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Response of hot pepper (*Capsicum annuum* L.) to mulching practices under planted greenhouse condition

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ABSTRACT

Mulch is considered a desirable management technology for conserving soil moisture, improving soil temperature and soil quality. This study aimed to investigate soil conditions and hot pepper (*Capsicum annuum* L.) performance in terms of leaf photosynthetic capacity, fruit yield and quality, and irrigation water use efficiency (IWUE) under such practices in greenhouse condition. A field experiment across 3 years was carried out with four types of mulch (without mulch [CK], wheat straw mulch [SM], plastic film mulch [FM], and combined mulch with plastic film and wheat straw [CM]). Mulch could improve soil physical properties regardless of mulch materials. FM and CM treatments improved soil moistures status and soil temperature in comparison to CK control, while SM increased soil water content and decreased soil temperature. Mulch increased leaf net photosynthesis rate (P_N), stomatal conductance to water vapor (gs), intercellular CO_2 concentration (Ci), and transpiration rate (E), but declined instant water use efficiency (WUEi). No significant effect of mulch application on chlorophyll fluorescence was existent for the entire growth season. Fruit yield and irrigation water use efficiency (IWUE) showed some increment under all the mulch conditions. Compared to CK, the yield was enhanced by 82.3%, 65.0%, and 111.5% in 2008; 38.1%, 17.4%, and 46.5% in 2009; and 14.3%, 6.5%, and 19.6% in 2010 under SM, FM, and CM conditions, respectively. Although FM produced better fruit quality than other treatments, CM is the recommended practice for hot pepper cultivation in greenhouse condition due to working well to facilitate soil condition (moisture and temperature), plant growth, and marketable yield.

1. Introduction

Mulching practices are popular to be used in wheat (Li et al., 2004), maize (Fisher, 1995; Liang et al., 2001), cotton (Dong et al., 2009), vegetables (Vázquez et al., 2006), and yam (Olasantan, 1999) production in the world. It is defined as the application of various kinds of cover materials to the soil surface. It benefits crop growth and development, increases economic benefit at upland and lowland, decreases the incidence of some plant diseases, and conserves soil moisture, as well as improving soil physical, chemical, and biological properties, especially in dry years (Bennett et al., 1966; Hillel, 1980; Salau et al., 1992; Elmer, 2000; Li et al., 2004; Mahajan et al., 2007; Zhang et al., 2009). Sharma et al. (1990) found that application of maize stalk mulching increased residual soil moisture in sandy loam soil. Olasantan (1999) and Fabrizzi et al. (2005) reported that soil temperature was increased during colder weather and decreased during warmer weather in mulched condition compared to in non-mulched condition. Some other benefits of mulching such as weed control, reduction of soil runoff and erosion, and improvement of plant earliness have also been recognized widely by both researchers and farmers (Dong et al., 2009; Jordán et al., 2010).

Hot pepper (*Capsicum annuum* L.), originating in the tropics area of Central and South America, is one of the most important vegetables in China due to its nutritional and economic values with 1.3 million ha, and the production is about 28 million t per year. With the development of facility agriculture, more and more pepper is grown in greenhouse to pursue the maximum economic profits. However, its cultivation is confined to warm and semi-arid countries where water is often a limiting factor for production (Dorjia et al., 2005). Due to improving soil moisture and

Abbreviations: Chl, chlorophyll; Ci, intercellular CO_2 concentration; DAT, days after treatments; E, transpiration rate; Ec, electrical conductivity; FMC, field moisture capacity; Fv/Fm, maximal PSII photochemistry efficiency in dark-adapted state; Fv′/Fm′, efficiency of excitation energy capture by open PSII reaction centers; Gs, stomatal conductance to water vapor; P_N, net photosynthetic rate; PSII, photosystem II; qP, photochemical quenching coefficient; qN, non-photochemical quenching coefficient; ΦPSII, maximal photochemical quantum efficiency of PSII; TSS, total soluble solids content; Vc, vitamin C content.

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temperature and the overall positive effect on crop growth and development, mulch is also recommended as a component within an integrated crop management (ICM) programme for hot pepper (Hassan et al., 1995; Vos et al., 1995). However, mulching practices change widely in terms of the materials and their differential effects in producing the hydrothermal regimes in soil and plants. The crop yield was higher in plastic film mulching than in un-mulched control treatment, but straw mulching had no significant effect (Gao et al., 2009). Plastic film mulching could improve maize yield in dryland (Fisher, 1995; Liang et al., 2001), but decrease spring wheat yield in semi-arid region (Li et al., 2005).

In recent years, mulching effects have been studied mainly in open-field condition; however, little information is available on the response of pepper to different mulching materials in greenhouse. It is well known that micro-climates were significantly different for the plants grown in greenhouse and open-field conditions. Whether mulch had similar influence on soil condition (moisture and temperature) in greenhouse as in open-field condition? Furthermore, plant growth and development are frequently dependent on photosynthesis due to providing energy and accumulating its own food (Ashraf and Bashir, 2003). Photosynthesis capacity is the very basis of any economic yield (Pessarakli, 2005) and the leaf photosynthesis is the component of canopy photosynthesis that accounts for most of the variation in yield (Takai et al., 2010). Singh et al. (2009) reported that mulch could improve leaf photosynthetic capacity, but Ferrini et al. (2008) argued that no significant effect on leaf photosynthesis was existent. Thereby, the objectives of current research was to assess the effects of three mulches of different composition (straw and plastic film) on soil moisture, soil temperature, and leaf photosynthesis, as well as the effect on marketable yield, water-use efficiency, and fruit quality in hot pepper crop under planted greenhouse.

2. Materials and methods

2.1. Study site

The trials were carried out in the experimental greenhouse of Institute of Soil and Water Conservation (ISWC), Northwest A&F University in Yangling (34°12′–34°20′N; 108°–108°7′E, elevation 560 m), Shaanxi, China, from May to September in 2008, 2009, and 2010 respectively. The annual mean air temperature is 12.9 °C and the average annual precipitation is 610 mm. The soil texture was dark loessial soil (54.8% sand, 39.0% silt, and 18.6% clay, on average). Soil water holding capacity was 24% (mass basis). The soil bulk density was 1.26 g cm^{-3} and the pre-sowing soil (0–30 cm layer) test indicated mean values of pH (water) was 7.9; organic matter content was 15.0 g kg^{-1}; total N content was 0.72 g kg^{-1}; total P_2O_5 content was 0.84 g kg^{-1}; available N (1 mol/L NaOH hydrolysis) was 25.0 mg kg^{-1}; available P (0.5 mol/L $NaHCO_3$) was 36.4 mg kg^{-1}; and available K (1 mol/L neutral NH_4OAc) was 144.0 mg kg^{-1}. Hot pepper plants (cultivar Nongcheng 2, a common variety, bred by the College of Horticulture of the Northwest A&F University) were transplanted on 15 May 2008, on 28 May 2009, and on 25 May 2010 with a density of 40,000 plants ha^{-1}. Plot size was 2.5 m long and 2.4 m wide, and four rows of pepper plants with a between-row spacing of 50 cm were transplanted in each plot in three years. The plastic membrane was set underground about 100 cm depth to prevent interpenetration of water. Fertilizers were applied with 150 kg ha^{-1} N (urea) and 100 kg ha^{-1} P_2O_5 (diammonium phosphate) for each plot on 14 May and 3 July 2008, on 27 May and 10 July 2009, and 24 May and 11 July 2010, respectively.

