Temperature Field Distribution Character in the Upper Soil Layer of Forest Nurseries after Water Steam Treatment

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Vasinauskienė, R. and Šilingienė, G. 2016. Temperature Field Distribution Character in the Upper Soil Layer of Forest Nurseries after Water Steam Treatment. *Baltic Forestry* 22(2): 297-306.

Abstract

Ecologization of agriculture and forestry directly and indirectly influences the environment, water, air, and landscape. Therefore, analysis of ecological forestry activities, evaluation and forecast are of scientific, ecological and political significance. Weed control and the resulting ecological farming and forestry issues have attracted greater attention to the use of physical methods in weed control, because this weed control method is effective and does not leave chemical residues neither in the soil, nor in water. One of the physical methods is thermal weed control method, which contrary to the other weed control methods, leaves only dead biomass, preventing self-sowing of weed seeds in the soil, destroys some of the pests and disinfects the surface layer of soil. However, it is very important to examine the possibilities of wet water steam dispersion in soil. The aim of the study was to determine temperature field distribution character and intensity in the upper layer of the inter-beds soil in forest nurseries. All analyses were carried out using air-dry soil *(Calc(ar)i-Epihypoglevic Luvisol, LVg-p-w-cc(sc))* passed through 1.7 mm sieve. Temperature field distribution character and its intensity in the upper soil layer was registered using 0.19 mm diameter nickel-chrome thermocouples, arranging them in the measuring planes according to the measuring schemes prepared in advance. The change of temperature field was registered using Almemo device. Study results showed the dependence of temperature field distribution character and intensity upon the duration of wet water steam supply, steam amount and overpressure under the cover. The data showed that weed seedlings in the depth of 0.5–2.5 cm would be killed treating the soil with wet water steam for 30-60 seconds. The results of the analysis provide a possibility to supplement the common existing weed control system using wet water steam with additional technology – weed seeds control in the upper soil layer.

Keywords: weed seeds, the upper soil layer, water steam, temperature field.

Introduction

In Lithuania as in all European Union too, general politics of agriculture and forestry sectors is oriented to ecological farming. The main tasks of ecological farming are to improve soil texture, reduce pollution of heavy metals, and increase stocks of humus and nutrients in the soil. One of the biggest problems that occur in ecological farming is weed control. This is particularly important in forestry nurseries because of demand for mechanical weeding (Tillet 2002, Barberi et al. 2010). Previous studies have revealed that steam treatment has the potential to be an efficient and environmentally acceptable method to reduce the negative influences that ericaceous ground vegetation has on the growth of planted coniferous seedlings (Norberg, Jaderlund, Zackrisson et al. 1997).

Big efforts are made on new technology development in order to solve that issue. New technologies are created involving different methods for reduction of environmental pollution and weed competition of crop (Jørgensen 2006, Sirvydas et al. 2006b, Virbickaitė et al. 2006). Physical methods of weed control using different environments, e.g. hot water, wet water steam, hot gas and infrared radiation have attracted big attention (Kurfess 2000, Hanson and Ascard 2002, Tei et al. 2003). Soil steaming applied in bands is also a new technology with the potential to radically reduce the burden of hand-weeding intra-row weeds in non-herbicidal vegetable cropping. Preliminary studies (Melanderand and Kristensen 2011) with band-steaming have shown effective control of viable weed seeds, when the maximum soil temperatures reach 60–80 °C. This temperature was very important in our research as well.

Physical methods are based on thermodynamic laws (Sirvydas et al. 2006a). Using wet water steam for weed control a temperature of 80-100 °C is raised in the surface of the soil under the cover in 5-6th day after sowing (Sirvydas et al. 2004, Kerpauskas et al. 2006). It is noticed that successful weed control is determined by the first weed removal under the closed cover, when 80-90% of short life cycle weeds are killed (Sirvydas et al. 2008). During the second weed removal later germinated weeds from deeper soil layers are removed (Vasinauskienė 2004).

Investigations using wet water steam technology for soil disinfection, pathogen destruction and weed control were made by many authors (Melander and Jørgensen 2005, Cisneros and Zandstra 2008, Barnabas et al. 2010). This method is effective yet expensive, because soil is heated 10-30 cm in depth. However, it is known that weeds intensively germinating in 0.5 cm depth intended most of them are destroyed at 70 °C (Vasinauskienė 2004). Therefore, the need for temperature spread investigation in soil during thermal weed control has appeared.

This study aimed to determine the influence of water steam supply duration in upper layer of the soil to temperature regime dynamics.

Materials and Methods

Soil for the research was sampled in nursery of the Research Station of Aleksandras Stulginskis University. Soil samples were placed into 50×50×10 cm boxes and transported for investigations to the Thermal Measurement Laboratory of the Institute of Energy and Biotechnology Engineering.

All analyses were carried out on air-dry soil *(Calc(ar)i-EpihypoglevicLuvisol, LVg-p-w-cc(sc))* passed through 1.7 mm sieve thus providing the most advantageous conditions for the expansion of wet water steam temperature field. The scheme of experimental set up is provided in Figure 1.

Wet water steam was provided in 15 kW boilers, *10*. Constant steam pressure of 0.4 bars was kept during the analyses. The amount of wet water steam in kilograms was measured during each experiment by control scales, *9* (minimum weight ± 0.2 g). Wet water steam was supplied to 0-3.5 cm upper soil layer to enclosed cavity, *12*, under the cover through steam outlet hose, *13* (Figure 1). Wet water steam pressure under the cover was measured by „U“ shaped micromanometer, *15*. Temperature shift character (temperature curves slope respect to time axis) and intensity in the upper layer of the soil, *11,* was recorded by temperature sensors, *1, 2, 3, 4, 5, 6, 7* and *8,* distributed in measurement planes, *16*. Wet water steam temperature under the cover was registered by control temperature sensor, *0*. Temperature shift under the cover and in the upper layer of the soil was registered by 0.19 mm in diameter nickel-chrome thermocouples, which were distributed according to the measurement scheme in the planes A, B, C and D (Figure 2).

