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Effects of Cover Methods and Nitrogen Levels on the Growth and Yield of Tomato

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Abstract

To study the effects of cover methods and nitrogen (N) levels on the growth and yield components of tomato Cv. Pear F1, field experiments with a 4x3 factorial design were conducted in the 2019 spring and winter seasons using a randomized complete block design with three replications. The cover methods included four treatments: bare soil (BS), black plastic mulch (BPM), transparent polypropylene row cover (RC), and a combination of BPM and RC (BPMRC) with the RC removed approximately 30 days after transplanting. Nitrogen (N) was applied at three levels (150, 180, and 210 kg N ha^{-1}). Using BPM and RC generally led to an increased air temperature, air humidity, soil moisture, and soil temperature compared to the BS treatment. Higher N rates (180 and 210 kg N ha^{-1}) did not result in different tomato fruit sizes and fruit weights but positively increased fruit yield and quality (Brix values and fruit dry weight) as compared to the 150 kg N ha^{-1} addition. The cover methods positively affected the yield components and fruit yield of tomato as well as the fruit characteristics compared to the BS treatment. Using cover materials (BPM and RC) combined with a higher N application significantly increased the yield attributes and fruit yield. The highest fruit yield was achieved under the mulching treatment by black plastic (BPM treatment) combined with a 210 kg N ha^{-1} application, resulting in 50.90 tons ha^{-1} in the spring and 58.27 tons ha^{-1} in the winter.

Keywords

Tomato yield, black plastic mulching, row cover, nitrogen levels

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Introduction

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important and popular vegetable crops grown commercially worldwide. Global tomato production in 2018 was about 182.3 million tons of fresh fruit from an estimated 4.76 million ha (FAO, 2018). In Vietnam, the planting area of tomato plants is on the rise due to its higher economic efficiency than other crops, however, the average yield is still very low (about 25.2 tons ha^{-1}) (Dao Xuan Canh, 2013) as compared to the world (34.1 tons ha^{-1}) (FAOSTAT, 2013). The main inhibition factor for tomato production is inadequate soil moisture, especially in the dry season, but mulching and covering technologies are common and effective practices to overcome this issue and improve crop production worldwide (Ogundare *et al*., 2015). Among all mulching materials, black plastic mulch (BPM) has been reported to be effective in increasing crop yield through improved topsoil temperature, which leads to better root growth, and promotes faster crop development during the early stages of plant growth (Diaz – Perez & Batal, 2002; Helaly *et al*., 2017). Furthermore, BPM can increase soil water use efficiency, mainly because of its ability to reduce soil evaporation, prevent capillarity, and reduce weed problems (Mehmood *et al.*, 2015; Wang *et al*., 2018a). Helaly *et al*. (2017) reported that mulching, especially BPM, reduced leaching of nutrients, so soil nutrient use efficiency was increased. Wang *et al.* (2018b) indicated that BPM generally increases the soil nitrogen (N) content by reducing N loss and significantly affects the N recovery efficiency and N use efficiency. In agriculture production, row cover (RC) has also been documented to effectively provide a favourable environment around the plant with higher air temperature, relative humidity, and soil temperature (Moreno *et al*., 2002; Hernandez *et al.*, 2004; Nair & Ngouajio, 2010; Muleke *et al.*, 2014), resulting in more rapid growth, earlier harvest, and increased crop yields in plants such as *Brassica rapa* subsp. pekinensis (Chinese cabbage) (Moreno *et al*., 2002; Hernandez *et al*., 2004; Kalisz *et al*., 2014), *Brassica campestris* L. (Pak–choi) (Okimura & Hanada, 1993), and *Cucumis sativus* (cucumber) (Nair & Ngouajio, 2010). Under the combination of RC with plastic mulch, greater growth rates as well as earlier – marketable – total yields of *Zea mays* L. (sweet corn) (Aguyoh *et al*.,1999) and *Cucurbita pepo* L. (summer squash) (Gordon *et al*., 2008) were reported in comparison with those grown in bare soil with or without RC.

