Effect of soil temperature on growth and yield of sweet potato (Ipomoea batatas L.) under cool climate

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Abstract

In cool climates, low temperature is critical for growth and yield of sweet potato (Ipomoea batatas L.). Despite its negative effects, few studies have quantified the impact. We evaluated effects of soil temperature ($T_s$) on growth and yield in sweet potato from 2-year field trials in northern Japan. $T_s$ was controlled by three steps using plastic mulch at different colors (green, black and white) with different $T_s$ ranged in 21–24°C especially at early growth before the surface of the mulch covered by plant canopy. Higher $T_s$ significantly increased vine elongation, branching, and leaf appearance, and the magnitude of increased by higher $T_s$ decreased with proceeding growth stages. Increasing $T_s$ significantly increased leaf chlorophyll content and stomatal conductance. Across treatments and years, aboveground biomass was linearly and positively correlated with $T_s$ and 58 g m\textsuperscript{2} increased in aboveground biomass was observed per 1°C increase in $T_s$. However, final storage root fresh yield was not significantly affected by high $T_s$ over years. Increased individual storage root weight at high $T_s$ was offset by decreased storage root number. The present quantitative study tested in northern Japan showed that, the enhanced aboveground growth in sweet potato at higher $T_s$, especially during early growth did not contribute to increase of storage root yields in cool climates.

Key words: Global warming, Plastic mulch, Sweet potato, Soil temperature, Yield

1. Introduction

Global temperature has increased by 0.85°C during 1880 to 2012, a much higher recent rate of increase in the last 15 years, although further increase is still predicted (IPCC, 2013). In the future warming world, while negative impacts of global warming have been projected for tropical areas, crop production in cool climates are predicted to benefit from temperature increase less than 3°C (Easterling et al., 2007).

Sweet potato (Ipomoea batatas L.) is an important vegetable crop that is mainly cultivated in tropical and subtropical region (Iese et al., 2018; Williams et al., 2013). Both the tubers and leaves are rich sources of vitamin, mineral and antioxidants (Teow et al., 2007). Global production of sweet potato in 2017 was over 100 million tonns which followed by potato and cassava, and Asia accounted for more than half of the sweet potato production (FAO, 2019).

Sweet potato has the ability to thrive in marginal growth conditions through its spreading growth habit, and relatively tolerant to abiotic stresses. However, as a tropical crop, sweet potato is highly sensitive to low temperatures (Osaki et al., 1996; Fujiiwara et al., 2004; Gajanayake et al., 2014; Wees et al., 2015).

Low temperature can reduce growth and yield of sweet potato throughout various processes such as seedling establishment, vine elongation, leaf appearance and expansion, canopy radiation capture, photosynthesis, tuber initiation and growth, nutrient uptake and translocations (Kim, 1961; Osaki et al., 1996; Gajanayake et al., 2014; Wees et al., 2015). Temperature is one of the most influential and uncontrollable factors affecting growth and yield of sweet potato in the natural-field environment.

Temperature response in sweet potato has been rarely evaluated compared to other major crop species such as rice (Moya et al., 1998; Shimono et al., 2002, 2004), wheat (Hein et al., 2019; Hazra et al., 2019), maize (Abebe et al., 2016; Siebers et al., 2017), soybean (Rosenthal et al., 2014; Palacios et al., 2019) and potato (Krauss and Marschner, 1984; Van Dam, 1996; Fleisher et al., 2006; Lizana et al., 2017). Most previous temperature response studies on sweet potato were conducted under pot condition and relatively focused on early growth stages. Gajanayake et al. (2014) evaluated 59 days growth response of sweet potato to temperature range of 16–32°C in Soil Plant Atmosphere Research (SPAR) chamber using 2-L pot, and found increased biomass production at temperature higher than 25°C. Hasegawa and Yahiro (1957) evaluated 58 days storage root yield response to soil temperature ($T_s$) above 23°C. Nighttime temperature response for 50 days was evaluated by...
Kim (1961) using 15 cm × 15 cm pot. Ten and 14 days exposure to air temperature of 23–35°C and Tₛ of 13–40°C were evaluated by Fujisawa et al. (2004) and Nakatani et al. (1986), respectively.

Field studies are the most reliable for understanding and predicting crop productivity, especially for root-crops including sweet potato under a condition without artifacts such as root-zone restrictions (Arp, 1991). Several methods have been used in previous studies to control temperature; using infrared heat array which directly heat plant surface temperatures used in previous studies to control temperature; using infrared root-zone restrictions to air temperature of 23~35°C were evaluated.