The cover of 20 × 20 × 10 cm was used for the local wet water steam supply to the upper layer of the soil. The connections on the cover top for wet water steam supply

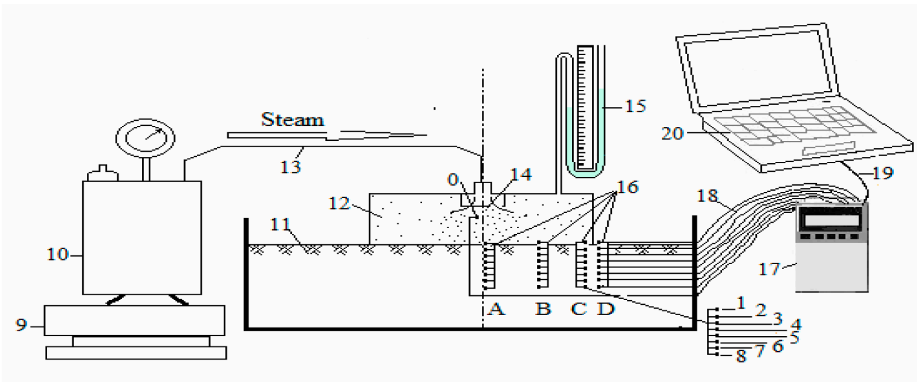

Figure 1. Principal scheme of experimental setup of temperature regime investigation in 0-3.5 cm upper soil layer treated by wet water steam

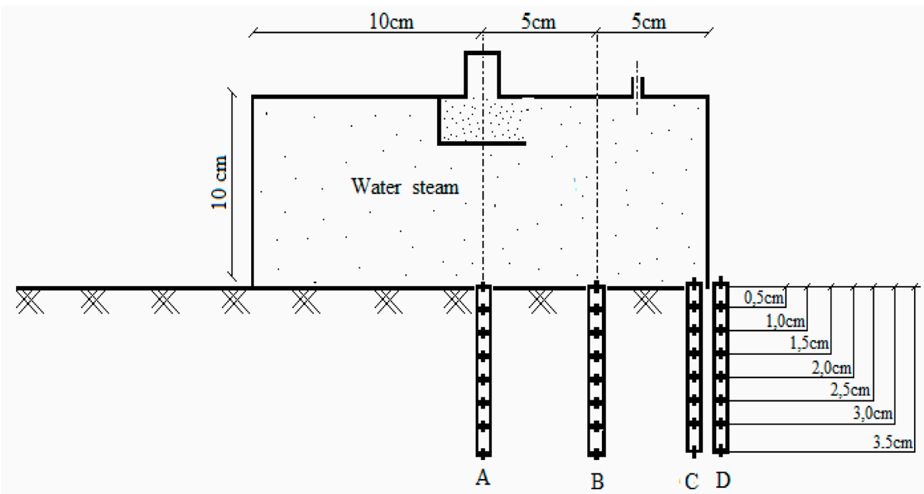

Figure 2. The scheme of thermocouples position in different measurement planes of soil

and micromanometer were assembled. Thermocouples were positioned in vertical measurement planes A, B, C and D. Vertical distribution of measurement planes in the upper layer of the soil was arranged in a way enabling to obtain the real illustration of temperature regime dynamics. Measurement plane A was assembled in the place of cover vertical symmetry axis. Measurement plane B was placed 5 cm vertically down the vertical symmetry axis, and measurement C was placed vertically down next to the inner wall surfaces of the cover. Thermocouples in measurement planes A, B and C registered temperature regime in the upper soil layer under the cover. Measurement plane D was placed vertically down next to the outer wall surfaces of the cover in order to register temperature changes out of the cover.

Eight thermocouples were distributed in vertical position in each *m* measurement plane. The first thermocouple registered temperature of soil surface, the rest registered soil temperature every 0.5 cm to depth (0.5 to 3.5 cm). This way of thermocouples distribution allowed registering real temperature shift in soil as well as character and intensity of 100 °C temperature field formation. Meeting requirements for temperature measurements, thermocouples were distributed agreeably to isotherm by length corresponding to 100 thermocouples diameters Temperature measurements were recorded by data logger ALMEMO-2590-9 17 (Figure 1) equipped with microprocessor data processing and storage systems. Connection with PC was made using Za 1909-DK5, *19* (Figure 1). Recorded data were loaded to computer using a serial interface with *AMR* software.

Temperature regime in measurement planes of upper layer of the soil was investigated under different wet water steam supply duration (5, 10, 20, 30, 40, 50 and 60 s). Each experiment was carried out for six times.

Data were subjected to analysis of variance ANOVA.

Results

Results shown in Figure 3 revealed that soil surface under the cover is heated up to 88 °C in the steam inlet spot (measurement plane A), when supply of wet water steam endured 5 seconds while in the depth of 0.5 cm temperature rose up to 81 °C. Temperature did not change in the depth of 1.0-3.5 cm.