On the other hand, tomato yields are highly responsive to the addition of N (Warner *et al*., 2004). Beyene & Mulu (2019) reported that N promotes vegetative growth and fruit yield, favours fruit development, and the application of the proper N level has a dramatic effect on tomato growth and development. Both the deficit and excess of N sources have negative impacts on plants: fruit production decreases, susceptibility to insect pests increases, and the nutritional quality of harvested products is reduced (Torres – Olivar *et al*., 2014). Previous studies have shown that increasing the N addition rate positively affects tomato growth and yield, and maximum fruit yield was reached under the higher N application rate from 100 to 160 kg N ha^{-1} (Aman & Rab, 2013; Etissa *et al.*, 2013; Rashid *et al*., 2016; Beyene & Mulu, 2019). However, the studies of Parisi *et al.* (2006) and Elia *et al.* (2007) indicated that a greater fruit yield and yield attributes were recorded by adding 200 kg N ha^{-1}, and further increases of N rates did not affect tomato yield. Over-use of N fertilization has been documented contributing to reduced N efficiency, causing considerable N leaching into groundwater and posing a danger to the environment, and is wasteful in terms of economic efficiency (Elia *et al*., 2007; Torres - Olivar *et al.*, 2014). According to Wang *et al.* (2018b), soil mulching in combination with N application has the best performance in promoting agricultural production. Therefore, the optimum N application rate in a plastic film cover system needs to be determined for high crop yield for crops such as tomato. Therefore, the aim of the study was to evaluate the effects of covering methods, including BPM and RC applications, and N rates on the growth, fruit yield, and quality of tomato in the open field.

Materials and Methods

Treatments and experimental design

The field experiments were conducted in the 2019 spring season (from February to May 2019) and winter season (from October 2019 to January 2020) at the experimental site of the Faculty of Agronomy, Vietnam National University of Agriculture, with the F1 Pear tomato variety (a determinate, heat-tolerant tomato variety with high resistance to bacterial wilt (*Pseudomonas* *solanacearum*), late blight (*Phytophthora infestans*), and tomato yellow leaf curl; fruits have a round shape, red flesh, and an average weight around 80-100g fruit^{-1}). The field was prepared by ploughing, harrowing, and creating 0.15-meter-high, 1.1-meter-wide, and 5.0-meter-long raised beds before planting. Twenty-five day old tomato seedlings were transplanted at a spacing of 60 x 45cm by making holes 5cm in diameter on the bare ground on February 10, 2019 in the spring season and on October 15, 2019 in the winter season.

The 4 x 3 factorial experiments were laid out in a randomized complete block design with three replications. The first factor was the cover method with four treatments: bare soil - BS, black plastic mulching - BPM, row cover - RC, and a combination of BPM with RC - BPMRC. For the BPM treatments, a layer of black polyethylene film was laid on the raised beds of the appropriate plots before transplanting. For the plots treated with the RC, four bamboo strips per plot were used to make a tunnel frame (1m wide, 1.2m high, and secured 0.2m into the ground) to support the nets over the plots. Then, a layer of colorless, transparent polypropylene film was placed over the tunnel frame immediately after planting and was removed approximately 30 DAT (**Figure 1**).

Data collection

The second factor was the nitrogen (N) fertilizer with three levels: 150 kg N ha^{-1}, 180 kg N ha^{-1}, and 210 kg ha^{-1}, which were applied during fertilization with 120 kg P_2O_5 + 150 kg K_2O. The chemical fertilizers used were urea (46% N), super phosphate (17% P_2O_5), and chloride potassium (60% K_2O). The pre-plant fertilizer was spread at the rate of 30% N + 100% P_2O_5 + 12% K_2O. The remaining amount of fertilizer (70% N + 88% K_2O) was applied at three different periods (5 DAT, at the flowering stage (25 DAT), and after the first harvest) in equal portions in both seasons.