To measure soil temperatures, chambers surrounding the plants including open-top chamber (Moya et al., 1998; Hazra et al., 2019; Abebe et al., 2016; Palacios et al., 2019) and open-closed chamber (Hein et al., 2019; Lizana et al., 2017). However, these methods require high equipment costs (chamber, data logger, heater) and a stable supply of electricity which can be difficult for developing countries, as indicated by a bias-distribution of climate-change research in the world by Leakey et al. (2012).

Plastic mulch which changes both the surface and underlying soil temperatures (Lamont, 2005; Kader et al., 2017) can be a useful option to test crop temperature response with relatively low cost. Different colors of plastic mulch such as black, red, green, blue and white can serve as opportunities for a range of Tₛ to modify root-zone microclimates. Black mulch, the predominant color use, is an opaque blackbody absorber, and increases Tₛ, while white mulch, reflecting radiation, can decrease Tₛ, and other family of mulches selectively transmits radiation. Tₛ as well as atmospheric air temperature, are important environmental factors for plant growth and development (Haque et al., 2018; Shehata et al., 2019; Chakraborty et al., 2008; Gordon et al., 2010; Filipovic et al., 2016; Sarkar et al., 2019; Awal and Ikeda, 2003). Note that Tₛ, difference from air temperature, is higher than air temperature before canopy closure.

In the present study, to test the hypothesis that increasing temperature by global warming will have positive impacts on sweet potato productivity in cool climates, we evaluated the effects of Tₛ on sweet potato growth and yield from 2-years field trials using plastic mulch with three colors.

### 2. Materials and Methods

#### 2.1 Planting materials and growth condition

Cuttings of sweet potato cultivar, “Beniazuma” (24 cm length) were transplanted on the field (Andosol) at Field Science Center, Iwate University in Takizawa, Japan (39°7′N, 141°13′E) on 23 May 2018 and 19 May 2019. Three different colors of plastic mulches (green, black and white) with 0.03 mm thickness and 1.35 m width (Okura Industrial Co. Ltd., Japan) were used to regulate Tₛ in the field, which were expected to give high Tₛ (HT), medium Tₛ (MT) and low Tₛ (LT), respectively. The transmittance of radiation is 50% for green mulch, and less than 1% for both black and white mulches, and the white mulch made cooler soil temperature than black mulch (referred to Okura Industrial Co. Ltd.), due to higher reflectance of radiation on the surface (Lamont, 2005; Kader et al., 2017). After basal fertilization (8.6 g N m⁻², 28.5 g P₂O₅ m⁻² and 28.5 g K m⁻²), 4 ridges (distance between tops of ridge as 1.4 m) with 0.4 m height and 0.8 m width were prepared, with lengths of 29.8 m and 21.7 m long in 2018 and 2019 respectively. The mulches were bedded on each of the 4 ridges at 3 m (2018) and 2.1 m length (2019) for each plot (north-south of the ridge orientation), and arranged in a randomized complete block design with three replications (Supplemental Fig. S1). In both years, 10 cm diameter holes were made and cuttings were planted at a spacing of 0.3 m (one cutting per spot) with a planting density of 4.17 per m² (0.3 m between spots × 0.8 m between rows). Half to two-thirds long of each cutting was inserted into the soil inclined at an angle of about 45° with nodes pointing upwards. Weeding was done by hand when necessary. Tₛ was recorded throughout the experiments at 5 and 10cm depth in 2018 and 5cm depth in 2019 at 30 minutes interval using temperature sensor (TR52, T&D Co., Japan). Precipitation data (Morioka) was obtained from Japan Meteorological Agency.

Additionally, in the present sweet-potato study, we did not set control Tₛ as bare-soil without mulch, to compare these mulches to no-mulch bare soil condition, we measured Tₛ for one month after sowing (20 May to 20 June) in soybean field, located at the adjacent to the sweet-potato field, using identical mulch materials in 2019. Also, soil moisture (volumetric water content) was measured on 10 July, with 100 mL soil core collected within 10 cm depth and oven dried at 105°C over 2 days. The soil sampling was conducted during the rainy season, but no precipitation was recorded during two days before the sampling.

#### 2.2 Measurements

Vine length, leaf and branch numbers were determined on six plants selected at random from the two middle ridges at every 7 or 14 days. Relative chlorophyll contents (SPAD values) were recorded on the youngest fully expanded leaf from top of the longest vine on the six plants per replicate using a portable chlorophyll meter (SPAD, Model 502, Minolta Co LTD, Japan). Leaf stomatal conductance was recorded three times daily on each recording time at morning (7:30–10:00), noon (10:00–12:00) and afternoon (12:00–14:00) from three of the six plants per replicate using a leaf porometer (Model SC-1, Decagon device, Inc., USA).

