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Original Research Article

Mulching type-induced soil moisture and temperature regimes and water use efficiency of soybean under rain-fed condition in central Japan

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ABSTRACT

Soybean (*Glycine max*) is a high water-demand crop and grown under moderate temperature in Japan. To protect the crop from hot summer and to utilize rainfall for its cultivation, selection of appropriate mulching material(s) is crucial. For optimum production of the crop, soil moisture and temperature regimes as well as water use efficiency (WUE) of the crop were investigated under straw, grass, paper, plastic and bare soil (control) mulching under rain-fed condition at Gifu university farm in Japan. The mulching treatments, compared to the control, lowered soil temperature by 2 °C at 5 cm depth and 0.5 °C at 15 and 25 cm depths. The plastic and straw mulching stored the highest quantity of soil moisture at 5 and 15 cm depths; the bare soil stored the lowest quantity. At 25 cm depth, soil-moisture content was the highest under paper mulch but invariable under the other mulches. Plastic mulching reduced evaporation rate from the soil surface and, consequently, the reduced soil-water consumption (SWC) from the root zone augmented WUE of soybean. The paper mulching, by conserving soil-moisture and reducing soil temperature, provided better crop growth attributes, while the plastic mulching improved WUE of green soybean. Therefore, the plastic mulch performed best in reducing soil-water consumption and increasing WUE, while the paper mulch was good for soil-moisture conservation and temperature modification that increased soybean yield.

1. Introduction

Vegetable soybean (*Glycine max*), called 'edamame', has been popularly cultivated in Japan for many years (Konovsky, Lumpkin, & McClary, 1994) and, recently, is being used as a fodder crop also (Uchino, Uozumi, Touno, Kawamoto, & Deguchi, 2016). The cultivation season of soybean varies at different areas in the country (Kono, 1989) depending on the location and weather, which also affect the quality and yield of the crop. The optimum temperature for cultivation of vegetable soybean is less than 25–30 °C during day time and more than 10–15 °C at night time (Kono, 1989). The growing period of the crop is 90–100 days. The seeding of soybean is done in May and the crop is harvested in August in the northern region like Hokkaido, whereas March to May is the seeding time and June to August is the harvesting time in the southern region like Kyushu (Kokobun, 1991). In central Japan, the sowing time is May to June when air temperature rises up to 42 °C in the hot-dry months. Mean annual rainfall in the area is 1800 mm, 34% of which occurs during June through August, with the highest rainfall (13.7%) in July. For satisfactory yield, it is necessary to conserve soil moisture and modify soil temperature for the cultivation of soybean in rain-fed condition. During the hot summer days (July–August), high soil temperature accelerates evaporation at soil surface and reduces soil moisture, with a consequent negative impact on the growth and development of the crop. The negative impacts of high temperature may, however, be minimized by employing mulching with suitable materials (Kader, Senge, Mojid, & Ito, 2017). The appropriate mulching materials, by controlling soil temperature and conserving soil moisture, can provide suitable soil microclimate for soybean cultivation in the hot summer.

There are a number of mulching materials in use from organic

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and inorganic sources. The popular organic mulching materials, such as straw and grass, have been used to retain soil moisture (Chakraborty et al., 2008) by reducing soil-water consumption/loss (Zribi, Aragüés, Medina, & Faci, 2015), maintain soil temperature (Ramakrishna, Tam, Wani, & Long, 2006) and increase crop production (Siczek & Lipiec, 2011). Organic materials like straw, grass and newspaper are environment friendly, and, after decomposition, add nutrients and organic matter to the soil (Kader, Senge, Mojid, & Ito, 2017). Although, plastic mulch provided better crop yield (Mehan & Singh, 2015), but straw mulch, in many cases, has been recommended for its local availability (Yin et al., 2016). The choice of selection of an appropriate mulching material depends on local climate, cost effectiveness (Wang, Zhao, Wu, & Chen, 2015) and crop feasibility. Cereal straw is a most common organic mulching material that has several benefits, and is better for soil-moisture storage than some other mulching materials (Ji & Unger, 2001). Dry grass and newspaper are inexpensive and, in general, easily available. Farmers can easily collect these materials as an alternate option of rice straw mulching, which is limited due to its unavailability in the field since this is, very often, also used for feeding ruminants or used as biofuel (INFONET-BIOVISION, 2010).