During the experiment periods, hand weeding and furrow irrigation were used. Pests and diseases were frequently observed and controlled when they occurred. Diafen 500WP (20g per bottle of 16L of water) was applied to control beet army worms (*Spodoptera exigua*), silverleaf whiteflies (*Bemisia tabac*i), and cotton aphids *(aphis gossypii*), and Kempo 790 SC (35mL per bottle of 16L of water) was applied to control phytophthora blight (*Phytophthora infestans*). Other crop management practices were applied following the recommended cultivation practices for tomato in Vietnam (Vietnam National Agriculture Extension Center, 2012).

Indicators and measurement methods

Soil and air sampling and characteristics: Air temperature and humidity were measured outside and inside the RC at 5, 15, and 25 DAT at 14:00 (2 PM) using an air thermometer

(a) **(b)** **(c)**

Figure 1. Field images for the (a) treatments of BPM, (b) treatments of RC, and (c) treatments of BPMRC

placed in the middle of the raised beds at a height of 10cm above the soil surface (Waterer, 1993). Soil temperature and moisture were taken at 5 DAT, the flowering stage, and after the first harvest. Therein, soil temperature was recorded at 14:00 (2 PM) by a soil thermometer inserted to a 5cm depth (Kader *et al*., 2017), and soil moisture (%) was determined by the drying method in an oven at 80°C for 48 hours.

Growth and development characteristics: Five randomly selected plants in each plot were used to measure the growth indicators (plant height and leaf number) at the last harvest. To determine the fruit characteristics, ten fruit samples at the second cluster were collected randomly by hand at 99 DAT in each plot to measure fresh fruit weight, fruit height, fruit diameter, and fruit flesh number (according to QCVN 01 – 70: 2011/BNNPTNT). The Brix values were measured by a Brix meter ATAGO N – 1E (Japan, with Brix values from 0 to 32%). Then fruit samples were dried separately in an oven at 80°C for 48h to determine the fruit dry weight. Yield components and fruit yield were measured by summing the results of all the harvest times. Therein, fruit weight, number of fruits, and weight per plant were observed on five randomly selected plants in each plot, and fruit yield was measured by harvesting the fruits of all the plants in each plot.

Statistical analyses

Analysis of variance (ANOVA) was performed to determine the effects of the covering methods, nitrogen levels, and their interactions. The treatment means were subjected to pairwise comparisons with LSD values using Statistic software version 8.2. Differences were considered statistically significant at $P< 0.05$.