Final sampling was done at 123 and 120 days after transplanting (DAT), and storage root yield was determined from nine and ten plants per replicate in 2018 and 2019, respectively. Harvested storage roots were washed and weighed individually. Plant organs (roots, stems, leaves and storage roots) were oven dried at 80°C for 72 hours and their component dry weights were determined. Leaves were separated from stem and measured with a leaf area meter (AAM-9, Hayashi denkou co., Japan).

#### 2.3 Statistic analysis

All data collected were statistically analyzed by two ways ANOVA using Excel 2016 (Microsoft, USA). Pearson’s linear regression analysis was conducted to determine the relationship between growth parameters, daily mean and cumulative soil temperatures.

### 3. Results

#### 3.1 Soil temperature with treatment effect

Daily average Tₛ (at 5 cm depth) for the white mulch treatment
was higher than air temperature by up to 3.8–4.5°C in both years, especially at early growth stages, with subsequent decreased as growth progressed (Fig. 1ab). As expected, $T_s$ differed by mulch color; the white and green mulch treatments produced the lowest and highest $T_s$, denoted as “LT$_s$” and “HT$_s$”, respectively, with the black mulch treatment ranked in the middle as “MT$_s$” (Fig. 1cd). In both years, clear variations among the treatments were observed during the first 60 DAT, but gradually decreased towards the end with canopy development. Difference in mean $T_s$ before 60 DAT was up to 2.5°C in 2018 (21.8°C for $LT_s$, 23.8°C for $MT_s$, and 24.3°C for $HT_s$), with only 0.4°C difference after 60 DAT (22.6°C for $LT_s$, 22.7°C for $MT_s$, and 23.0°C for $HT_s$). Consequently, full season difference was up to 1.4°C with mean $T_s$ of 22.2, 23.2 and 23.6°C for $LT_s$, $MT_s$ and $HT_s$ respectively. Similar 2.5°C difference in mean $T_s$ before 60 DAT was observed in 2019 (21.1°C for $LT_s$, 23.4°C for $MT_s$, and 23.6°C for $HT_s$) with 0.6°C difference after 60 DAT (23.8°C for $LT_s$, 24.1°C for $MT_s$, and 24.4°C for $HT_s$) and 1.6°C full season difference (22.4°C for $LT_s$, 23.7°C for $MT_s$, and 24.0°C for $HT_s$). Additionally, differences in maximum $T_s$ (Supplemental Fig. S2) 2018

![Figure 1a](image1.png)

2019

![Figure 1b](image2.png)

Fig. 1. Seasonal change of daily average soil temperature at 5 cm depth ($MT_s$, black mulch), air temperature (°C) and solar radiation (MJ m$^{-2}$ d$^{-1}$) (a, b), differences in $T_s$ of high (green mulch) and low (white mulch) to $MT_s$ of black mulch (°C) (c, d), and relationship between difference in $T_s$ from $MT_s$ against solar radiation before 60 DAT (e, f) in 2018 and 2019. Values outside and inside parenthesis indicates mean before and after 60 DAT, respectively. $LT_s$ (○), (●) and $HT_s$ (△), (▲), open symbols: 2018, closed symbols: 2019.
were more apparent than minimum $T_s$ especially before 60 DAT (Supplemental Fig. S3).

Daily variation in average $T_s$ before 30 DAT was well explained from solar radiation (Fig. 1ef), and a 0.22–0.47°C increase per 10 MJ m$^{-2}$ solar radiation was observed at $HT_s$ compared to $MT_s$, and a 0.75–1.12°C decrease per 10 MJ m$^{-2}$ was observed at $LT_s$ compared to $MT_s$. However, the relationship at the period after 30 DAT was getting weaker (data not shown). $T_s$ at 10 cm depth also showed variations with mulch color, but the magnitude was smaller than $T_s$ at 5 cm (Supplemental Fig. S4).