Thermocouples placed in measurement plane B registered temperature change only on the surface of the soil and water steam temperature under the cover. It is seen that temperature of soil surface rises up to 79 °C, while in the depth of 0.5-3.5 cm it remained stable. Temperature in the measurement plane C changed under the cover and on the soil surface. It rose up to 50 °C, while in the depth of 0.5-3.5 cm it remained stable. Temperature measurement data in the measurement plane D showed no temperature

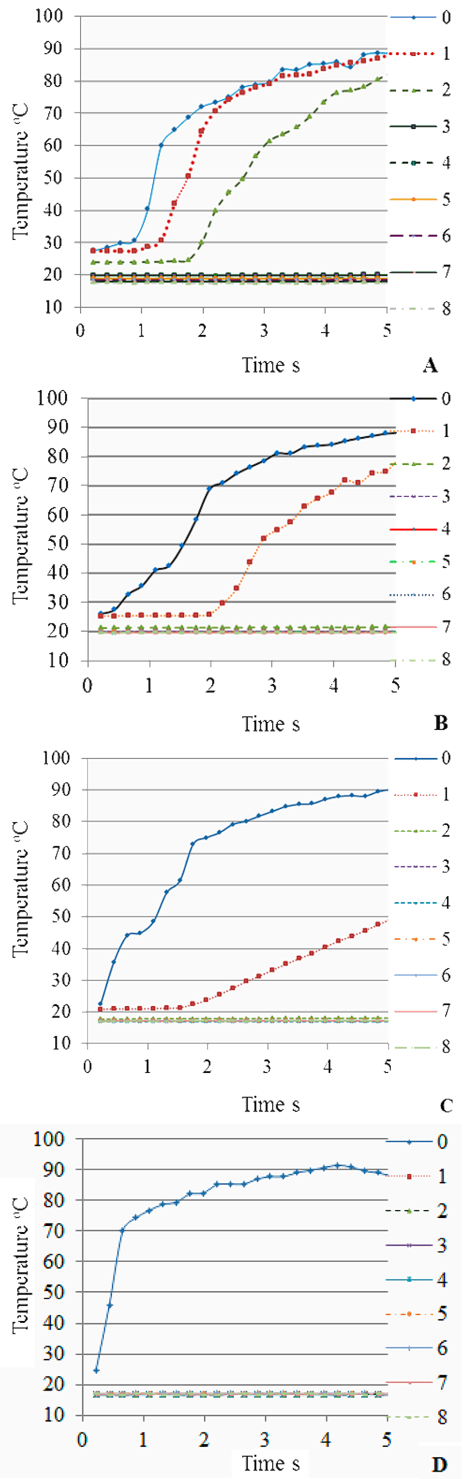

Figure 3. Temperature regime dynamics under the cover in the upper layer of the soil, when steam supply duration was 5 seconds

Note. A, B, C and D – temperature measurement planes, 0 - temperature change in the environment under the cover; 1 - the change of temperature on the surface of the soil; 2-8 – change of temperature every 0.5 cm in depth (0.5 to 3.5 cm) fluctuations presenting on soil surface as well as in the depth of 0.5-3.5 cm. The results of investigation from all measurement planes showed that the temperature of wet water steam under the cover reached only 90 °C.

As it is seen from the data in the Figure 4, in the measurement plane A temperature of soil surface rose up to 95 °C when wet water steam supply under the cover was prolonged to 10 s while in the depth of 0.5 cm it reached 88 °C. The temperature remained stable in the deeper soil layers (1.0-3.5 cm). Temperature change to 90 °C was registered only on the surface of the soil in the measurement plane B, no temperature changes were registered in deeper soil layers (0.5 to 3.5 cm). The temperature rose up to 65 °C in the measurement plane C, while it remained unchanged in the deeper layers. The temperature of the soil surface rose very insignificantly (to 23 °C) and remained stable in deeper layers in the measurement plane D. Wet water steam temperature under the cover was 100 °C in all the cases.

When the supply of wet water steam was prolonged to 20 seconds, dynamics of temperature curves in measurement planes was more intensive (Figure 5).

Dynamics of temperature curves shows that the temperature rose up to 100 °C on the soil surface and in the depth of 0.5 cm, while in the deeper layers no temperature changes were registered. The temperature of 100 °C was registered on the soil surface in the measurement plane B. The temperature of the soil rose up to 95 °C in the depth of 0.5 cm and up to 28 °C in 1.0 cm, while in the deeper layers it remained stable. Temperature of the soil surface rose up to 96 °C in the measurement plane C, up to 90 °C and up to 50 °C in the depth of 0.5 cm and 1.0 cm, respectively. No temperature changes were registered in deeper soil layers (1.5 to 3.5 cm). The temperature of soil surface rose up to 60 °C in the measurement plane D, up to 38 °C in the depth of 0.5 cm, while in the deeper layers (1.0 to 3.5 cm) remained unchanged. Figure 6 shows the results, which were gotten when wet water steam supply was prolonged to 30 seconds.

Temperature dynamics in measurement plane A reveals that the temperature of 100 °C was reached on the soil surface and in the depth of 0.5-1.5 cm. The temperature of 100 °C reached the soil surface and depth of 0.5 cm in measurement plane B, while in the depth of 1.0 cm the temperature rose up to 80 °C. Temperature rose up to 100 °C on the soil surface and in depth of 0.5 cm in the measurement plane C, while in the depth of 1.0 cm it rose up to 30 °C. The dynamics of temperature curves in measurement planes A; B and C reveals that the temperature remained unchanged in the soil depth of 2.0-3.5 cm. In measurement plane D temperature rose up to 98 °C on the soil surface; up to 80 °C; up to 50 °C and up to 23°C in the depth of 0.5; 1.0 and 1.5 cm, respectively. Temperature did not change in deeper layers of 2.0 to 3.5 cm. The