2.2. Experimental design

There were four treatments including control (CK, conventional practice without mulch), straw mulch (SM, 5 cm length of wheat straw hay with 10,000 kg ha^{-1}), plastic film mulch (FM, a common method, the first step was to cover 0.01 mm transparent polythene film, and then to dibble on film and transplant pepper plants in holes), and combined mulch with plastic film and straw (CM, plastic film covered in planting row and then wheat straw covered in operation row). A completed random block design with four replications was used. Treatments were established on 5 June 2008, 19 June 2009, and 21 June 2010, respectively. On average, soil moisture (0–40 cm layer) was maintained around 75–90% of field moisture capacity (FMC) with drip irrigation system using TDR (Time Domain Reflectometry) measurement, which was embedded to the depth of 40 cm in the soil. Three probes were used as replicates in each plot. When reduced to lower 70% FMC, soil water content was increased to 90% FMC.

2.3. Sampling and plant measurements

2.3.1. Soil conditions

Soil physical properties (0–40 cm) were determined after harvest in 2010. Each sample was dried at laboratory room temperature (25 °C) to a constant weight and sieved (0.25 mm) to eliminate coarse soil particles. Soil organic matter was measured by the Walkley–Black method (Walkley and Black, 1934); soil bulk density was determined by the core method (Blake and Hartge, 1986); soil article density was determined by the picnometer method (Blake and Hartge, 1986). Total porosity was calculated from the bulk density (BD) values and the measured particle density as TP = 1 − BD/PD (Jordán et al., 2010).

Soil temperature in each plot was measured for the entire observed periods at 10 cm depth in 2008 and at 5 cm, 10 cm, 15 cm, and 20 cm depths in 2009 and 2010, respectively, with portable LCD soil temperature meter (Mod. TPJ-21, Zhejiang Top Instrument Co., Ltd., China).

Soil moisture (0–20 cm) was recorded with TDR (Time Domain Reflectometry) measurement, which was calibrated by gravimetry in each measurement.

2.3.2. Leaf gas-exchange

The nine young fully expanded leaves of pepper plants were monitored for each plot in 2008, 2009, and 2010. Leaf gas-exchange was measured from 9:00 am to 17:00 pm in 2008 and from 9:00 am to 11:00 am in 2009 and 2010 on sunny days using an infrared gas analyzer (IRGA), model LI-6400 (Li-COR Biosciences, Lincoln, NE, USA). The LI-6400 was operated as an open system. The leaf temperature was set at 27 °C, flow rate at 500 μmol s^{-1}, and CO_2 (Ref CO_2) at 400 mL L^{-1}. Net assimilation rate (P_N), stomatal conductance to water vapor (gs), transpiration rate (E), and intercellular CO_2 concentration (Ci) were recorded for actual photosynthetic photon flux density (PPFD). The diurnal patterns of photosynthetically active radiation (PAR) and the ratio of vapour pressure deficit and leaf temperature in 2008 were present in Fig. 1. The leaves attached to the stem were inserted into the chamber (2 cm × 3 cm). The detecting head of LI-6400 was held horizontally in order to receive the enough sun-light within the chamber, which is transparent and square. Diurnal variations were determined within continued three days at 50, 51, and 52 days after treatment [DAT] in 2008. Photosynthesis parameters were measured 3 times at 40, 50, and 57 DAT in 2009 and 5 times at 35, 46, 47, 68, and 80 DAT in 2010.

2.3.3. Chlorophyll fluorescence

Chlorophyll fluorescence was also measured with LI-6400 (Li-Cor, Inc., USA) on the same leaves as gas-exchange was performed in each plot. Fluorescence parameters were set following the recommended values published in the LI-COR 6400 manual (Yu et al., 2010). Before measurement, the sample leaves were dark-adapted for 24 h with dark adapting clips to measure the initial

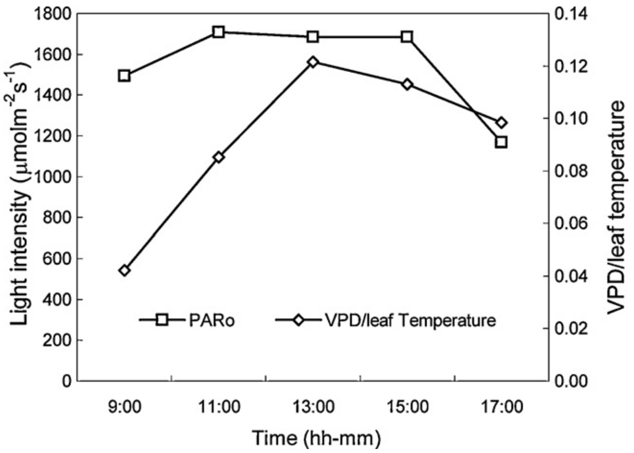

Fig. 1. The diurnal patterns of photosynthetically active radiation (PAR) and the ratio of vapour pressure deficit and leaf temperature in 2008.

fluorescence (Fo) and maximal fluorescence (Fm) in 2009 and 2010. The steady state value of fluorescence (Fs), maximal fluorescence in the light-adapted state (Fm′) and basal fluorescence (Fo′) were determined after far-red illumination. The photochemical quenching coefficient (qP), the non-photochemical quenching coefficient (qN), the maximal photochemical efficiency of PSII (Fv′/Fm′), and quantum yield of PSII (ΦPSII) were calculated as follows: $qP = (Fm' - Fs)/(Fm' - Fo')$, $qN = 1 - (Fm' - Fo')/(Fm - Fo)$, $Fv'/Fm' = (Fm' - Fo')/Fm'$, and $\Phi PSII = (Fm' - Fs)/Fm'$, respectively (Bilger and Schreiber, 1986; Kitajima and Butler, 1975). The photoinhibition extent was calculated as $(1 - qP)\ Fv'/Fm'$ (Kornyeyev et al., 2003). In 2008, diurnal variations of Chl fluorescence parameters were determined on same sampling date with leaf gas-exchange. Chl fluorescence was measured 5 times at 40, 50, 57, 64, and 70 DAT in 2009 and at 35, 46, 57, 68, and 80 DAT in 2010, respectively.