Results and Discussion

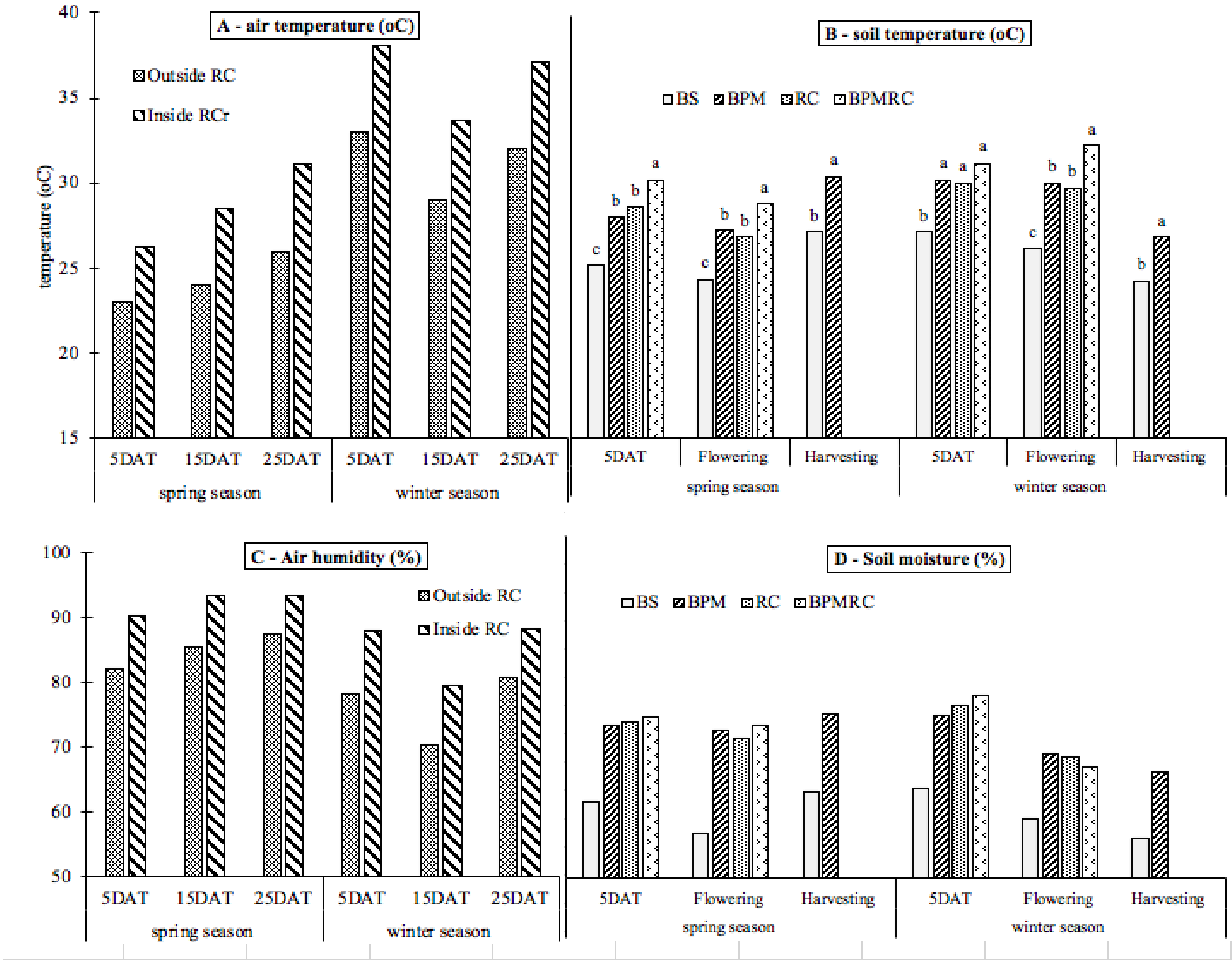
Characteristics of air and soil under cover treatments

In both the spring and winter seasons, there were similar trends of the air and soil characteristics under the effects of the BPM and RC. Air temperature and humidity tended to be higher under the addition of the RC (**Figures 2A** and **2C**). In the winter, at the early stage of tomato production, the thermal gap between the covered and uncovered micro-climates near the plant's canopy was greater because of higher outdoor air temperature as compared to those in the spring season. Using cover materials led to increased soil temperatures and soil moisture in comparison to the BS. Besides, the combination of BPM with RC resulted in higher soil temperatures than the plots treated by the BPM or RC only (**Figure 2B**). Higher soil moisture values were recorded under plots covered by the RC and BPM than in the non-covered BS plots (**Figure 2D**).