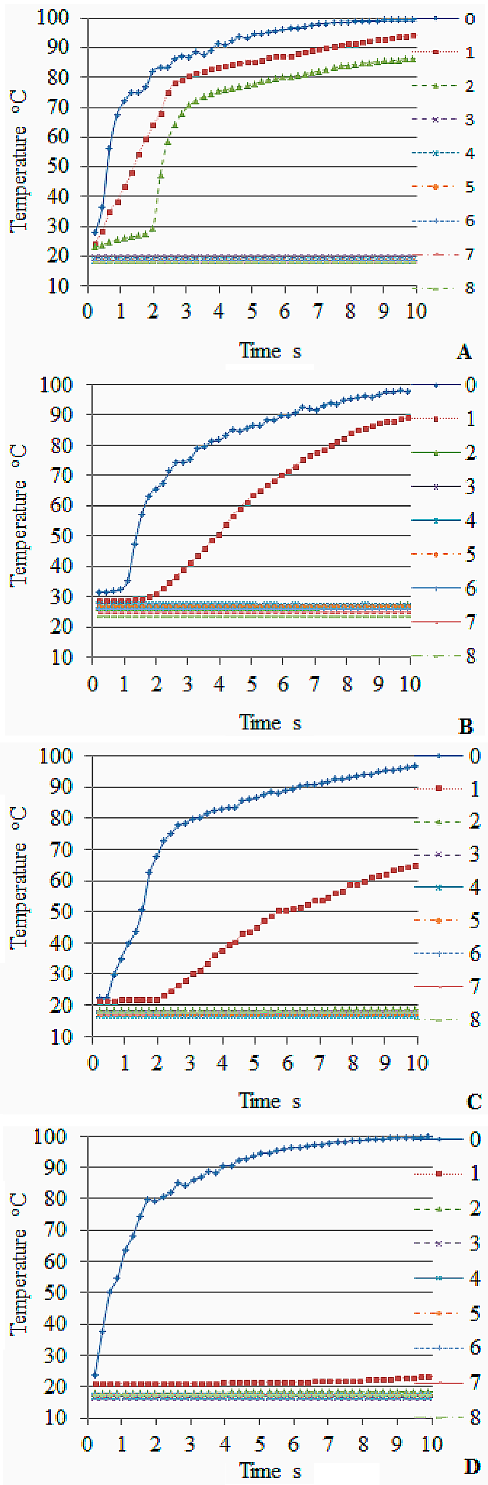

Figure 4. The dynamics of temperature regime under the cover in the upper layer of soil, when steam supply duration was 10 seconds

Note. A; B; C and D - temperature measurement planes,
0 - temperature change in the environment under the cover;
1 - temperature change on the soil surface; 2–8 - temperature change every 0.5 cm in depth (0.5 to 3.5 cm)

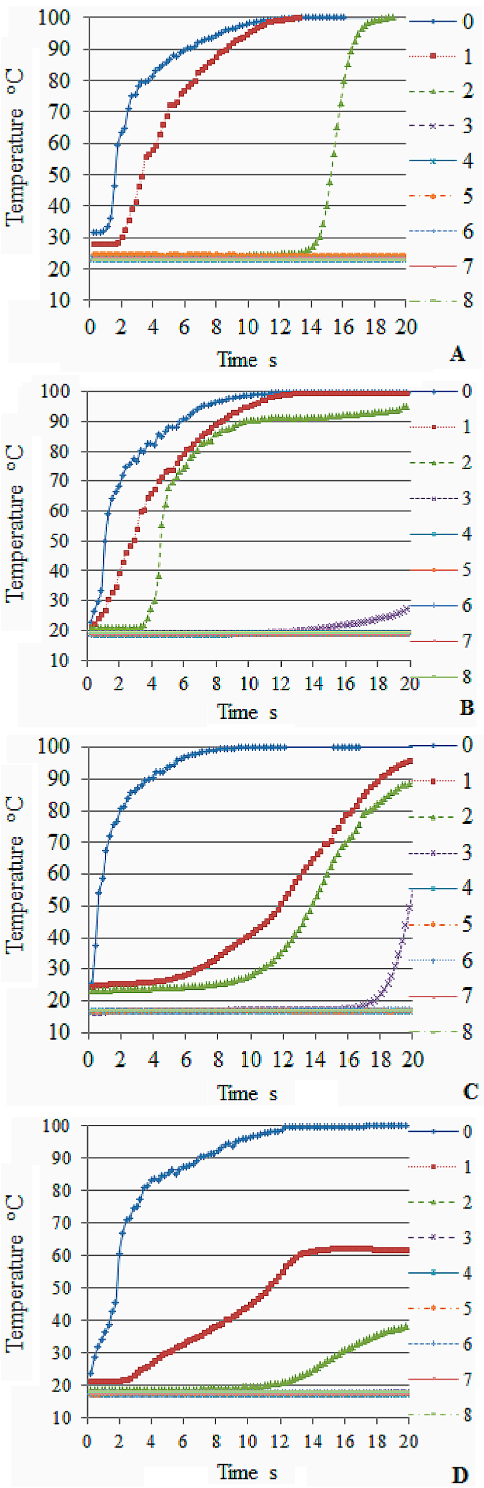

Figure 5. The dynamics of temperature regime under the cover in the upper layer of soil, when steam supply duration was 20 seconds

Note. A, B, C and D - temperature measurement planes, 0 - temperature change in the environment under the cover; 1 - temperature change on the soil surface; 2-8 – temperature change every 0.5 cm in depth (0.5 to 3.5 cm)