2.3.4. Yield and water-use efficient (WUE)

Fruits of pepper were harvested completely on 1st, 20th, and 25th September in 2008, 2009, and 2010, respectively, and the total fresh yield was determined. Economic income was determined by fresh fruit yield and supermarket price. Water use efficiency for the cropping season was calculated based on total yield. No deep drainage or surface runoff was considered. Yield irrigation water use efficiency (WUE) and economic irrigation water use efficiency (IWUE) were calculated as fresh bell pepper yield and economic income divided by total seasonal irrigation water applied, respectively (Sezen et al., 2006).

2.3.5. Fruit quality

Fruit quality parameters were determined in green mature fruits. During the middle of the harvest period, six uniform fruits were selected from each replicate (one per plant) to measure fruit quality. For each replicate, three fruit extracts obtained from liquefying the mesocarp were combined and centrifuged for measurement of pH, electrical conductivity (Ec), saline iron, and total soluble solids content (TSS). pH was determined with PHB-4 pH meter (China); Ec ($ms\,cm^{-1}$) and saline iron (%) were measured with B-173 electrical conductivity meter (Japan), and TSS was determined on juice using a handheld refractometer (ATC-1 Atago, Tokyo, Japan) with automatic temperature compensation. The other fruit samplings were used to measure vitamin C content (Vc) and nitrate content. Vc and nitrate contents were determined using 2,6-dichloro-indophenol titration and sulfuric acid - salicylic acid colorimetry approaches, respectively.

Table 1
Effects of different mulch treatments on soil properties after harvest in 2010.

Treatments	Soil organic matter (%)	Soil bulk density ($g\,cm^{-3}$)	Soil porosity (%)
CK	1.49 d[a]	1.32 a	50.0 d
SM	1.54 c	1.27 b	52.0 c
FM	1.66 b	1.24 c	53.1 b
CM	1.79 a	1.23 d	53.7 a

[a] The different letters indicate significant difference among treatments at $p \leq 0.05$ level based on Tukey's test.

2.4. Statistical analysis

The database was subject to analyses of variance (ANOVA) using SAS software package 9.1 (SAS Institute, 2003) with PROC MIXED procedure. Comparison among treatments was performed using Tukey's multiple range tests at the 0.05 probability level. The time-repeated measures analysis (repeated ANOVA) was used to determine the influences of mulching on parameters of interest during the whole observed period in 2009, and 2010, respectively, with the SAS PROC MIXED procedure (Klaus and Oscar, 2008).

3. Results

3.1. Soil conditions in response to mulching

3.1.1. Soil physical properties

Application of mulch over soil produced an significant increment in soil organic matter content and soil porosity with respect to control, but reduction in soil bulk density (Table 1). Among mulch treatments, the lowest value was obtained under SM and the highest under CM conditions in soil organic matter content and soil porosity, and gotten the inverse results in soil bulk density.

3.1.2. Soil temperature

Soil temperature was affected significantly by mulching in three years (Fig. 2). In all case, it was higher under plastic film mulch (FM) and combined mulch with plastic film and straw (CM), but lower under straw mulch (SM) in comparison to without mulch (CK). At the later stage of pepper growth, the difference among treatments decreased gradually. On average, soil temperature was high 1.9 °C and 1.1 °C in FM and CM treatments, but low 0.1 °C in SM treatment at 10 cm depth in 2008. In 2009, SM, FM, and CM increased by −0.3 °C, 0.9 °C, and 0.7 °C at 5 cm depth, respectively, −0.2 °C, 0.6 °C, and 0.4 °C at 10 cm depth, −0.2 °C, 0.6 °C, and 0.4 °C at 15 cm depth, and −0.1 °C, 0.5 °C, and 0.3 °C at 20 cm depth. In 2010, SM, FM, and CM increased by −1.84 °C, 1.75 °C, and 0.35 °C at 5 cm depth, −1.39 °C, 1.56 °C, and 0.37 °C at 10 cm depth, −0.94 °C, 1.49 °C, and 0.47 °C at 15 cm depth, and −0.71 °C, 1.18 °C, and 0.48 °C at 20 cm depth.

3.1.3. Soil moisture

Soil moisture under the different mulching was influenced strongly by the composition of the mulch material employed in trials (Fig. 3). The lowest value was attained under SM and the highest under CM conditions. In all case, the soil moisture measured in un-mulched soil was always lower than that got across all mulch materials, and followed a similar pattern to them. In comparison to CK, the average mean soil moisture was increased by 22.1%, 32.8%, and 44.1% under SM, FM, and CM conditions, respectively, in 2008; 18.9%, 22.4%, and 21.3% in 2009; and 10.8%, 10.0%, and 19.3% in 2010 for the entire growth season.