To compare these mulches covered to no-mulch bare soil conditions, we measured $T_s$ for one month (20 May to 20 June) of soybean field adjacent to the sweet-potato field using identical mulch materials in 2019, and found that $T_s$ for no-mulch condition was 19.1°C. White mulch with $T_s$ of 17.9°C was lower than no-mulch condition, black and green mulches which recorded $T_s$ of 21.3°C and 22.1°C respectively, was higher than no-mulch (Table 2). Soil moisture content was not different among mulches and ranged 41–43% of wet condition, higher than non-mulch of 36%. This suggested that our conditions

Fig. 2. Growth characteristics of sweet potato in response to soil temperature in 2018 and 2019. $LT_s$ (○), $MT_s$ ( ■ ), $HT_s$ (△), open symbols: 2018, closed symbols: 2019. ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$, +$P < 0.1$, ns not significant, NA- not available.
in sweet potato would serve as $T_s$ from sub-ambient to supra-ambient, and optimal wet conditions. Precipitation during the season (June to September) was 630 mm (2018) and 363 mm (2019) in which the 30-year mean was 640 mm.

3.2 Morphology, SPAD and stomatal conductance

Vine elongation was significantly different among $T_s$ treatments especially at early growth stages, with the magnitude of the difference decrease as growth progressed in both years (Fig. 2ab). Similar trend was observed for branch and leaf number per plant (Fig. 2deg). $HT_s$ and $MT_s$ treatments had significantly higher SPAD values in both years (Fig. 2ij), and the difference was more apparent in 2018. Over 95% of the variations of vine length (Fig. 2c), branch and leaf numbers (Fig. 2fh) caused by different years, stages, and $T_s$ were explained as function of cumulative $T_s$. In contrast, SPAD values in $MT_s$ and $HT_s$ treatments were higher than $LT_s$ treatment even at identical cumulative $T_s$ over years (Fig. 2k), although the difference decreased with increasing cumulative $T_s$.

Leaf stomatal conductance was highest at noon and afternoon for the all treatments (Fig. 3). Even though the aboveground temperature was not controlled in this study, $HT_s$ significantly increased leaf stomatal conductance relative to $LT_s$ by 10–37% and 3–54% in 2018 and 2019, respectively.

3.3 Biomass and storage root yield

Higher $T_s$ significantly increased leaf and stem biomass in both years ($P < 0.05$) (Table 1). No significant treatment differences were observed in yields, root and storage root biomass in both years. Biomass partition to roots and storage roots were significantly decreased by higher $T_s$.

Relationships between aboveground biomass, root biomass and storage root production against mean $T_s$ before 60 DAT are presented in Figure 4. Positive correlation was observed.

**Fig. 3.** Leaf stomatal conductance ($g_s$) of sweet potato in response to soil temperature at different day time (morning, 8:00 ~ 10:00, noon, 10:00 ~ 12:00 and afternoon, 12:00 ~ 14:00) in 2018 and 2019. $LT_s$ (○), $MT_s$ (□), and $HT_s$ (△), open symbols: 2018, closed symbols: 2019. *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$, + $P < 0.1$, ns not significant.
between $T_c$ and aboveground biomass ($P < 0.001$) (Fig. 4a). No relationships were observed with root biomass (Fig. 4b) and storage root yield (Fig. 4c), which was the result of trade-off relationship between storage root number (Fig. 4d) and storage root size (Fig. 4e); where higher $T_c$ increased individual storage root size, but decreased storage root number. Relationships of all parameters against mean $T_c$ after 60 DAT were not significant, except for root biomass (Fig. 5).

4. Discussion

We tested the hypothesis that increase in soil temperature by global warming especially during early growth will have positive impacts on sweet potato productivity in cool climates, but our hypothesis was denied based on 2-year field trials (Fig. 4).

This is the first report that quantify sweet potato response to early growth $T_c$ under multi-year field experiments in cool climates. Our $T_c$ treatments which were in the range of 21-24°C before 60 DAT, strongly influenced aboveground growth (Fig. 4a), with no significant effects on root biomass (Fig. 4b) and storage root yields (Fig. 4c). Most previous season-long field studies on sweet potato were conducted under natural environment without controlling temperatures (Ogasawara and Nakatani, 1950; Osaki et al., 1996; Sumi and Koriyama, 2013). Osaki et al. (1996) reported lower productivity of sweet potato compared to potato and beet in a single season experiment under temperature limited conditions in Hokkaido, Japan. Ogasawara and Nakatani (1950) reported positive correlation between storage root yield and air temperature especially at early growth stage during 13-seasons field experiments under cool climate in northern Japan. These studies were conducted under natural field conditions without controlling targeted environment, so the impact of temperature on productivity was confounded with other climate variables such as solar radiation. The present quantitative field study controlling $T_c$ would fill the knowledge gap in sweet potato response to temperature, for which information is relatively limited when compared to potato (Krauss and Marschner, 1984; Van Dam et al., 1996; Fleisher et al., 2006), cereals and legumes (Moya et al., 1998; Shimono et al., 2002, 2004; Hein et al., 2019; Hazra et al., 2019; Abebe et al., 2016; Siebers et al., 2017; Rosenthal et al., 2014; Palacios et al., 2019).