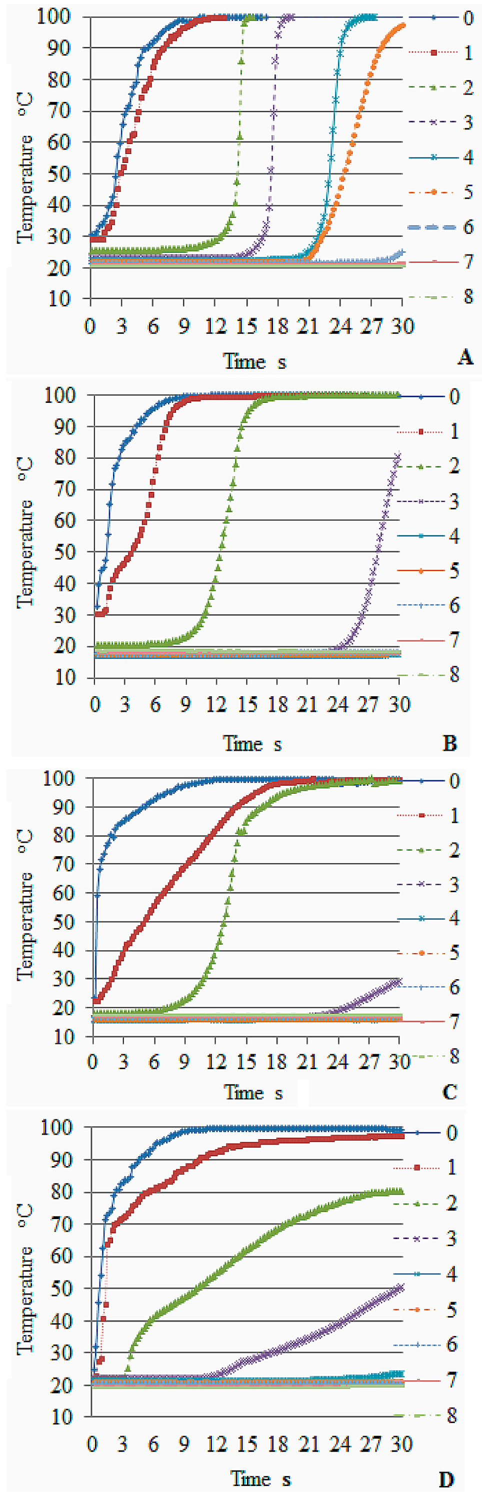

Figure 6. The dynamics of temperature regime under the cover in the upper layer of soil, when steam supply duration was 30 seconds

Note. A, B, C and D – temperature measurement planes, 0 – the change of temperature in the environment under the cover; 1 – the change of temperature on the soil surface; 2 - 8 – the change of temperature every 0.5 cm in depth (0.5 cm to 3.5 cm) results of the investigation presented in Figure 7 reveals more intensive temperature regime dynamics when wet water steam supply duration under the cover was 40 seconds. This is proved by temperature dynamics change in the measurement plane A. Data results revealed temperature rise up to 100 °C on soil surface and in soil layers of 0.5-2.0 cm in depth. Temperature rose up to 94 °C and up to 40 °C in 2.5 and 3.0 cm, respectively. Temperature remained unchanged in the depth of 3.5 cm. In measurement plane B the temperature of 100 °C was registered on the soil surface and in depth of 0.5-1.5 cm. Layer of 2.0 cm in depth was heated up to 40 °C while deeper layers (2.5 to 3.5 cm) were not affected. In measurement plane C the temperature of soil surface rose up to 100 °C, layers of 0.5 cm and 1.0 cm were heated up to 95 °C and 23 °C, respectively, while temperature of deeper layers remained unchanged. The temperature of soil surface in measurement plane D was 100 °C, in the depth of 0.5 cm it was 92 °C and remained unchanged in deeper layers.

Figure 8 shows the results, when the supply of wet water steam was prolonged to 50 s. Temperature curves intensity reveals the most intensive temperature change being in measurement plane A. Soil surface and layers of 0.5-3.0 cm depth were heated up to 100 °C, the temperature of the deepest layer reached 95 °C. Thermocouples registered less intensive temperature dynamics in measurement plane B. Temperature rose up to 100 °C on the soil surface and in soil depth of 0.5-2.0 cm, while in the depth of 2.5 cm temperature rose up to 32 °C and remained unchanged in deeper layers (3.0-3.5 cm). Temperature regime dynamics intensity decreased in measurement plane C. Soil surface and the layers of 0.5-1.0 cm in depth were heated up to 100 °C; temperatures of 88 °C and 75 °C were reached in layers of 1.5 cm and 2.0 cm, respectively, while the temperature in deeper layers (2.5-3.5 cm) did not changed. Temperature rose up to 100 °C in soil surface and in the 0.5 cm depth at measurement plane D. Temperature rose up to 45 °C in the layer of 1.0 cm in depth and remained unchanged in deeper layers (1.5-3.5 cm).

Temperature change dynamics in the upper layer of soil, when supply of wet water steam under the cover endured 60 s is shown in Figure 9.

Temperature change intensity and distribution character reveals the most intensive soil heating up to 100 °C being at the measurement plane A. Soil surface and layers of 0.5-3.5 cm in depth reached 100 °C. Less intensive temperature changes were observed in measurement plane B. The temperature of 100 °C reached the surface of the soil and layers of 0.5-2.5 cm in depth, while deeper layers had lower temperature: 96 °C at 3.0 cm and 32 °C at 3.5 cm significant changes of temperature were registered at measurement plane C. The temperature of 100 °C reached the surface of soil and the layers of 0.5-2.5 cm in depth, temperature of 45 °C reached the layer of the soil