The changes of the micro-climate around the tomato plants under the effects of cover materials in our study reflected similar trends with the studies of Moreno *et al*. (2002) and Muleke *et al.* (2014) who reported that air temperature, relative humidity, and soil moisture content were higher in covered plots compared to uncovered treatments. The RC increased air temperature by reducing the mixing of outside air with inside air, and thus, reduced heat loss to the atmosphere (Moreno *et al*., 2002) and increased air humidity through reduced evapotranspiration and condensation of water within the RC under field conditions (Hernandez *et al.*, 2004; Nair & Ngouajio, 2010). Plastic mulching has been documented as being able to promote a net radiation at the soil surface and increase soil heat flux leading to increased soil temperatures in relation to the BS (Rajablariani *et al.*, 2012; Kader *et al.*, 2017). In addition, the plastic mulch prevented soil surface evaporation and also capillary flux from below the root zone leading to increased soil moisture (Kader *et al.* 2017). According to Ibarra-Jiménez *et al.* (2004), BPM absorbed 96% of short-wave radiation, which was held by the upper layer of the RC, causing the surrounding environment to heat, resulting in higher air and soil temperatures for plants grown on soil mulch plus RC than for soil mulch alone.

The effects of cover methods and nitrogen levels on plant growth of tomato

The results from **Table 1** show that using covering methods significantly affected the plant



Note: In Figure 2B, values followed by different letters within a measured stage (5 DAT, flowering, and harvesting) in different seasons (spring and winter) indicate significant differences at the 5% level.

Figure 2. Effects of cover methods on soil and air characteristics

height of tomato ($P < 0.05$), and therein, the highest plant height was observed in the plots treated with the RC and BPMRC in both seasons (126.98cm and 124.52cm in spring 2019, and 123.64cm and 123.90cm in winter 2019, respectively). In the spring season, although there was no difference in the number of leaves among tomatoes treated by the cover materials, only the RC treatment (17.91 leaves stem^{-1}) was significantly higher than the BS treatment for this indicator. In the winter season, no difference in the number of leaves was found between the covering treatments.

The role of the cover materials in promoting tomato plant growth recorded in this study was due to their abilities to warm the soil, conserve soil moisture, and reduce fertilizer leaching (Diaz – Perez & Batal, 2002; Ibarra-Jiménez *et al.*, 2004; Fan *et al.*, 2017; Helaly *et al.*, 2017). Soil mulching in combination with the RC resulted in improved soil moisture conservation and increased air and soil temperatures (**Figures 2A and 2B**), thus creating a favourable micro-climate surrounding the plants, resulting in the promoted growth of the vegetative organs and nutrient absorption ability of the plants, leading to faster crop growth under the covered plots by the two cover materials at the early plant growth stages.

On the other hand, higher N applications (180-210 kg N ha^{-1}) significantly increased the plant height in the spring season. Plant height in the winter season and the number of leaves in both seasons were not affected by N application.

Table 1. Effects of cover methods and N levels on tomato vegetative growth indicators

Treatments		Spring season		Winter season	
Cover methods	Nitrogen levels	Plant height (cm)	Number of leaves (leaves stem^{-1})	Plant height (cm)	Number of leaves (leaves stem^{-1})
BS	150 kg N ha^{-1}	114.10^{e}	16.80^{c}	118.22^{abcde}	16.45^{ab}
	180 kg N ha^{-1}	119.06^{de}	16.80^{c}	117.40^{bcde}	15.92^{abc}
	210 kg N ha^{-1}	118.25^{e}	18.00^{ab}	110.40^{e}	15.53^{bc}
BPM	150 kg N ha^{-1}	117.07^{e}	17.33^{bc}	112.88^{cde}	16.20^{abc}
	180 kg N ha^{-1}	119.83^{cde}	17.20^{bc}	119.05^{abcde}	16.33^{ab}
	210 kg N ha^{-1}	129.03^{ab}	17.33^{bc}	111.47^{de}	16.68^{ab}
RC	150 kg N ha^{-1}	124.27^{bcd}	17.33^{bc}	123.93^{ab}	16.47^{ab}
	180 kg N ha^{-1}	125.10^{bc}	17.93^{ab}	125.77^{ab}	16.53^{ab}
	210 kg N ha^{-1}	131.57^{a}	18.47^{a}	121.22^{abc}	14.93^{c}
BPMRC	150 kg N ha^{-1}	119.40^{cde}	17.50^{abc}	120.18^{abcd}	15.73^{abc}
	180 kg N ha^{-1}	124.43^{bcd}	18.13^{ab}	124.53^{ab}	16.32^{ab}
	210 kg N ha^{-1}	129.73^{ab}	17.27^{bc}	127.00^{a}	17.00^{a}
$LSD_{0.05}$		5.83	1.09	9.06	1.31
Mean	BS	117.14^{c}	17.20^{b}	115.34^{b}	15.97^{a}
	BPM	121.98^{b}	17.29^{ab}	114.47^{b}	16.41^{a}
	RC	126.98^{a}	17.91^{a}	123.64^{a}	15.98^{a}
	BPMRC	124.52^{ab}	17.63^{ab}	123.90^{a}	16.35^{a}
	$LSD_{0.05}$	3.37	0.63	5.23	0.75
	150 kg N ha^{-1}	118.71^{c}	17.24^{a}	118.80^{a}	16.21^{a}
	180 kg N ha^{-1}	122.11^{b}	17.52^{a}	121.69^{a}	16.28^{a}
	210 kg N ha^{-1}	127.15^{a}	17.77^{a}	117.52^{a}	16.04^{a}
	$LSD_{0.05}$	2.91	0.54	4.52	0.65