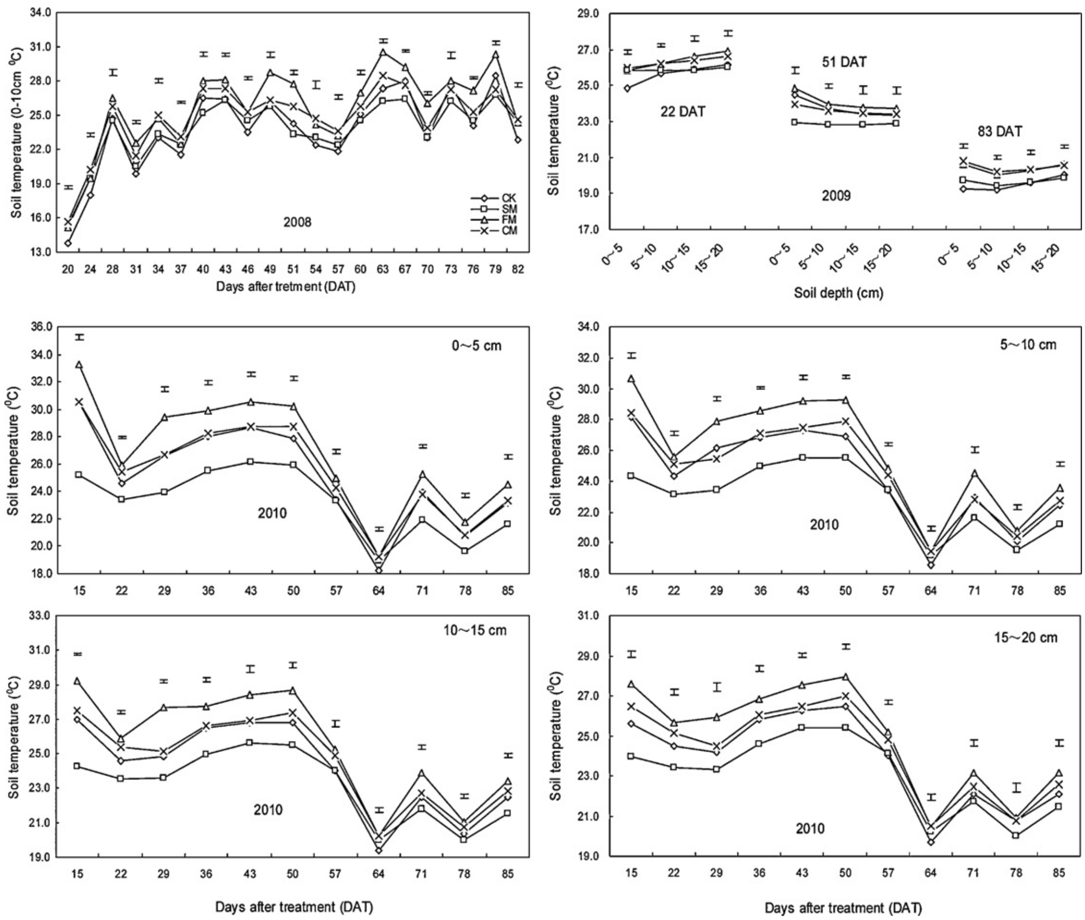

Fig. 2. Evaluation of soil temperatures in each mulch treatment during the growth cycle in 2008, 2009, and 2010. Data measured at 8.00, 14:00, and 20:00 h and averaged data was shown. Soil temperature at a depth of 10 cm in 2008 and 0–20 cm in 2009 and 2010, respectively. CK, un-mulched control; SM, wheat straw mulch; FM, plastic film mulch; CM, combined mulch with plastic film and wheat straw. Vertical bars represent Tukey's test among treatments ($p < 0.05$).

3.2. Leaf photosynthesis capacity in response to mulching

3.2.1. Leaf gas-exchange

Mulching practices had significant influences on leaf photosynthesis in three years, however, the exact influence varied among years (Fig. 4, Table 2). The diurnal patterns of leaf gas-exchange were observed in 2008. Growth conditions had significant effects on photosynthetic patterns. The daily highest P_N values were achieved at 11:00 in FM and CK treatments, but at 13:00 in SM and CM treatments (Fig. 4a). The daily average P_N was 24.9, 22.9, 21.8, and 27.6 $\mu mol\ CO_2\ m^{-2}\ s^{-1}$ in CK, SM, FM, and CM treatments, respectively. gs was highest at 9:00 in CK, SM, and FM treatments but at 11:00 in CM treatment. Like P_N, gs decreased in SM and FM and increased in CM treatment (Fig. 4b). Ci presented a double-peak curve in a sunny day (Fig. 4c). The highest Ci was gotten at 11:00 and 15:00 and the lowest was recorded at 13:00 in all of treatments. Its values increased in SM and CM conditions, but declined in FM condition. E increased to the peak at 11:00 in SM treatment and 13:00 in FM, CM, and CK treatments (Fig. 4d). Mulch treatments (SM, FM, and CM) could improved E significantly, but reduced the instant WUE (WUEi) values compared to CK (Fig. 4e).

Response of photosynthesis to mulching with growth process was recorded in 2009 and 2010, respectively. The large variability in photosynthetic parameters throughout the fruit growth season (data not shown) made it difficult to evaluate treatment effect, but taking into account the continuous impacts of mulch and time (Table 2) alleviated the problem, showing that among all effects in the full model, mulch, time, and their interactions affected significantly on leaf gas-exchange in pepper. Mulch could improve greatly P_N, gs, Ci, and *E*, particular CM and FM treatments (Table 2), however, reduced WUEi although there was no significant mulch effect on WUEi in 2010. Among mulch treatments, SM was lower in P_N, gs, and *E* than FM and CM, but no significant difference between FM and CM was observed. Ci was significantly higher in CM than in SM and FM. On averaged, SM, FM, and CM increased P_N by 2.2%, 14.7%, and 12.5% in 2009 and by 4.5%, 15.2%, and 7.9% in 2010.

3.2.2. Chlorophyll florescence

Diurnal recordings of Chl fluorescence parameters in 2008 experiment (Fig. 5) indicated that efficiency of excitation energy capture by open PSII reaction centers, as revealed by Fv′/Fm′ ratio, fluctuated slightly before 15:00 but increased steeply at 17:00 (Fig. 5a). The difference between mulching treatments and control increased with time process. The daily averaged Fv′/Fm′ values was 0.227, 0.314, 0.332, and 0.422 in CK, SM, FM, and CM. Although mulch had no significant effects on Fv′/Fm′ and the maximal quantum yield of PSII (Fv/Fm) for the entire fruit growth stage based on repeated analysis in 2009 and 2010, Fv′/Fm′ and Fv/Fm values were higher in mulch treatments than in control (Table 3).

The photochemical quantum efficiency of PSII (ΦPSII) had similar pattern in all of treatments with diurnal time in 2008 (Fig. 5b). Like Fv′/Fm′, ΦPSII changed slightly before 15:00, but increased rapidly at 17:00. CM treatment was higher in ΦPSII than CK treatment during a day, but SM and FM treatments had little effects. In 2009, ΦPSII increased significantly ($p < 0.05$) under mulching growth conditions (Table 3). The highest value was attained in CM and the lowest in FM treatments. However, there was no significant effect on ΦPSII in 2010 (Table 3).