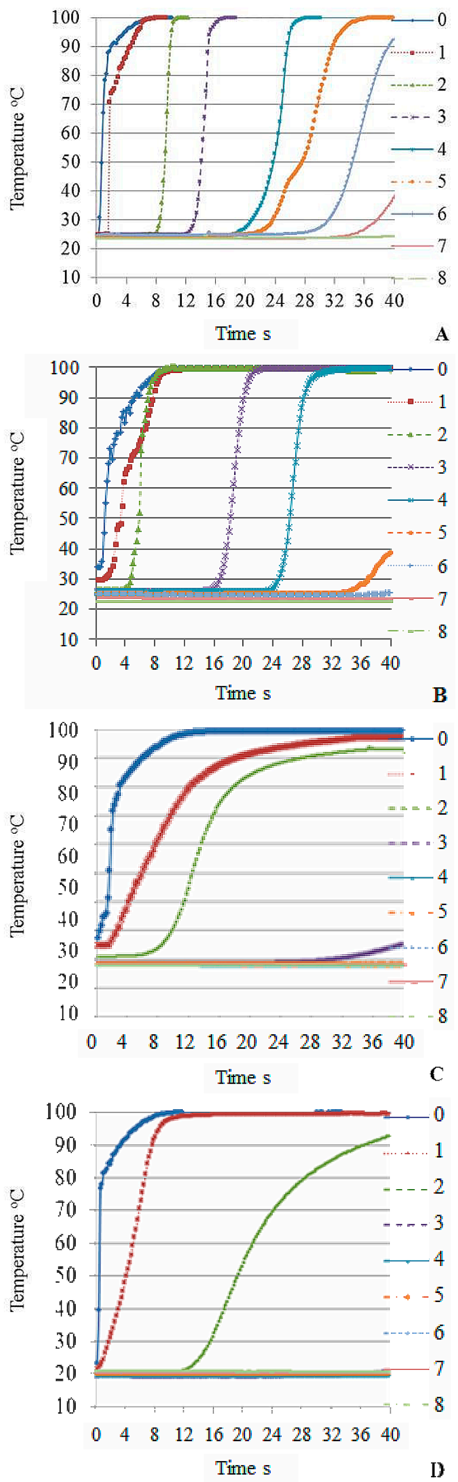

Figure 7. The dynamics of temperature regime under the cover in the upper layer of soil, when the duration of steam supply was 40 seconds

Note. A; B; C and D- temperature measurement planes, 0-the change of temperature in the environment under the cover; 1 - the change of temperature on the soil surface; 2-8 - the change of temperature every 0.5 cm in depth (0.5 to 3.5 cm)

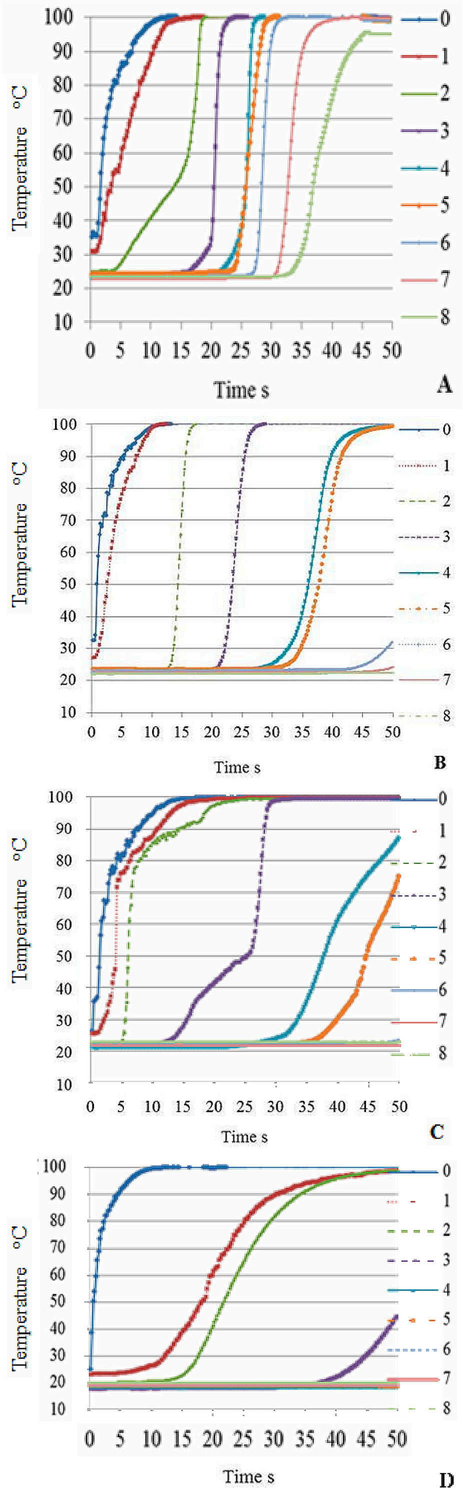

Figure 8. The dynamics of temperature regime under the cover in the upper layer of soil, when the duration of steam supply was 50 seconds

Note. A, B, C and D - temperature measurement planes, 0 – the change of temperature in the environment under the cover; 1 – the change of temperature on the soil surface; 2 - 8 – the change of temperature every 0.5 cm in depth (0.5 to 3.5 cm)

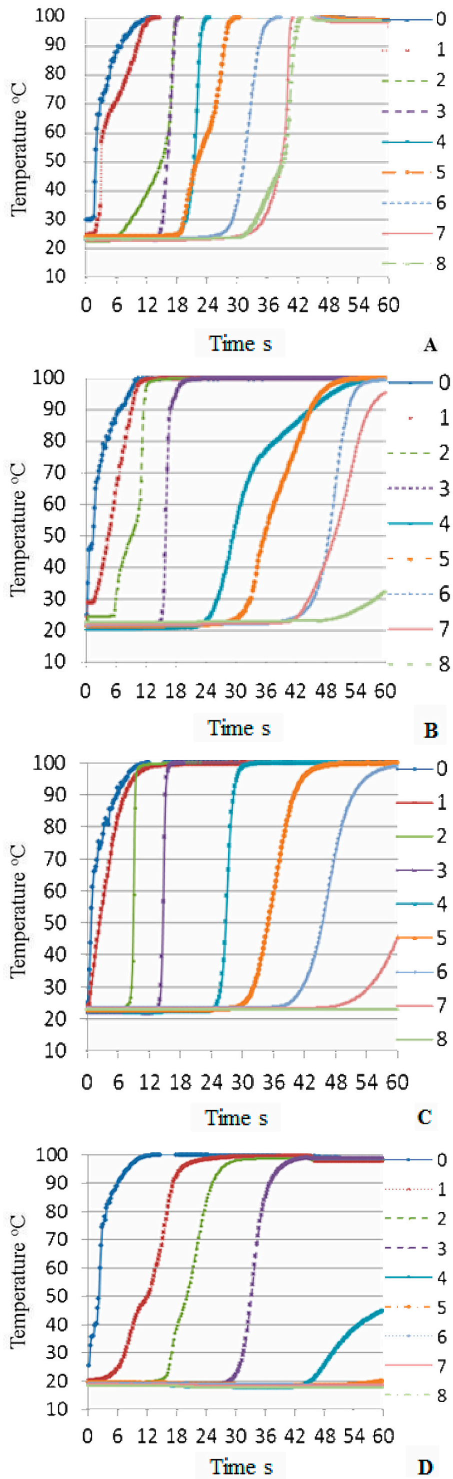

Figure 9. The dynamics of temperature regime under the cover in the upper layer of the soil, when the duration of steam supply was 60 seconds

