INTRA-ROW WEED CONTROL BY USE OF BAND STEAMING

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Introduction

Soil disinfection by steam is a well-known technique used within horticulture and market gardening. The most common steam application technique is sheet steaming, where the soil is covered with a thermo resistant sheet, which is sealed at the edges and then blowing steam under the sheet so that the steam penetrates through the soil. When the desired soil temperature is reached, the equipment is moved stepwise forward over the area to be treated. The method is effective for control of weed, plant pathogens and nematodes (White et al., 1999) and it represents a viable alternative to the use of pesticides. However, high fuel consumption and low capacity are serious disadvantages.The method requires 3000–5000 l of oil per hectare (White et al., 1999). Moreover all living organisms, harmful and useful, in the treated soil are killed, and therefore the method is not in line with the basis ideas of organic farming.

Most vegetables are grown in rows, and automatic vision-controlled equipment for the elimination of weeds between rows is currently available commercially (Tillett et al., 2002). Automatic, “non-chemical” systems for the effective elimination of weeds in the intra-row area are not available. One way to eliminate intra-row weeds without the use of chemical agents could be to destroy the germination capacity of the weed seeds under the rows by heating a narrow band of soil around the rows to about 70–90°C before seeding. As only a very few weed species will germinate from deep soil layers (White et al., 1999), only the topmost 5 cm of the soil will need to be heated. A new concept and technique for performing such a band heating by use of steam has been developed (Jørgensen et al., 2004). By heating only a narrow band of 6–8 cm around the rows to a depth of 5 cm, energy savings of more than 90% can be anticipated, compared with a full steaming of the entire soil surface. In practice, the system may be combined with a computer-controlled sowing machine for the subsequent sowing of plants in the centre of the treated bands. The system will result in the crop growing in rows free of plant competition. This also provides favourable conditions for the functional capacity of a subsequent operation involving vision-based row guidance.

Materials and methods

When steam is used for soil heating, its ability to transfer energy to the soil, e.g. during combustion of oil, can be exploited, as the evaporation energy of the water will be released when the steam condenses into the soil. In order to limit heat loss to the air, it is essential that the soil surface is only heated enough to destroy the germination capacity of the weed seeds. This project has included establishment of a laboratory test rig for detailed analyses of the thermal processes involved as well as development of a prototype machine to be used for field trials. An important subject has been the design and construction of application for effective and controlled penetration of the steam in the soil. In the test rig steam jets were used for the injection of heat to the soil.

Experimental test rig

To enable the dimensioning and designing of the steam jets, as well as testing the heat treatment of soil samples under controlled conditions, a laboratory rig with a soil capacity of 33 l was constructed. The test rig consists of a 105-mm-thick, 1220-mm-diameter horizontal revolving disc with a variable rotation speed (rpm). The upper part of the disc consists of several loose rings of different diameters. In order to create a ditch 85 mm deep and 50–170 mm wide, the rings can be added or removed as necessary. The ditch can be filled with soil, which can be heated by means of steam. The steam was injected from four jets lowered into the soil during the operation. The test rig was used for two sets of experiments; one to determine the process temperature needed to destroy the germination ability of the weed seeds and the other to address the design challenge of obtaining a uniform temperature in the processed soil profile. For the first analysis, the ditch was made narrow around the jets and the chamber was isolated. For the analysis of the temperature profile, the ditch was made broader to involve the heat transfer to the surroundings.

Steam generators

Each steam jet was supplied with steam from an electrically heated steam generator. The steam generators could be controlled by a pressure switch, which interrupted the heater at a pressure of 4 bar. The steam could be turned on/off by means of magnet valves placed in the generators; all four magnet valves could be turned on at the same time. Each steam generator had a nominal effect of 2.2 kW.

Injection tines
The steam jet consisted of a flattened pipe that could penetrate the soil to a depth of 4–5 cm. The lower end of the pipe was closed, and the upper end connected to the steam generator. Steam was ejected into the soil through two 1.5-mm-diameter holes placed at the side of the jet, 10 and 30 mm from the tip. The four steam jets were mounted on a cross-shaped frame over the revolving ditch. Two jets were placed on either side of the treated soil band with the jet openings pointing toward the soil band. On either side, the jets operate at depths of 4 and 5 cm, respectively, under the soil surface to ensure a four-level injection of the steam at either side of the soil band, i.e. 1, 2, 3 and 4 cm under the soil surface.

Thermosensors in the heated band
During steaming and cooling of the soil, the temperature of the heated soil band was measured continuously by means of 12 thermosensors connected to a datalogger. The thermosensors, type K thermocouples, were mounted on four vertical tubes at three levels. Two of the sensor tubes were placed in positions where they will be able to measure the soil temperatures about 10 mm from either side, while the other two tubes measured the temperatures at the centre of the soil band.