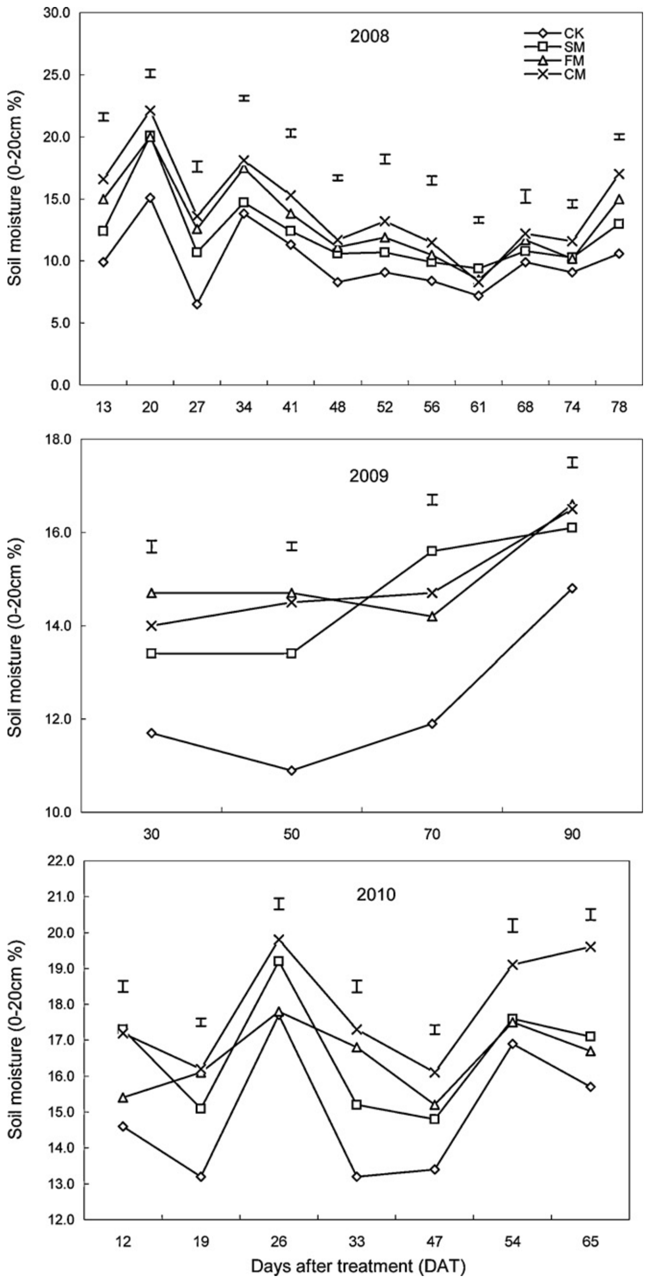

Fig. 3. Evaluation of soil water content in each mulch treatment during the growth cycle in 2008, 2009, and 2010. Soil water content at a depth of 20 cm in 2008, 2009 and 2010, respectively. CK, un-mulched control; SM, wheat straw mulch; FM, plastic film mulch; CM, combined mulch with plastic film and wheat straw. Vertical bars represent Tukey's test among treatments ($p < 0.05$).

The photochemical quenching (qP) was lowest from 11:00 to 13:00 in SM and FM treatments, but increased gradually in CM and CK treatments with diurnal time in 2008 (Fig. 5c). The peaks were present at 17:00 in all of treatments. The daily averaged qP was 0.425, 0.542, 0.413, 0.580 in CK, SM, FM, and CM treatments, respectively. For the entire fruit growth season, qP increased by 0.148, 0.12, and 0.179 units under SM, FM, and CM growth conditions in 2009; and 0.043, 0.021, and 0.04 units in 2010 (Table 3). Although no significant effects of mulch on non-photochemical quenching (qN) were observed during the whole experiment in 2009 and 2010 (Table 3), FM and CM decreased qN compared to CK treatment in two years.

The photo-inhibition extents, expressed as $(1 - qP)Fv'/Fm'$, varied quadratically with the diurnal time in 2008 because the peak was obtained at 11:00 (Fig. 5d). On each measurement time during the day, FM was higher than other treatments. In 2009 and 2010, CM treatment resulted in reduction in $(1 - qP)Fv'/Fm$, despite no significant effects of mulch were observed during the whole observed periods in 2010 (Table 3).

3.3. *Fresh fruit yield and quality in response to mulching*

3.3.1. *Fresh fruit yield and irrigation water-use efficiency (IWUE)*

In three years, mulching increased significantly the marketable yield and water-use efficiency (WUE) (Table 4). The requirement of irrigation was decreased strongly in mulching treatments. In comparison to CK control, SM, FM, and CM treatments reduced by −8.3%, 16.8% and 17.2% in 2008; 32.6%, 28.2%, and 31.7% in 2009; 42.2%, 33.5%, and 41.4% in 2010. The yield or economic income was improved by 82.3%, 65.0%, and 111.5% under SM, FM, and CM conditions in 2008; 38.1%, 17.4%, and 46.5% in 2009; and 14.3%, 6.5%, and 19.6% in 2010. Accordingly, yield IWUE or economic IWUE was increased by 68.3%, 98.4%, and 155.5% in 2008; 104.8%, 63.6%, and 114.4% in 2009; and 97.9%, 60.1%, and 104.0% in 2010.

3.3.2. *Fruit quality*

The effect of different mulches on quality of hot pepper cultivars is given in Table 5. Fruit pH and Vc content were higher in mulching treatments than in CK control, with the exception of CM influence on pH due to no significance. Oppositely, electrical conductivity (Ec) and total soluble solids content (TSS) declined significantly in FM treatment, but reduced slightly in SM and CM treatments. Cation exchange increased remarkably in SM and CM treatments by 2.4% and 5.3%, respectively, but decreased by 23.1% in FM treatment. A significant reduction (−42.3%) in nitrate content was measured in FM treatment, but a strong increment (48.5%) was observed in CM treatment compared to CK, while SM had little influence.

4. Discussion

Mulch improves soil quality and productivity through its favorable effects on soil properties (Jordán et al., 2010). Mulumba and Lal (2008) and García-Orenes et al. (2009) found that mulch was able to significantly improve soil properties, in agreement with the results of this work. However, the contradictory result was attained in soil bulk density. Bottenberg et al. (1999) observed that mulching increased significantly soil bulk density, in inversion with the current trial, and Acosta et al. (1999) argued no significant effects. The various results likely were due to differences in management practices, soil type, and the type of mulch material used (Mulumba and Lal, 2008).

The effects of mulch on soil temperature and soil moisture have been widely reported (Fisher, 1995; Li et al., 2004; Yang et al., 2006; Chakraborty et al., 2008). The variation of soil temperature, being the initial response of mulching application, changes with the composition of the mulch material (Yang et al., 2006). In current experiment, plastic film mulch (FM) and combined mulch with plastic film and straw (CM) increased soil temperature in comparison to un-mulched control during the entire growth season, in agreement with Li et al. (2004), Yang et al. (2006), and Moreno and Moreno (2008). But soil temperature decreased in straw mulch (SM) treatment, in conformity with Cook et al. (2006) and Yang et al. (2006). This is likely attributable to change in albedo and surface roughness, increment in plant cover, and higher soil moisture at the soil surface (Buerkert et al., 2000). However, Fan et al. (2003) reported that straw mulch increased soil temperature in winter and decreased in spring. Ramakrishna et al. (2006) documented that straw mulch increased soil temperature. Dong and Qian (2002) illustrated that straw mulch decreased soil temperature in the day and conserved at night. These contradictions could

Table 2
Net photosynthetic rate (P_N) (μmol CO_2 m^{-2} s^{-1}), stomatal conductance to water vapor (gs) (mmol m^{-2} s^{-1}), intercellular CO_2 concentration (Ci) (μmol mol^{-1}), transpiration rate (E) (mmol H_2O m^{-2} s^{-1}), and instant water use efficiency (WUEi) (μmol CO_2 mol^{-1} H_2O) least squares means computed from the time-repeated measures analysis for the entire fruit growth stage in 2009 and 2010.

