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A steaming method for killing weed seeds produced in the current year under untilled conditions

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ABSTRACT

Steam application is an effective method for controlling weed seed infestation but is not efficient for applying to a broad area in open fields. To overcome this problem, we proposed a steam application method involving localized treatment of weed seeds on the soil surface produced during the current year under untilled conditions. We investigated the effects of high temperature and short exposure time depending on the operating speed on weed seed mortality. Further, we determined how seed mortality varied with steam conditions and treatment season in open fields. The operating speed increased with decreasing maximum temperature and duration times above 60 °C. Regardless of treatment season, saturated steam produced heat at a more stable temperature than superheated steam. Seed mortality of 90% was achieved at an operating speed of 0.3–1 km h^{-1} for *Ipomoea lacunosa* and 0.3–1.6 km h^{-1} for *Lolium multiflorum*, suggesting that the operating speed differed across treatment seasons. Suitable steam conditions also differed across weed species and treatment seasons. Thus, the steaming method modified according to weed species and treatment season might require shorter exposure times to disinfest weed seeds.

1. Introduction

Weed seedbank management is an important component of a long-term weed management strategy (Swanton and Booth, 2004; Gallandt, 2006). The size, composition, and distribution of weed seedbanks are strongly influenced by cropping systems and tillage regime; in particular, the vertical distribution of seeds soon after seed dispersal is different between untilled and tilled fields (Kobayashi and Oyanagi, 2005; Vasileiadis et al., 2007). Weed seeds tend to accumulate on or near the soil surface in untilled or minimally tilled fields (Tørrensen et al., 2003). Weed seedling recruitment from deep layers of the soil makes only a small contribution to the weed population (Benvenuti et al., 2001); therefore, the reduction of seedbanks on and/or near the soil surface can lead to the effective control of weeds in no-till or minimum tillage systems. Moreover, post dispersal seed processes play an important role in the regulation of weed population dynamics (Gallandt, 2006; Bagavathiannan and Norsworthy, 2013). Simulation models for weed population dynamics have shown that post-dispersal seed loss and annual seedbank loss are two important parameters (Davis et al., 2004). The reduction of seeds produced in the current year can largely control weed emergence in the following year; consequently, annual seedbank loss will lead to lower weed pressure in subsequent years.

Application of steam to soil is a very effective measure for soil disinfestation, including the control of weed seeds (Van Loenen et al., 2003; Melander and Jorgensen, 2005; Peruzzi et al., 2012). Recently, increasing attention has been paid to soil steaming, particularly since the use of methyl bromide as a soil disinfectant has been prohibited (Samtani et al., 2011). Unlike other thermal weed control methods against weed seeds, i.e., soil solarization and dry heating such as flaming, steam has the advantage of requiring a short heating time to achieve high temperatures. Various soil steaming methods, such as sheet steaming and steaming using fixed tube pipes, have been developed and used for supplying steam in open fields and greenhouse horticulture (Gay et al.,

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2010a). The drawbacks of these methods are that they are costly, due to the high fuel consumption, and laborious. Some papers have recently carried out the studies aimed at improving the steam supply method to reduce the working capacity (Hoyle and McElroy, 2012; Vidotto et al., 2013). These improvements have led to the development of self-propelled machines (Gay et al., 2010b); for example, the band-steaming machine for intra-row weed emergence (Melander and Jorgensen, 2005) and the Ecostar SC600 equipped with a special blade and adding activating compounds (KOH or CaO) to raise soil temperature (Barberi et al., 2009; Peruzzi et al., 2012). The previous studies have indicated that the working efficiency and fuel consumption can be greatly influenced by nature of the targeted taxonomic groups (belowground pathogens, nematodes and pests, and/or aboveground weeds), and growth stages (belowground and/or aboveground seeds, aboveground seedlings, and/or adult plants). For example, the volume of soil that requires steaming differs depending on the belowground or aboveground targets, and thus the exposure time and temperature necessary to steam soil varies according to soil volume and texture. Steam application is a technique used both in the open field and in glasshouses, although to date it has limited application in the protection of high-value crops. Therefore, it is difficult to apply this technique to broad-scale steaming for the protection of major food crops, e.g., rice, soybean, and wheat in Japan, in land-extensive farming. Application of steam over broad areas requires technological progress that allows faster application and lower costs. One possible adaptation for increasing operating speed and lower fuel consumption would be to apply steam only to the soil surface. This would entail limiting the aboveground target to post-dispersal seeds produced in the current year under untilled conditions.