Note: Values followed by different letters within a column indicate significant differences at the 5% level.

The different observed results in the two seasons might be related to higher temperatures and light intensity at the final harvest in the spring season than those in the winter season. Etissa *et al.* (2013), Rashid *et al.* (2016), and Beyene & Mulu (2019) showed that with increasing N levels, tomato vegetative growth dramatically increased and reached the maximum values under applications of the highest N rate in their studies (150 kg N ha^{-1}). More specifically, Rashid et al. (2016) reported that N fertilizer increased the vegetative growth of plants and endogenous auxin, which promotes gibberellin activity and increased tomato plant growth.

The combination of cover methods and N rates dramatically affected the growth indicators in both seasons. In the spring season, all the covered treatments (BPM, RC, and BPMRC) combined with the higher N addition generally increased the vegetative growth of the tomato plants. In the winter season, the plants covered by the RC and BPMRC treated with additional N presented significantly higher plant heights than the other treatments, while the number of leaves showed greater values in the covered plants treated with higher N levels. The differences between the growth characteristics of the tomato plants in the two seasons might be related to the higher thermal gaps of soil and air between the covered and uncovered plots by the RC in winter than those in spring, which supported the important role of the RC in promoting plant growth. In addition, the cover materials use led to increased soil water conservation (**Figure 2),** which stimulated root growth and promoted a higher use efficiency of soil N. This is supported by the study of Wang *et al.* (2018b), who showed that the lowest N loss was observed in the treatment with plastic mulching and plastic mulching increased N uptake in the crop.

Effects of covering methods and nitrogen levels on fruit characteristics of tomato

As shown in **Table 2**, in both seasons, the use of cover materials combined with a higher N addition led to increased fruit heights and fruit diameters. In the spring, plants grown under the RC gave the highest fruit height and fruit diameter; however, these indicators achieved the maximum values under the BPM and BPMRC in the winter. The lowest fruit sizes were recorded in plants grown on BS in both seasons. In both seasons, plants grown on BS and under the RC were recorded with higher fruit flesh thicknesses than the other treatments. Higher N additions generally tended to increase fruit size, however, there were no statistical differences among N treatments.

The results from **Table 3** show that the highest Brix value (5.01%) was reached in the plants treated with 180 kg N ha^{-1}, which was on par with those treated with 210 kg N ha^{-1} (4.88%) in the spring. In the winter, the N rates resulted in non-significant differences of the Brix values. In terms of the covering methods, plants grown under the BPMRC treatment gave fruits with the highest Brix values in both seasons, with 5.09% in the spring and 4.39% in the winter. The interaction of cover methods and N level resulted in significantly different Brix values of the tomato fruits. In the spring, the Brix values generally tended to be higher in the fruits of plants covered by the RC and BPMRC treated with additional N. In the winter, within all the N treatments, higher Brix values were recorded in plants grown under the cover materials than those grown on BS.