Treatments	P_N	gs	Ci	E	WUEi
2009					
CK	13.3 b[a]	0.163 c	273.5 b	4.07 c	3.27 a
SM	13.6 b	0.183 bc	286.8 ab	4.55 b	2.99 b
FM	15.6 a	0.219 a	301.6 ab	7.46 a	2.09 b
CM	15.2 a	0.206 ab	312.3 a	7.02 a	2.17 b
Significant *p* values					
Mulch	0.0070	0.0034	0.04230	0.0007	0.0120
Time[b]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mulch × time	0.0007	0.0022	<0.0001	0.00150	<0.0001
2010					
CK	12.8 b	0.225 b	242.5 ab	6.17 b	2.35 a
SM	13.4 ab	0.299 ab	234.0 b	6.68 ab	2.29 a
FM	15.1 a	0.321 a	246.2 ab	7.70 a	2.26 a
CM	13.9 ab	0.319 ab	276.8 a	7.08 ab	1.96 a
Significant *p* values					
Mulch	0.0415	0.0434	0.027	0.0092	0.1343
Time	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mulch × time	0.0012	0.0555	<0.0001	0.0816	<0.0001

[a] The different letters indicate significant difference among treatments at $p \le 0.05$ level based on Tukey's test.
[b] Time indicates days after treatment (DAT).

Table 3
Chlorophyll fluorescence parameters least squares means computed from the time-repeated measures analysis for the entire fruit growth stage in 2009 and 2010.

Treatments	Fv/Fm	Fv′/Fm′	ΦPSII	qP	qN	(1 – qP) Fv′/Fm′
2009						
CK	0.790 a[a]	0.500 a	0.061 c	0.115 b	0.440 a	0.440 a
SM	0.797 a	0.521 a	0.141 ab	0.263 a	0.418 a	0.377 ab
FM	0.809 a	0.533 a	0.116 b	0.235 a	0.406 a	0.408 ab
CM	0.814 a	0.521 a	0.167 a	0.294 a	0.388 a	0.355 b
Significant *p* values						
Mulch	0.083	0.1443	0.0021	0.0069	0.3096	0.024
Time[b]	0.0529	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mulch × time	0.0168	0.3318	<0.0001	0.0004	0.0301	0.002
2010						
CK	0.796 a	0.557 a	0.387 a	0.654 a	0.626 a	0.202 a
SM	0.800 a	0.573 a	0.351 a	0.611 a	0.644 a	0.206 a
FM	0.801 a	0.582 a	0.369 a	0.632 a	0.608 a	0.214 a
CM	0.796 a	0.567 a	0.379 a	0.651 a	0.588 a	0.188 a
Significant *p* values						
Mulch	0.3227	0.703	0.0743	0.1625	0.1341	0.6125
Time	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mulch × time	0.0103	0.1532	0.036	0.0239	0.1907	0.3925

[a] The different letters indicate significant difference among treatments at $p \le 0.05$ level based on Tukey's test.
[b] Time indicates days after treatment (DAT).

Table 4
Influences of mulching on yield and irrigation water-use efficiency (IWUE) of hot pepper in 2008, 2009, and 2010 experiments.

Treatment	Irrigation amount (kg m^{-2})	Yield (kg m^{-2})	Economic income (US\$ m^{-2})	Yield IWUE (kg m^{-3})	Economic IWUE (US\$ m^{-3})
2008					
CK	184.7 b[a]	2.43 c	0.52 c	13.2 c	2.8 c
SM	200.1 a	4.43 b	0.94 b	22.1 b	4.8 b
FM	153.6 c	4.01 b	0.85 b	26.1 b	5.6 b
CM	152.9 c	5.14 a	1.09 a	33.6 a	7.2 a
2009					
CK	110.1 a	1.55 c	0.33 c	14.1 d	3.0 d
SM	74.2 c	2.14 a	0.46 a	28.9 b	6.1 b
FM	79.0 b	1.82 b	0.39 b	23.4 c	4.9 c
CM	75.2 c	2.27 a	0.48 a	30.3 a	6.4 a
2010					
CK	150.3 a	2.45 c	0.52 c	16.3 d	3.5 d
SM	86.8 c	2.80 a	0.60 a	32.6 b	6.9 b
FM	100.0 b	2.61 b	0.56 b	26.1 c	5.6 c
CM	88.1 c	2.93 a	0.62 a	33.3 a	7.1 a

[a] The different letters indicate significant difference among treatments at $p \le 0.05$ level based on Tukey's test.

