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The Thermal Effect of Laser Radiation on Plants

As a contribution to the development of non-chemical methods of weed control, studies with lasers under laboratory conditions are being carried out in Potsdam. For the examination of the effects of laser radiation on plant material, a carbon dioxide laser and an Nd: YAG laser were available. This contribution presents fundamental considerations on the use of laser technology for weed control as well as initial results of the experiments. The technological conditions for weed control by means of laser radiation as well as aspects of use under field conditions are discussed.

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Fig. 1: CO_2- laser, model Laserbrand XL used

Weeds compete with cultivated crops for space, water, and nutrients. If the damage threshold principle is applied, the yield-reducing effect is no longer tolerated if the yield losses are higher than the expenditures for their treatment. In this case, different methods of treatment are applied in both ecological and integrated farming [1]. Area-wise, chemical weed treatment is the most widely used method. However, synthetic herbicides are viewed critically with regard to their environmental impacts, and their use is not permitted in ecological farming. Alternative methods of weed treatment, such as flaming or foaming-in have so far been unable to establish themselves in arable farming [2].

The general possibility of using laser radiation in order to damage weed plants is mentioned in patent specifications [3] and reference [4]. Some scientific publications report on the damaging effect of CO_2 laser radiation on plants under laboratory conditions [5; 6]. In these experiments, stems of weeds and sugar beet were exposed to the beams of a CO_2 laser, whose intensity was able to be adjusted, and the damaging effect was evaluated. Since the laser beam could not be guided parallel to the soil, the pots with the cultivated test plants were inclined at an angle of 15°. Under field conditions, this angle of 15° will not be sufficient in order to prevent damage to the laser caused by stones or earth walls. In order to secure a vehicle-based laser system sufficiently against mechanical damage and environmental influences, such as splashing water or dust, the laser beam should be vertical, and the distance between the beam and the soil should be at least 500 mm.

In order to be able to treat weeds effectively with laser beams, three fundamental technical problems must be solved:

- Reliable techniques of image analysis for weed detection, distinction between crops and weeds, and precise determination of the target coordinates for the laser actorics
- Precise laser actorics for quick orientation towards the target coordinates which take the motion speed of the agricultural machine into account
- Quick heating of the weeds or significant parts of them within a few milliseconds and acceptable limits of energy expenditure.

The present contribution on weed control with the aid of laser beams focuses on the last-mentioned problem because its solution is an absolutely necessary prerequisite for the applicability of laser techniques.

Experimental Methods and Lasers Used

Carbon dioxide lasers (CO_2 lasers) emit laser radiation in the infrared range at a wavelength of 10.6 µm. This wavelength is within the range of a water absorption band. Thus, plant material rich in water absorbs CO_2 radiation very well and can be heated

Table 1: Technical parameters of the laser systems used

	Lasag SLS 200	Lumonics Laserbrand XL
Wavelength of radiation	1,06 µm	10,6 µm
Energy per impulse	adjustable, max. 50 J	5 J
Average pulse power	10 W to 220 W	40 W
Duration of an impulse	0,1 ms to 20 ms	1 µs to 10 µs
Pulse frequency	0,1 Hz to1000 Hz	1 Hz to 720 Hz

Fig. 3: Laser head of Lasag SLS 200

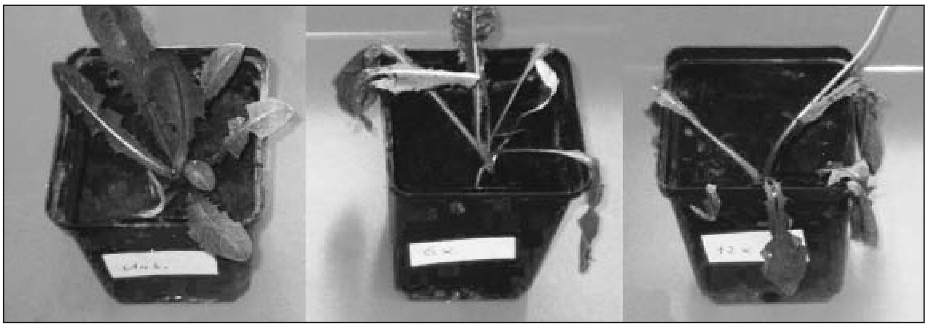

Fig. 2: Taraxacum officinale treated with 6 pulses (center) and treated with 12 pulses (right) of the Laserbrand XL system relative to the untreated plant (left).

quickly. However, the penetration depth of a CO_2 laser beam into the plant material is less than 0.1 mm. For this reason, its thermal effect in leaves is generally limited to the upper epidermis [7].