Thermosensors in the cross-section
In order to obtain accurate results from the temperature measurements of the treated soil band and the surrounding soil, a special temperature-monitoring apparatus was developed (Figure 1). The apparatus consists of 63 vertical thermosensors placed in a 120 × 160 mm grid at intervals of 20 mm. The apparatus measured the temperatures at seven different soil depths from 0 to 6 cm from the soil surface for every 20 mm across the treated soil band. For technical reasons, the seven measurements were not made at exactly the same locations, but at seven different locations at intervals of 20 mm along the soil band. The instrument was also used at field tests.
The sensors used were soldered-type T thermocomponent conductors that were wedged on to the tip of a 4 mm stainless steel tube. At the touch of a single key, all 63 temperatures were recorded and memorised by a datalogger within about 2 s.

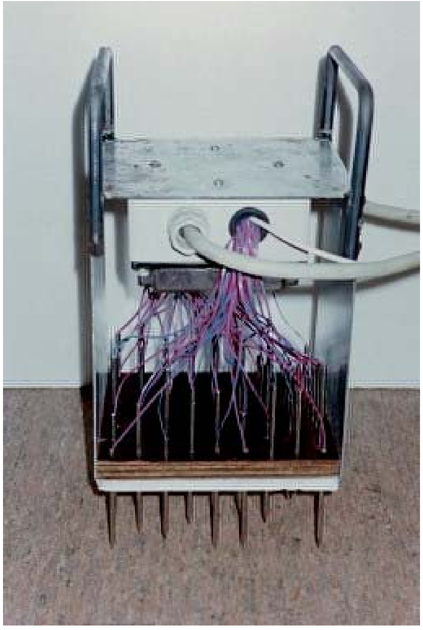

Figure 1. Instrument for measurement of soil temperatures across the heated band

Measurement procedure
The test rig was primarily used for steam heating of different soil samples with a known content of weed seeds at temperatures of 60, 70, 80 and 90°C. The soil sample was left untouched for 10 min in the ditch before they were removed and prepared for the subsequent germination analysis, which took place in a greenhouse under controlled conditions. The number of plants that germinated was counted every week over a period of 3 months.

The test rig was also used for an estimation of the efficiency of energy transfers from steam to soil and of the heat-energy distribution between the heated band and the surrounding soil. For these measurements, a ditch width of 170 mm was used. The steamed soil band at the centre of the ditch was only about 6 cm. The soil temperatures were measured by means of the instrument described above. After that, the temperature distribution was again measured three times at random points within the soil band at intervals of 2 min in order to observe the heat distribution in the soil during the cooling period.

Results and discussion

Treatment of soil samples containing weed seeds

The purpose of the soil sample steaming was to study the effect on the weed seeds when different soil types with varying water contents were exposed to steaming. Figure 2 shows an example of soil temperature after treatment in the test rig.

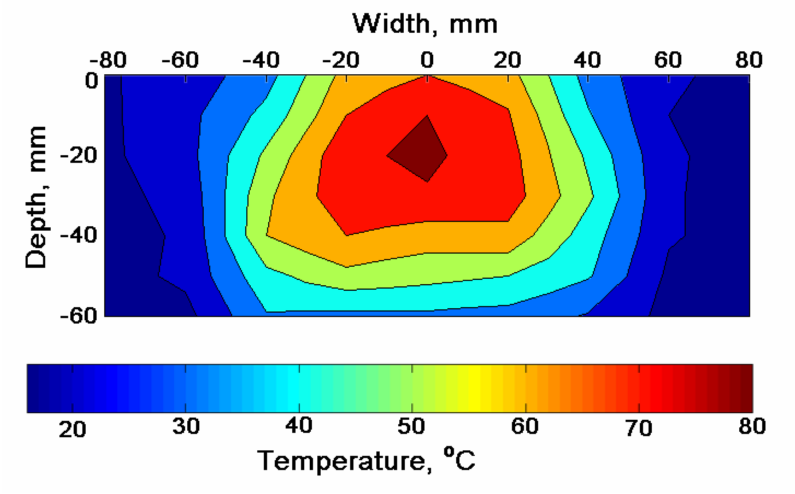

Figure 2. Soil temperatures from a cross-section across the groove, measured 40 sec. after treatment. The width is measured from centre of the treated band. Treated area: With –30 - +30, depth 0 - 50 mm.

The results of the germination tests show that at a temperature of about 65–70°C the weed seeds generally lose their ability to germinate (figure 3). From a technical point of view, this means that the control system for field application has to ensure that the temperature in the processed soil band uniformly reaches at least 70°C. Higher temperatures mean a loss of energy, especially if they rise to above 90°C, when evaporation of soil water starts to take place. In subsequent field trials, increased effects on weed germination were observed at increasing treatment temperatures up to about 90°C. This may be due to uneven heat distribution in the soil and higher heat loss to the surroundings.