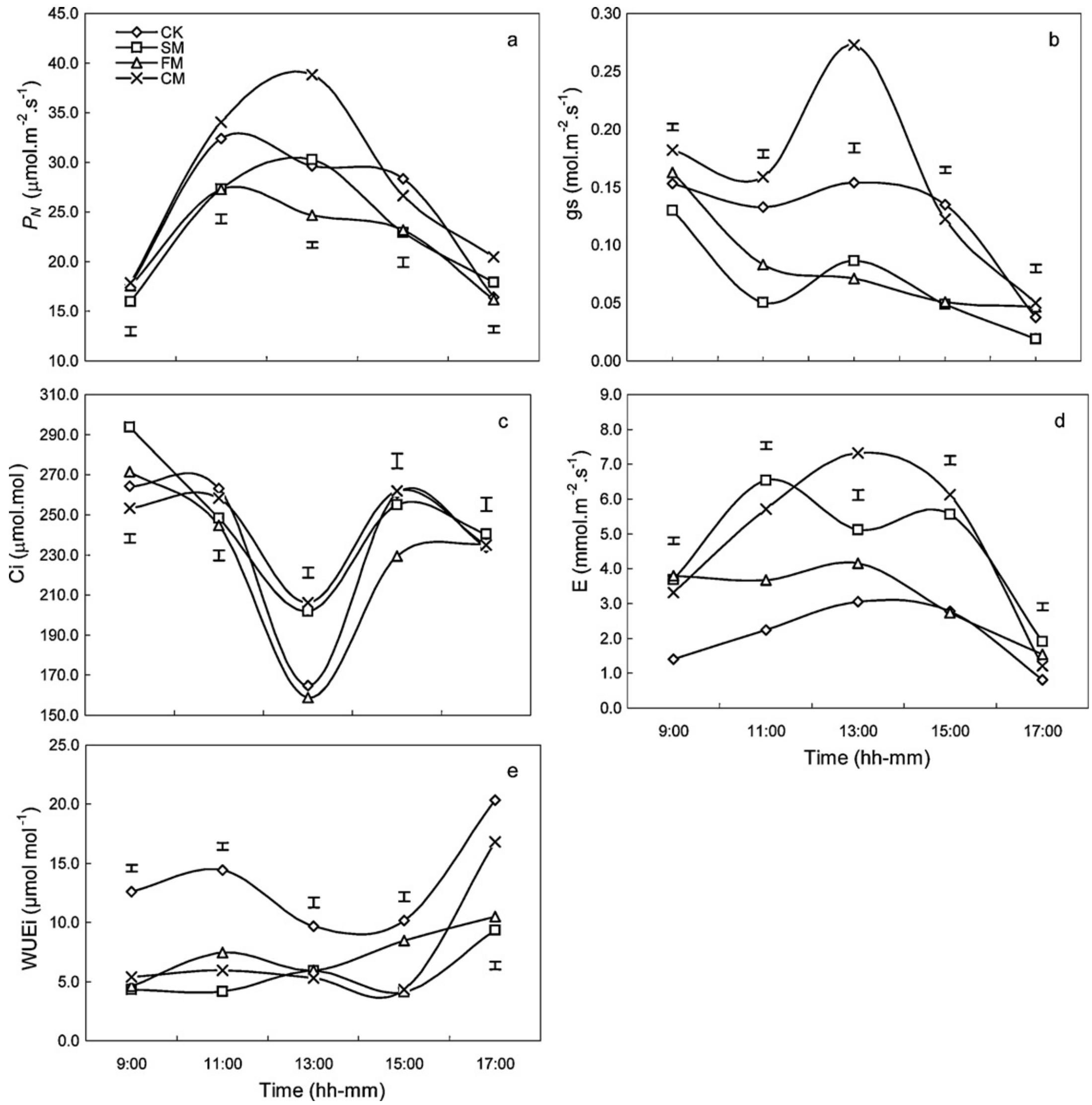

Fig. 4. Influences of mulching treatments on leaf gas-exchange parameters at different time during a day in 2008. The data was collected within continued three days at 50, 51, and 52 days after treatment and the averaged data was used P_N: net assimilation rate; Gs: stomatal conductance to water vapor; E: transpiration rate; and Ci: intercellular CO_2 concentration. CK, un-mulched control; SM, wheat straw mulch; FM, plastic film mulch; CM, combined mulch with plastic film and wheat straw. Vertical bars represent Tukey's test among treatments ($p < 0.05$).

be largely attributed to differences in climatic conditions (Yi et al., 2011).

The highest increments (or decreases) of soil temperature under the different mulches in relation to control occurred during the early crop season, in agreement with Moreno and Moreno (2008). In the CM mulch, this fact linked to the inverse effects of mulch materials (plastic film and straw) on soil temperature throughout the growing season, caused that the differences in temperature in relation to control were undetectable at the end of the periods.

The mulch layer over the soil can prevent water exchange between the soil and air leading to reduction in evaporation and ineffective water consumption (Yang et al., 2006). Mulch increased soil moisture in relation to un-mulched control, in agreement with the results obtained present work. But the degree of increment was influenced greatly by the composition of the mulch materials. CM was most effective in soil water conservation due to highest soil porosity. It seemed that FM was better than SM in conserving soil moisture, but FM need much irrigation amounts due to increasing the most soil temperature. Among mulch treatments, combined mulch with plastic film and straw was more favorable either in preserving soil water or improving soil temperature.

Table 5
Influences of mulching on fruit quality for hot pepper in 2008 experiment.

Treatments	pH	Vc[a] (g 100 g^{-1} FW)	Ec (ms cm^{-1})	TSS (%)	Cation exchange (%)	Nitrate content (mg kg^{-1} FW)
CK	4.8 c[b]	8.5 c	4.93 a	9.8 a	0.247 b	19.4 b
SM	5.3 b	10.1 b	4.72 a	8.9 a	0.253 ab	16.8 b
FM	5.5 a	13.3 a	3.63 b	6.0 b	0.190 c	11.2 c
CM	4.8 c	12.2 ab	4.60 a	9.7 a	0.260 a	28.8 a

[a] Vc, vitamin C content; FW, fresh weight; Ec, electrical conductivity; TSS, total soluble solids content.
[b] The different letters indicate significant difference among treatments at $p \leq 0.05$ level based on Tukey's test.

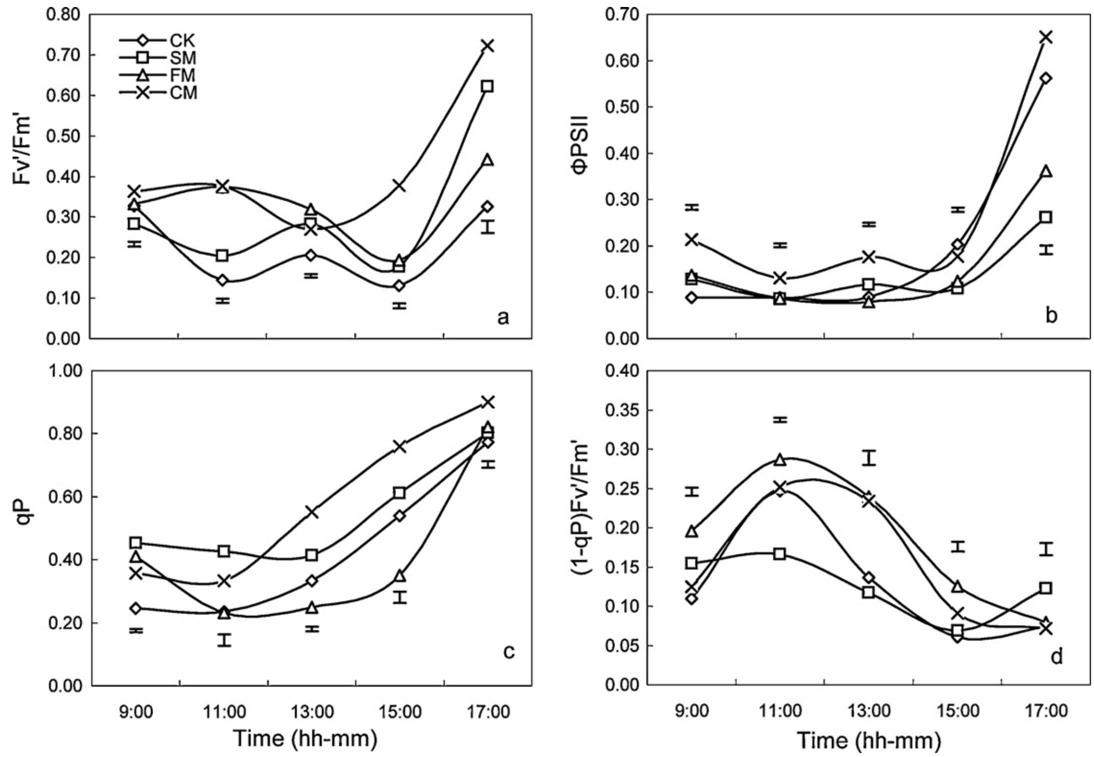

Fig. 5. Influences of mulching on chlorophyll fluorescence at different time during a day in 2008. Fv′/Fm′: efficiency of excitation energy capture by open PSII reaction centers; qP: photochemical quenching coefficient; ΦPSII: maximal photochemical quantum efficiency of PSII; CK, un-mulched control; SM, wheat straw mulch; FM, plastic film mulch; CM, combined mulch with plastic film and wheat straw. Vertical bars represent Tukey's test among treatments ($p < 0.05$).