Note. A, B, C and D - temperature measurement planes, 0 – the change of temperature in the environment under the cover; 1 – the change of temperature on the soil surface; 2 - 8 – the change of temperature every 0.5 cm in depth (0.5 to 3.5 cm) in 3.0 cm depth, while the temperature in 3.5 cm depth remained unchanged. The least intensive temperature changes were observed at measurement plane D. Temperature rose up to 100 °C on the surface of soil as well as in the depth of 0.5-1.0 cm. The temperature of 45 °C was reached in the depth of 1.5 cm, while temperature remained unchanged in deeper layers.

Discussion

Earlier investigations of the soil surface treatment by applying wet water steam were carried out by Sirvydas and Kerpauskas (2012). They investigated soil heating process under completely different conditions, thus the comparison of those results to ours is not possible. The results show the dependence of temperature regime intensity (dynamics of heating of different soil layers) on wet water steam supply duration, place where heat exchange processes occur and dislocation under the cover. Wet water steam supply under the cover transfers heat quantity. The biggest part of the heat quantity is used for the upper soil layer heating. The rest part is used for air and cover walls heating as well as for the dissipation (Figure 10).

Taking into account the quantities of heat mentioned above, soil heating process could be described by this heat balance equation:

$$q_g = q_d + q_n + q_k + q_0 , \quad (1)$$

where

q_d is the quantity of heat used for soil heating, kJ kg^{-1};

q_n is the heat loss in environment, kJ kg^{-1};

q_k is the heat loss because of heating the walls of cover, kJ kg^{-1};

q_0 is heat lost for air heating under the cover, kJ kg^{-1}.

Quite a big portion of heat quantity was used for the air and cover walls heating to 100 °C (steam condensation temperature) in the beginning of wet water steam supply under the cover. When the duration of wet water

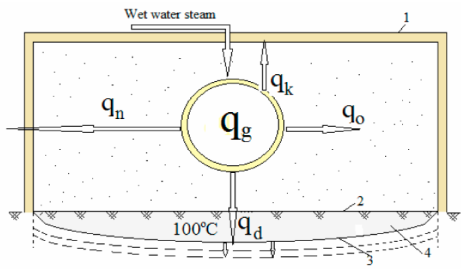

Figure 10. The components of heat quantity in 100 °C temperature field formation: 1 – cover box, 2 – soil surface, 3 – 100 °C temperature front, 4 – initiation of 100 °C temperature field formation

steam supply was 5 seconds, heat quantity, q_g, was insufficient not only for soil surface but also for air heating up to 100 °C because of big heat loss, q_0 and q_k. This is clearly seen from the character of wet water steam and soil surface temperature changes in measurement planes A; B; C and D (Figure 3). In that case the temperature of steam under the cover rose up to 90 °C and the highest temperature of the soil surface reached approximately 89 °C (measurement plane A).

When the duration of wet water steam supply was prolonged to 10 seconds, steam temperature reached 100 °C, however temperature of 100 °C was not reached in any measurement plane. The highest soil surface temperature (95 °C) was registered in measurement plane A, temperature of 89 °C was reached in measurement plane B; 65 °C – in measurement plane C while in the measurement plane D it remained almost unchanged. This proved that 5-10 seconds wet water steam supply did not ensure sufficient steam amount for soil surface heating. When the duration of steam supply ensured sufficient amount of wet water steam the air under the cover and cover box, *1* (Figure 10), was heated up to 100 °C (water steam condensation temperature); the equation of heat balance could be described as follows:

$$q_g = q_d + q_n \quad (2).$$

In the case of balanced heat regime member of equation q_n is constant; its value in comparison with q_d is insignificant. Heat lost to the environment (q_n) could be further reduced by thermal insulation of the cover.

When the supply of heat quantity (wet water steam) under the cover was sufficient, water steam condensate in contact with soil surface, *2* (Figure 10), and heated it up to 100 °C. As high as 100 °C temperature front, *3*, appeared on the surface of the soil and spread further to the deeper soil layers in the process of water steam supply (Figure 10). The field of 100 °C temperature, *4,* was formed above the temperature front. Qualitative change of temperature regime was obtained when the supply of wet water steam under the cover endured 20 seconds. Temperature curve change character showed 100 °C temperature present on the soil surface and in the depth of 0.5 cm (Figure 5, measurement planes A and B). Temperature of 100 °C was not registered in measurement planes C and D. Temperature field formed in the soil was limited by temperature front illustrated by curve 1 (Figure 11).

When steam supply under the cover endured 30 s (Figure 6) temperature of 100 °C was reached in soil surface (measurement planes A, B and C) in the depth of 0.5 cm (measurement planes A, B and C) and in the depth of 1.5 cm (measurement plane A). As high as 100 °C temperature field (Figure 11) was limited by temperature front illustrated by curve 2. When steam supply under the cover