Plastic mulch affects the thermal regime of a soil by altering soil temperature (Arora, Singh, Sidhu, & Thind, 2011; Pramanik, Bandyopadhyay, Bhaduri, Bhattacharyya, & Aggarwal, 2015). It also reduces water loss by preventing surface evaporation (Zribi, Aragues, Medina, & Faci, 2015), improves crop-water use efficiency (Almeida, Lima, & Pereira, 2015) and minimizes salt build-up in the crop root zone (Dong, Li, Tang, & Zhang, 2009). The effect of mulching on soil temperature is, however, highly variable; it depends on the type of mulch and color of the plastic film. Plastic film mulching is more effective for reducing soil-water consumption/loss compared to straw mulching. While black plastic mulch increases soil temperature (Ibarra et al., 2012), silver color plastic mulch reduces it (Lamont, 1993). The color of the plastic mulch affects microclimate around the crop by modifying radiation budget (absorptivity vs. reflectivity) of the surface (Filipović et al., 2016) that can reduce soil-water consumption (Deng, Shan, Zhang, & Turner, 2006) and increase water use efficiency (Kumar & Dey, 2011). However, use of plastic films for mulching is often limited due to their high cost as well as high cost of their collection and recycling of their residues (Qin, Wang, Guo, Yang, & Oenema, 2015). Selection of appropriate mulching materials for green soybean production under rain-fed conditions in hot summer, like at central Japan, is very important. This study investigated the effects of organic and inorganic materials on soil hydrothermal regimes, which influence growth, yield and water-use efficiency of green soybean under rain-fed condition in central Japan.

2. Materials and methods

2.1. Description of study site and treatments

The field experiment was conducted at Gifu University farm in Japan (35° 27' N and 136° 44' E, 12 m above sea level) by cultivating soybean (*Glycine max*) during 20 May to 27 August 2015. The long-term (2000–2014) temperature and precipitation data of the site, collected from a nearby weather station (Gifu WMO station ID: 47632), are illustrated in Fig. 1. The mean air temperature during the soybean growing season increased from 22.0 °C in May to 28.4 °C in August; the average temperature was 24.7 °C. Both the maximum and minimum temperatures were greater in August than in the other months (Table 1). The solar radiation varied from 11.1 to 17.0 MJ m^{-2} day^{-1} over the crop period. The average relative humidity was 80.3%. Total 874.4 mm rainfall, with the maximum quantity in July (during flowering and development stages of soybean), occurred during the crop season. No irrigation was applied to the crop. The reference evapotranspiration (ET_o) was 5.6 mm day^{-1} that fluctuated with the varying air temperature and solar radiation. The experiment was done with five different mulching treatments; a no mulching treatment was used as control. The treatments included three organic mulches – rice straw (0.46 kg m^{-2}), dry grass (0.40 kg m^{-2}) and shaded newspaper (0.20 kg m^{-2}); an inorganic plastic film (silver color) mulching (0.02 mm thick and one layer) and a bare soil (no mulch). The plot size for each mulching treatment was 12.5 m^2 (5 m × 2.5 m) with a buffer zone of 0.5 m surrounding the treatments.

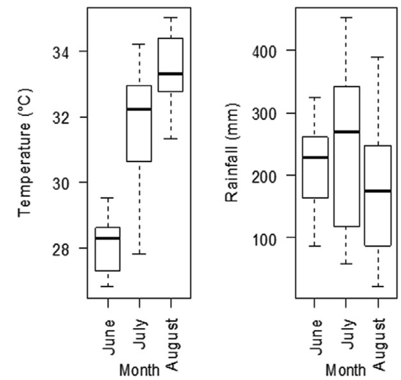

Fig. 1. Daily mean air temperature and monthly average rainfall during the crop-growing months (June, July and August) over the year 2000–2014 in the study site.

2.2. Soil physical properties

Undisturbed soil samples were collected from the root zone of soybean: 0–10, 10–20 and 20–30 cm soil profile under each mulching treatment by using core samplers. Texturally, the soil in the study site was loamy sand and loam in the 0–30 cm soil layer. The moisture contents of the soil samples over field capacity (–33 kPa) to permanent wilting point (–1500 kPa) were determined by centrifugation (Russel & Richards, 1939) with a Kokusan H-2000B centrifuge machine. The bulk densities of the soils were determined by drying the samples in oven at 105 °C for 24 h. Soil organic matter (OM) content was determined by ignition method (Storer, 1984) in which weight loss of the soil samples on ignition was measured. Soil hydraulic properties, bulk density and organic matter content under different mulching treatments are given in Table 2.

2.3. Weather and soil environment

Major climatic data relevant to soybean cultivation: rainfall, soil and air temperatures, relative humidity, solar radiation and soil moisture were measured throughout the period of the experiment. Reference evapotranspiration, ET_o, was estimated using climatic data by Penman-Monteith equation (Allen, Pereira, Raes, & Smith, 1998). The depth of main root zone of crop was less than 30 cm from field observation. The volumetric soil-moisture content and soil temperature were measured at three depths (5, 15 and 25 cm) under each mulching treatment at 1-h interval by employing two different types of probes. One probe type consisted of two-rod TDR probes (CS615, Campbell Scientific, Inc., USA) connected to a datalogger (CR10X, Campbell Scientific, Inc., USA). The other type, a simultaneous soil-moisture and temperature measurement system, consisted of 5TM and Em50 probes (Decagon Devices, Inc., USA). Additionally, soil temperatures were recorded with TMC20-HD sensors connected to a U12-008 logger (Onset Computer Corporation, USA). The soil-water consumption

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