To improve the working efficiency of thermal weed control, several researchers have investigated methods for soil treatment that can achieve high temperatures over short periods (Hoyle and McEloroy, 2012; Vidotto et al., 2013). They have shown that the primary factor in reducing heat exposure times is the maximum temperature required to inhibit seed germination. An inverse relationship has been reported to exist between optimal temperature and exposure time (Thompson et al., 1997; Dahlquist et al., 2007; Melander and Jorgensen, 2005). Thus, the temperature achieved and exposure times are the important interactive factors that influence the efficacy of weed control. However, these studies have been performed in the laboratory, and few studies have investigated the effectiveness of short exposure times in open fields. Different environmental conditions in an open field, such as air temperature, soil moisture, and soil texture, are known to influence seed susceptibility to steam heating (Gay et al., 2010a; Melander and Kristensen, 2011). Therefore, this information should be evaluated while taking various environmental conditions in open fields into consideration.

We are currently exploring a self-propelled machine for steaming with improved working efficiency for the application of steam to broad areas in open fields. This machine has a steel hood specialized to spray steam near the soil surface, and is equipped with a steam generator operating at a pressure of 0.4 MPa, with a flow rate of approximately 420 kg h^{-1}, reaching a maximum boiler temperature of 300 °C. The temperature in this steam boiler can be regulated from 150 to 300 °C, and it can generate saturated and superheated steam. Superheated steam can allow the application of high temperatures and drier heat, unlike saturated steam at the same pressure. High temperature treatment using superheated steam might allow a reduction in exposure time, thereby increasing the operating speed and, in turn, facilitating the application of steam over a broad area in open fields. Some studies on soil steaming have investigated the regulation of exposure times; however, information on the steam output is not yet available. Establishing a steaming technology suitable for different treatment seasons or field conditions might improve the working efficiency. Therefore, this study aimed (1) to measure the effects of steam application near the soil surface on weed seed mortality, (2) to investigate the effects of the interaction between exposure time and temperature on seed mortality, and (3) to determine how seed mortality varies according to steam conditions and treatment season in an open field. Finally, we detect an efficient steam application method that will facilitate an increase in the acreage treated.

2. Materials and methods

2.1. Steam treatment system

In this study, the machine used for steam treatment was an

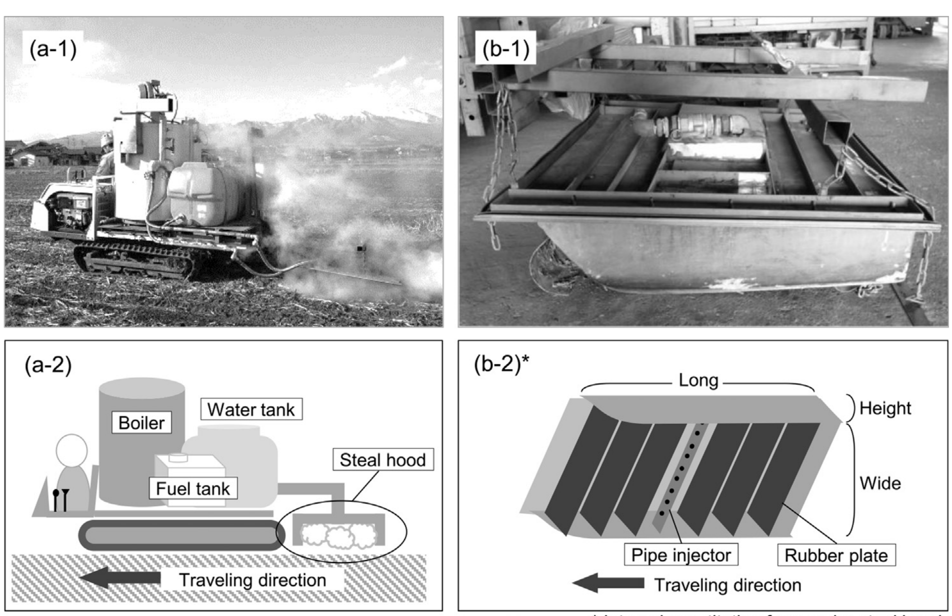

Fig. 1. (a) The farm machine equipped with a JJ-5.0 steam generator, and (b) the steel hood-covered steam pipe injector.