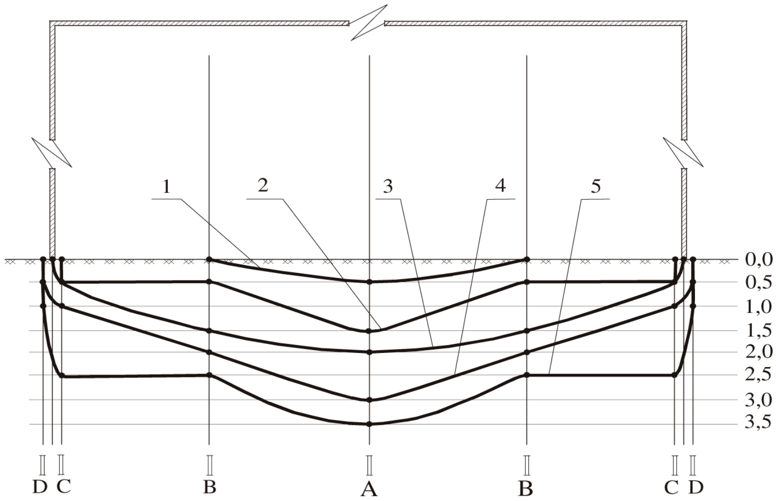

Figure 11. As high as 100°C temperature field change dynamics in the upper layer of soil when steam supply under the cover endured 1 – 20 s; 2 – 30 s; 3 – 40 s; 4 – 50 s; 5 – 60 s; A; B; C and D – measurement planes

endured 30 s 100 °C temperature front deepened to 1.5 cm beside vertical cover axis. When the duration of wet water steam supply was increased to 40 seconds (Figure 7) 100 °C temperature was reached in the soil surface in all measurement planes (A, B, C and D) in the depth of 0.5 cm (measurement planes A, B and C) in the depth of 1.0-1.5 cm (measurement plane A and B) and 2 cm (measurement plane A). The temperature of 100 °C temperature field configuration was limited by temperature front illustrated by curve 3 (Figure 11). When wet water steam supply under the cover endured 40 s temperature front beside vertical cover axis deepened to 2 cm.

Temperature regime dynamics in the soil surface significantly changed, when duration of wet water steam supply under the cover increased to 50 s (Figure 8). As it is seen in Figure 8 the temperature of 100°C was reached at soil surface (measurement planes A, B, C and D) as well as in the depth of 1.0 cm (measurement planes A, B and C); 2.0 cm (measurement planes A and B) and 3.0 cm (measurement plane A). Temperature of 100°C temperature field was limited by temperature front illustrated by curve 4 (Figure 11). After 50 s temperature front deepened to 3.0 cm.

Dynamics of temperature regime was even more intensive, when duration of wet water steam supply under the cover was 60 s. As it is seen from Figure 9, the temperature of 100 °C was reached in the surface of soil and in the depth of 0.5-1.10 cm (measurement plane), in the depth of 1.5–2.5 cm (measurement planes A, B, C) while in the depth of 3.0 – 3.5 cm only in the measurement plane A. Temperature of 100 °C temperature field was limited by temperature front illustrated by curve 5 (Figure 11). When wet water steam supply under the cover endured 60 s 100 °C temperature front deepened to 3.5 cm beside the cover axis.

The results of the investigation show (Figures 3-9) the most intensive change of temperature regime dynamics being registered in the measurement planes A and B. Measurement planes C and D exhibited significantly less changes of temperature regime. This proves that more favourable conditions for soil heating up to 100 °C and temperature field formation were provided under the cover not next to the cover inner and outer walls (measurement planes C and D).

Different conditions for heating the upper soil layer and 100 °C temperature field formation developed because the heat from cover walls was transferred out to the cooler soil layers thus the heating of soil was less intensive in these spots. Temperature regime dynamics change of the upper layer of the soil fundamentally depends on wet water steam supply duration, τ. longer duration, τ, means larger amount of water steam and heat quantity q_g under the cover. Bigger amounts of steam and heat determined more intensive temperature change as well as favourable condition for 100 °C temperature field formation in the upper layer of the soil.

Measurements of wet water steam amount, d, used were made in presence of different steam supply durations, τ. Their results are shown in Figure 12. This dependence can be described by the equation:

$$y = 0.004x + 5E - 17, R^2 = 1.$$

The pressure of wet water steam was monitored during the investigation. When the supply of water steam endured 5-10 seconds insignificant 3-5 mm of H_2O column overpressure was registered. Enhancement from 20 to 60 seconds in duration of wet water steam supply significantly increased amount of wet water steam thus determining increased steam overpressure under the cover.

Overpressure of steam under the cover changed from 10 to 40 mm of H_2O column, when wet water steam supply was prolonged 20 to 60 seconds. Local burst of wet water steam from under the cover appeared due to the enhance-

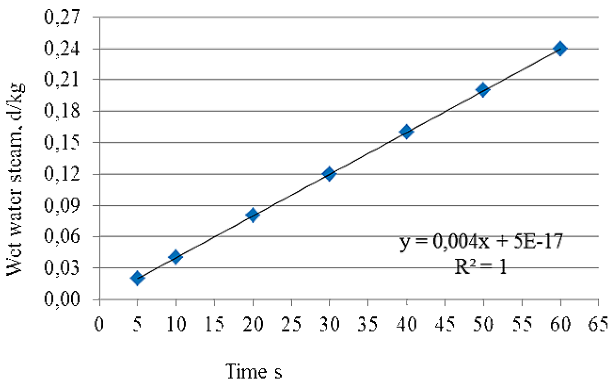

Figure 12. Dependence of wet water steam supply duration, τ, on the amount of water steam

ment of steam overpressure. This created additional steam loss and decreased the value of heat quantity balance component, q_d. Overpressure under the cover promoted direct (mechanical) steam leakage to deeper soil layers. Thus temperature front besides the vertical axis of the cover gained the shape of down pointed hoop (Figure 11).

Conclusions

The duration of wet water steam supply for 5-10 seconds under the cover does not ensure appropriate wet water steam amount for upper layer heating of air dry soil.

Front of 100 °C temperature forms on the surface of the soil and spreads to deeper soil layers, when wet water steam amount is sufficient.

Wet water steam supply duration for 20-60 seconds forms 10-40 mm water overpressure under the cover affecting intensity of 100 °C temperature field formation intensity and the shape of temperature front in the bottom part.

Data results shows that weed seedlings in the depth of 0.5–2.5 cm would be killed by treatment of the soil with wet water steam for 30-60 seconds.

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Received 23 June 2014
Accepted 30 September 2016