Aboveground responses to $T_c$

Even though aboveground temperature was not controlled in this study, higher $T_c$ significantly improved vine length, branch and leaf number before 60 DAT (Fig. 2abd). The effects of $T_c$ on morphology gradually decreased with days as well regressed by cumulative $T_c$ (Fig. 2cfh), but still aboveground biomass at harvest was increased by 10-12% per 1°C increase in $T_c$ (increase of 58 g m$^{-2}$C relative to $LT_c$ of 473-572 g m$^{-2}$) (Fig. 4a). Our range of effect was similar with previous studies; about 10% increase of aboveground biomass per 1°C increase of air temperature (7 g/C increase from 17°C to 26°C at 59d, calculated from their Fig. 6) (Gajanayake et al., 2014), and 6-7% increase of aboveground biomass per 1°C increase of $T_c$ (30-33g/C increase from 23°C to 32°C at 58d, calculated from their Table 1) (Hasegawa and Yahiro, 1957).

Underlying physiological mechanism of increased aboveground growth at higher $T_c$ might be attributed to root activity and/or hydraulic conductance for water transport. As shown in Figure 3, gs of the uppermost leaves were consistently increased by higher $T_c$ from morning to afternoon throughout the seasons. Shimono et al. (2004) reported that, root cooling of rice in a temperature range of 16-25°C decreased gs, and plant water content, despite rice is grown under flooding condition. Similar response associated with increase of water fluxes of transpiration was reported by McWilliam et al. (1982) for cotton and bean.
indicating lowered hydraulic conductance. Murai-Hatano et al. (2008) evaluated response of root hydraulic conductance to temperature in rice, and found increased root conductance with increasing temperature, and associated the increase to be regulated by gene expressions of aquaporin. Aboveground growth in our study might have been promoted partially through increase of turgor pressure affecting cell division and elongation (Cosgrove, 1993) although we did not measure the plant water status.

Additionally, SPAD values were also increased at higher $T_s$ (Fig. 2ij), indicating the high N uptake ability of roots under higher $T_s$. Engles (1994) found significantly low N uptake rate of maize under low root zone temperature of 12 and 16°C compared to 20°C. Although we did not measure leaf photosynthesis, the increase of SPAD and $g_s$ suggested increase of leaf photosynthesis (Shimono et al., 2004). Thus, in our study, aboveground growth at $HT_s$ was suggested to be improved through the enhanced ability of the roots to uptake sufficient nutrients and water indirectly.

In terms of radiation environment, plants under white mulch of $LT_s$ would capture more radiation by the reflectance from the mulch surface than other colors, and possibly promoting photosynthesis (Lamont, 2005; Kader et al., 2017), but the above-ground growth of $LT_s$ was lowered than other mulch colors (Fig. 2), indicating negative effects of lower $T_s$ overcame the positive effects of higher radiation in the white mulch.

**Storage root yield to $T_s$**

Contrast with aboveground growth response to $T_s$, storage root yield was not significantly affected by higher $T_s$ in the range of our 120-d field study over years (Fig. 4c). Yield in sweet potato is determined by storage root number and individual size. In the present study, higher $T_s$ tended to increase individual size of storage roots (Fig. 4d) while decrease storage roots number (Fig. 4e). Gajanayake et al. (2014) reported decreased

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**Fig. 4.** Relationships of above-ground biomass, root biomass, storage root fresh yield, number of storage root and individual storage root fresh yield of sweet potato against soil temperatures at 0-60 DAT in 2018 and 2019. Regression in Fig. 4e was conducted excluding one outlier (dotted circle). $LT_s$, $MT_s$, $HT_s$, open symbols: 2018, closed symbols: 2019.
maximum storage roots number at air temperature above 25°C in a short-term study of 59 days. We did not monitor number of storage root after initiation, but aboveground growth response in our study was well explained by cumulative $T_s$ (Fig. 2cfh). This indicated acceleration of the development stages including belowground growth at high temperature, resulting to a shorter duration for storage root initiation, thus, the decreased number of storage roots under higher $T_s$.