Photosynthesis is the primary physiological process and the foundation of the crop yield formation (Zou et al., 2007). It varies with the change in growing condition thereby influencing plant growth and final yield (Ashraf, 2001). Leaves being the main site of photosynthesis possess a close relationship to the crop's marketable yield (Ashraf and Bashir, 2003) and its photosynthetic activity is crucially important during reproductive periods when the fruit is a harvestable yield (Hansen, 1969). Cai et al. (2007) and Dong et al. (2009) reported that mulch improved strongly leaf photosynthetic capacity. The current trial provided the evidence that the three compositions of mulch materials could increase leaf photosynthetic capacity. Soil moisture and temperature were better in mulch growth conditions than in control for pepper resulting in the increment in stomatal conductance to water vapor (gs) and intercellular CO_2 concentration (Ci), which contributed to the increment in net photosynthesis rate (P_N). Under suitable temperature and moisture conditions, although strong light aggravated the midday depression of photosynthesis and photo-inhibition to leaf, plants probably started photorespiration, xanthophylls circulation, and active oxygen scavenging system to defend itself against high light destruction and maintain high photosynthesis ability (Xu et al., 2002). Leaf photosynthesis rates kept high at midday only in CM condition during a day. For the entire fruit growth stages, CM and FM treatments were more favorable than SM material in leaf gas-exchange. Some results of leaf gas-exchange in 2008 were not consistent with those in 2009 and 2010, likely due to the significant influence of the sampling date. Due to increasing leaf transpiration rate (E), mulch decreased the instant water use efficiency (WUEi) in three years compared to un-mulched control.

The chlorophyll fluorescence analysis allows non-invasive, near-instantaneous measurement of key aspects of photosynthetic light capture and electron transport (Campbell et al., 1998) to evaluate the state of energy distribution in the thylakoid membrane, the quantum efficiency of PSII, and the photo-inhibition extent (Wang et al., 2007). It estimated the leaf photosynthetic capacity based on the operating quantum efficiency of electron transport through photosystem II (PSII). Fv′/Fm′ represents the efficiency of energy conversion of open PSII. At the low light intensity, the leaves allocated a high proportion of energy that they absorbed to their photochemical reaction so that the PSII quantum yield (ΦPS II) was high; otherwise, the leaves dissipate a large proportion of energy they absorbed through non-photochemical process causing reduction in the amount of the absorbed light energy to open PSII centers (Papageorgiou and Govindjee, 2004). Park et al. (1996) and Baroli and Melis (1998) demonstrated that lowering the absorbed light energy of PSII is an efficient way to circumvent photo-inhibition and energy dissipation through electron transport, in conformity with the results of present work in 2008 that Fv′/Fm′, Φ PSII, and qP were highest under low light intensity around 17:00 during the day, while photo-inhibition (expressed as (1 − qP)Fv′/Fm′) was lowest. For the entire fruit growth season, mulch had limited effects on chlorophyll fluorescence. It indicated that much did not influence the 'internal' fluorescence characteristics of the pepper plants in greenhouse condition and the lower P_N values obtained in un-mulched control plants than in mulch plants might be due to stomatal closure, rather than damage to photosystem II.

According to Hassan et al. (1995), mulch is practically beneficial in hot pepper production and may be related to favorable soil moisture status and optimal temperature, which is positively correlated to crop yield. The relationship between soil temperature and yield was quadratic, but between the rate of optimal average soil temperature values and yield the relationship was nearly linear (Horel, 2006). The optimal average soil temperature was range from 20 to 25 °C for hot pepper. In this experiment, mean seasonal soil temperature only exceeded 25 °C in FM treatment (approximately 25.8 °C) at 0–20 cm depth. Thus, soil temperature probably was slightly harmful to the pepper plants in FM treatment, but soil moisture was better than un-mulched control resulting in improvement in fresh fruit yield. Gao et al. (2009) reported that no grain yield increased with straw mulch compared with no mulch ascribed to low soil temperature, but SM could increased pepper marketable yield although soil temperature was also lower than control in current trials. It indicated that differences in fruit yield can be mainly attributed to differences in soil moisture in greenhouse condition.

Ekinci and Dursun (2009) illustrated that no significant difference in fruit quality among the mulch applications was found, in agreement with the result of SM in current trial. However, Zhang et al. (2008) demonstrated that mulch improved the quality of crops, in conformity with the result of FM in current trial. The contradicted results were obtained maybe attributed to different environmental condition and plants. Among mulch materials, plastic film mulch resulted in best pepper fruit quality due to lowest nitrate content because N uptake by plants was lower in plastic film mulch than in the un-mulched treatment (Gao et al., 2009). Due to high soil moisture and temperature, wheat straw could release certain nutrition leading to highest nitrate accumulation in pepper fruit in combined mulch with plastic film and wheat straw condition.

5. Conclusion

Mulch is useful in altering soil hydrothermal regime and produces well soil environment for plant growth and development. Among mulch materials employed in current experiment, combined much with plastic film and straw was more pronounced for improving soil environment than plastic film and straw mulches alone. It significantly increased soil moisture status and temperature and reached to suitable values thereby promoting plant growth and development. Although plastic film mulch and combined much with plastic film and straw had little difference in leaf photosynthesis capacity for pepper plant in greenhouse condition, combined much with plastic film and straw produced higher marketable yield than plastic film mulch likely due to warm soil less and water soil more. Plastic film mulch may be advantageous in areas with cool conditions and straw mulch might be favorable in areas with hot conditions. Although FM most improved the fresh fruit quality of hot pepper, the cost for combined mulch with plastic film and straw is less than that for plastic film mulch because of less irrigation amount, less environmental damage, less plastic residues left rotting out in the fields (Gao et al., 2009), and a better use of wheat straw. This indicates that combining plastic film with straw mulch works well to facilitate soil condition (moisture and temperature), plant growth, and marketable yield of hot pepper in greenhouse condition.

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