For experiments with plants, a Laserbrand XL CO_2 laser system from the company GSI Lumonics was available. The Laserbrand XL system consists of a laser module with a resonator, an optical system, high-voltage electricity supply, and control electronics (*Fig. 1*) as well as several additional units, such as beam de-coupling, a control unit, and an integrated protection- and control system for the protection of persons. The Laserbrand XL system produces very short laser flashes (shorter than 10 µs) at high pulse frequency.

In an initial series of experiments, weed plants at an advanced growth stage were used. Using dandelion as an example, the suitability of the CO_2 laser for the treatment of problematic weeds was tested. The plants were radiated vertically from above on the growth centre at a distance of 450 mm from the laser head with the maximum available impulse energy of 5 J.

As a example, the effect of treatment with 6 and 12 CO_2 laser impulses is shown in *Figure 2* (centre, right) in comparison with an untreated dandelion plant (left).

Neodymium: Yttrium-aluminium-garnet laser (Nd: YAG-laser)

These are solid body lasers which emit radiation at a wavelength of 1.06 µm in the infrared spectral range. For the experiment, an Nd: YAG welding laser SLS 200[1]) from the company Lasag was available. The laser system SLS 200 consists of a beam generator, beam decoupling by a light-conducting fibre, and laser actorics, which allow the laser beam to be positioned precisely on the target coordinates (*Fig. 3*).

For experiments with the Nd: YAG laser, 100 plants were grown in four plant bowls. Of these, two bowls were treated with laser radiation 14 days after sowing, whereas two bowls remained untreated for reference. The plants were treated with the Nd: YAG laser vertically from above at a fixed distance of 915 mm from the laser head. In both plant bowls, one half of the bowls each (50 plants) was treated at an energy density of 2.5 J/cm^2, while the other half (50 plants) was treated at an energy density of 5 J/cm^2. By widening the laser beam to a diameter of 5 cm, the entire plant surface was able to be radiated.

A general comparison of the laser types shows that CO_2 lasers are able to provide the greatest radiation output in a temporal average. With regard to individual impulses, however, Nd: YAG lasers reach greater outputs of several 10 kW [8]. In the experiments, the SLS 200 system from the company Lasag proved advantageous because the parameters of the individual impulses were able to be adjusted very flexibly and the laser head was able to be positioned freely above the samples. This enabled the laser head to scan the plant bowls automatically.

[1]) The experiments with the Nd: YAG laser SLS 200 were carried out at the Technical College of Brandenburg.

Results

The results of the laser treatments were evaluated according to the following grading system: no visual damage = 1, slight necrosis up to 25% = 2, medium necrosis (~ 50%) = 3, heavy necrosis (~ 75%) = 4, total plant destruction = 5. Dandelion plants were evaluated for three days after treatment. *Table 2* lists the arithmetically averaged evaluation results of the plants according to the kind of treatment. Treatment with 6 or 12 laser impulses each shows that heavy plant necrosis requires at least six 5 J impulses.

Table 3 shows the results in two plant bowls with field salad which were treated with ND: YAG laser radiation. The degree of damage or growth depression due to laser treatment was evaluated for five days. The energy densities applied of 2.5 J/cm^2 did not prove sufficient for heavy plant necrosis.

The smaller effect of Nd: YAG radiation as compared with the first experiment has two reasons:

- Given the shorter wavelength of 1.06 µm, less Nd: YAG radiation is absorbed by the plant material.
- The fundamentally different treatment of field salad (treatment of the entire surface with a widened laser beam) leads to radiation losses. Given an estimated covering degree of the plant bowls of 75% within the laser-radiated areas, 25% of the Nd: YAG radiation did not act on the plant material.

The results allow the conclusion to be drawn that the application of laser radiation in arable farming cannot replace mechanical weed treatment or field sprayers.

Treatment	Number	1. day	2. day	3. day
1 Impulse , 5 J	5	1,2	2,5	2,5
6 Impulse , 5 J	10	2,3	4,5	5
12 Impulse , 5 J	10	4,5	5	5

Table 2: Mean values of Taraxacum officinale ratings

Treatment	Number	1. day	3. day	5. day
Energy density 2,5 J/cm^2	100	1,5	2,3	2,5
Energy density 5 J/cm^2	100	2,5	4	4

Table 3: Mean values of Valerianella olitoria ratings

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