Pazardjik, the financial expenses for the autumn deep ploughing, for the spring fertilizing with nitrogen fertilizers, for anti-weed processing with the "Guardian" agent, for the six-fold watering, for the fenological observations, for the physiological and biometric measurements come to 148,93 BGN for 1 dka, while for the total area of 5 dka it is 744.65 BGN.

5. Conclusions

1. The laser radiation can have a beneficial effect in maize and wheat growing.

2. The increase in the crop yield in some variants as a result of irradiation leads to economical profits.

3. The experiments should continue during the next years till the mechanism of the laser irradiation from a laser diode is investigated completely.

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Спектральное влияние лазерной радиации на параметры кукуруза и пшеницы

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Обсуждаются некоторые аспекты применения лазерной технологии в аграрной практике. Исследуется положительный эффект лазерной радиации на развитие кукуруза и пшеницы. Доказано повышение урожая этих культур после ее использовании в реальных условиях теста.