On the other hand, individual storage root size was increased at higher $T_s$ (Table 1). There was a positive relationship between individual storage root size and $T_s$ before 60 DAT (excluding one outlier point) (Figure 4e), but no relationship with $T_s$ after 60 DAT even with the excluding of one outlier point (Fig. 5). Struik et al. (1990) reported that, storage root growth is strongly affected by the sum of daily PAR intercepted by leaves, and carbohydrate supply from above to below ground which would compensate to maintain individual storage root size. Additionally, the relationship was not significant with $T_s$ after 60 DAT, but since the difference in $T_s$ among treatments was in the range of 0.2~0.6°C, this might have positive impact of storage root growth (Krauss and Marschener, 1984). In our study, the enhanced carbohydrate supply from above-ground at higher $T_s$ might support to increase the individual storage size. To adapt to the future warming world, selection of cultivars with less phenological sensitivity to temperature increase with maximizing the duration of storage root initiation might be one option.

Another possibility of different response of yield to $T_s$ compared to above-ground response to $T_s$ is the over-nutrition due to enhanced soil N mineralization by higher $T_s$, so-called as ‘Excessive vine growth’ (Sawahata, 1989). Further studies are required to examine effects of $T_s$ on growth and yield at range of N fertilization with considering the processes of the dry matter partitioning.

![Fig. 5. Relationships of above-ground biomass, root biomass, storage root fresh yield, number of storage root and individual storage root fresh yield of sweet potato against soil temperatures at 60~120 (123) DAT in 2018 and 2019. Regression in Fig. 5e was conducted excluding one outlier (dotted circle). $LT_s$, ($\bigcirc$), ($\bullet$); $MT_s$, ($\Box$), ($\blacksquare$); $HT_s$, ($\triangle$), ($\blacktriangle$), open symbols: 2018, closed symbols: 2019.](image-url)
Methodologies for controlling soil temperature

The use of plastic mulch to control temperature will be one useful option to evaluate environmental responsiveness (Lamont, 2005), as applied to several plant species including rice (Haque et al., 2018), potato (Shehata et al., 2019), wheat (Chakraborty, 2008), okra (Gordon et al., 2010), bell pepper (Filipovic et al., 2016), onion (Sarkar et al., 2019) and peanut (Awal and Ikeda, 2003). In our study, we successfully controlled $T_s$ with three plastic film colors (Fig. 1, Supplemental Fig. S1, 2, 3), agreed with previous studies (Lamont, 2005; Gordon et al., 2010). We quantified $T_s$ change before canopy cover as function of solar radiation. The increased in $T_s$ by 0.68–1.40°C and 1.23–1.71°C per 10 MJ m$^{-2}$ increase in solar radiation for black and green colored mulch compared to white respectively (Fig. 1ef), will serve as criteria for plastic mulch application in different locations and environments, although the magnitude can also be affected by other climate factors such as wind speed and soil characteristics.

Disadvantages of the use of plastic mulch are; firstly, since the source of temperature is solar radiation, plastic mulch was difficult to control $T_s$ in our study after full canopy expansion during the latter growth period, especially with the creeping growth habit of sweet potato (Fig. 1). However, for erect plant species such as wheat, soybean and also with early maturing species, plastic mulch might control $T_s$ for the longer growing season than sweet potato. Secondly, plastic mulch can affect microclimate with reflectance of radiation to aboveground (Ai et al., 2018); white mulch can reflect more microclimate of plant (Privé et al., 2008), although we did measure the reflectance and its positive effects on photosynthesis. In addition, plastic mulch can increase soil moisture (Lamont, 2005) throughout the growing season which can be different for bare-soil of the natural environment, and this might affect $T_s$ predictions for future climate. In fact, the soil moisture content was kept as wet in our study for soybean using identical mulches (Table 2).

Despite these disadvantage, plastic mulch with different colors will be useful to evaluate plant response to $T_s$ with very low cost relative to other methodologies such as infrared heat array (Kimball et al., 2008; Siebers et al., 2017; Rosenthal et al., 2014) and chambers surrounding the plants including open-top chamber (Moya et al., 1998; Hazra et al., 2019; Abebe et al., 2016; Palacios et al., 2019) and open-closed chamber (Hein et al., 2019; Lizana et al., 2017), and this will help to increase our knowledge about climate change effects on various plant species in the world including developing countries.

Conclusion

Our 2-year field trials showed that aboveground growth of sweet potato was significantly increased by higher $T_s$, and it was well expressed as a function of $T_s$. However, storage root yield was less affected by higher $T_s$ especially at early growth.

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