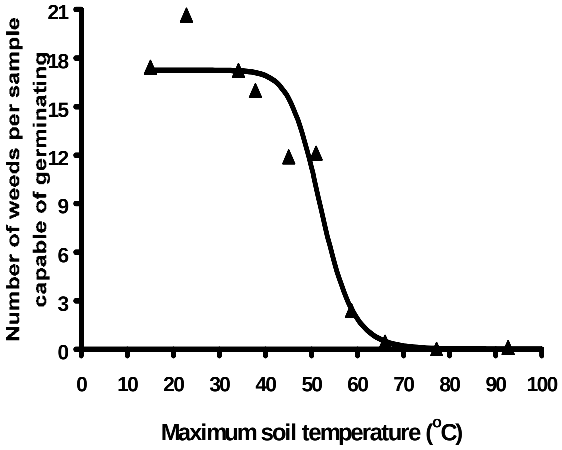

Figure 3. Number of surviving weed plants in relation to the soil temperature

Measurement of efficiency in heat transfer from steam to soil
Measurements on energy flow during soil steaming were made for sandy soil and clay soil. Both soil types were examined at two different moisture contents. The main issue under investigation was the efficiency obtained during the transfer of steam energy to soil, in order to determine how much energy would be transferred to the air during steaming. Therefore, all the soil in the test rig ditch was used for calculation of the total energy absorption. Results from the energy measurements are shown in Table 1. Each value represents the average of three individual measurements for the same soil type.

Table 1. Transmission of steam energy to soil

Soil type	Moisture, % DB	Specific heat, KJ/kg*K	Soil mass, kg	ΔT in soil, °C	Energy received, MJ	Energy delivered, MJ	Efficiency, %
Normal sand	8.7	1.124	36.51	27.6	1.133	1.230	92
Dry sand	5.6	1.035	40.00	28.1	1.163	1.230	95
Normal clay	10.0	1.195	37.82	24.8	1.121	1.230	91
Dry clay	8.8	1.162	38.92	27.2	1.230	1.230	100

An efficiency of 91–100% was obtained by transferring steam energy to the soil. The loss of efficiency (0–9%) was due to the loss of steam to the air. The lowest losses were observed on dry soils. This is probably due to the fact that dry soil exposed to steaming will absorb the steam more easily than the moist soil will. From Table 1 it can be seen that the energy loss to the air was insignificant during the heating period. However, a considerable amount of energy was transferred to the surrounding soil, as indicated in Figure 2. The energy transferred to the surrounding soil will be of no use, because the temperatures obtained will be below 70°C. By comparing the volume of the soil in the steamed band with that of the soil in the entire ditch, the soil mass in the band can be estimated quite precisely, and by comparing the soil mass with the achieved temperatures, the energy absorption in the soil band can be estimated. By relating the energy utilisation to the energy liberated from each soil type, it will be seen that the efficiency is reduced to 50–60%.

Under practical field conditions, the heat loss will be smaller, while the efficiency of an oil-fired steam generator will be lower than that for small, electrically heated steam generators. Therefore, total efficiencies higher than 55% will not be feasible under practical field conditions. For the steaming of 6-cm-wide and 5-cm-deep soil bands with a row interval of 50 cm, 60 m^3 of soil should be heated per hectare. For soil with the same density and the same water content as “normal clay”, about 5.8 GJ/ha should be used in order to obtain a net temperature increase from 10 to 80°C. For an efficiency of 55%, this will correspond to a consumption of about 300 l of diesel oil per hectare. This was verified by field test with a one-row band steamer prototype machine (figure 4)

Figure 4. Prototype band steaming machine

By band steaming the microbiological flora and fauna is influenced in the local area representing less than 10% of the total volume calculated in a 15cm surface layer. The microbiological life is affected during the growing season (Elsgaard et al., 2004), but after a primary tillage operation the influence is erased.

Conclusions

An experimental test rig, used for steaming soil samples mixed with weed seeds and for examining the thermal efficiency involved in soil steaming, has been developed. It was seen that soil temperatures exceeding 70°C will be needed in order to destroy the germination capacity of the weed seeds. At the field trial slightly higher temperatures, 80-90°C, were needed to achieve god effect. In connection with the transfer of steam energy to the soil, efficiencies of 91–100% were found. Part of the energy will, however, be transferred to the soil surrounding the steamed band, and therefore, in the case where a 6 × 5 cm soil band is exposed to steaming, the efficiency will only be 50–60%. For an efficiency of 55% and a row interval of 50 cm, about 300 l/ha of oil will be needed to heat a 6 × 5 cm soil band to a temperature of 80°C. On the basis of the experiments in the test rig, a prototype one-row band steamer has been developed for field purposes. Good results have been achieved from the preliminary tests.

References

Elsgaard, L.;Elmholt, S.;Jørgensen, M.H. (2004). The microbiological life in the soil is affected by steaming (In Danish). Frugt og Grønt 3, 114-115

Jørgensen, M. H.; Kristensen, E. F.; Kristensen, J. K.; Melander, B. (2004)Thermal Band Heating for Intra-Row Weed Control. EurAgEng, Paper No. 287, AgEng , Leuven, Belgium

Tillett, N. D.; Hauge, T.; Miles, S. J. (2002). Inter-row vision guidance for mechanical weed control in sugar beet. Computers and Electronics in Agriculture, **33**, 163–177

White, J. G.; Bond, B.; de Courcy, M.; Pinel, M. P. C. (1999). Field vegetables: assessment of the potential for mobile soil steaming machinery to control diseases, weeds and mites of field salad and related crops. Final Report FV 229. Horticultural Development Council