Fruit dry weight in the spring dramatically increased in response to higher N rates and reached the highest value (4.35 g fruit^{-1}) under the addition of 210 kg N ha^{-1}. However, in the winter, this characteristic was highest under the 180 kg N ha^{-1} treatment (3.87 g fruit^{-1}). In terms of the cover methods, the highest fruit dry matter in the spring was recorded under the RC (4.18 g fruit^{-1}), which was on par with the BPMRC treatment. However, in the winter, the fluctuation of this indicator was not similar. The fruit dry weight values were significantly lower under the treatments of RC and BPMRC, and no difference was found between these two treatments. Fruit dry weight was found to be significantly different under the integrated effect of cover methods and N levels. In the spring, fruit dry weight was generally higher under higher N rates (180 and 210 kg N ha^{-1}) in all the cover treatments. In contrast, the highest fruit dry weight in the winter was recorded in the uncovered plants treated by 180 kg N ha^{-1} (4.22 g fruit^{-1}) and 210 kg N ha^{-1} (4.13 g fruit^{-1}).

The observed results are in line with the studies of Erdal *et al*. (2007), Kirimi *et al*. (2011), and Helaly *et al*. (2017). According to Kebede & Woldewahid (2014), fruit size is dependent on assimilate distribution, which is controlled by the activity of both source and sink. Higher N addition played a vital role in promoting plant growth, which was presented in the increases of plant height and number of leaves (**Table 1**), and consequently increased the chlorophyll content of the plants (Helaly *et al*., 2017). This resulted in higher dry matter accumulation partitioned in the tomato fruits, which was reflected in the increased Brix values and fruit dry weights. Low N levels led to a competition for the photosynthetic products between the vegetative and reproductive organs of the plants and between fruits, resulting in reductions of fruit size. Kirimi *et al*. (2011) reported that N availability affected the sink function of fruits and higher N rates were seen to be related to

Table 2. Effects of cover methods and N levels on tomato fruit characteristics

Treatments		Spring season			Winter season		
Cover methods	Nitrogen levels	Fruit height (cm)	Fruit diameter (cm)	Fruit flesh thickness (cm)	Fruit height (cm)	Fruit diameter (cm)	Fruit flesh thickness (cm)
BS	150 kg N ha^{-1}	4.28^{c}	4.60^{d}	0.62^{bcd}	4.18^{de}	4.17^{e}	0.79^{bcde}
	180 kg N ha^{-1}	4.60^{ab}	4.89^{bcd}	0.71^{a}	4.11^{e}	4.32^{de}	0.75^{ef}
	210 kg N ha^{-1}	4.71^{ab}	4.90^{bcd}	0.71^{a}	4.37^{cde}	4.57^{cd}	0.72^{f}
BPM	150 kg N ha^{-1}	4.82^{ab}	4.87^{bcd}	0.64^{abc}	4.74^{ab}	4.76^{abc}	0.84^{bc}
	180 kg N ha^{-1}	4.76^{ab}	4.83^{bcd}	0.57^{cde}	4.79^{a}	4.68^{bc}	0.79^{bcde}
	210 kg N ha^{-1}	4.54^{bc}	4.83^{bcd}	0.54d^{e}	4.81^{a}	5.00^{a}	0.86^{ab}
RC	150 kg N ha^{-1}	4.81^{ab}	5.11^{ab}	0.70^{a}	4.56^{abc}	4.64^{cd}	0.74^{ef}
	180 kg N ha^{-1}	4.73^{ab}	5.00^{abc}	0.59^{cd}	4.41^{bcde}	4.67^{c}	0.79^{bcde}
	210 kg N ha^{-1}	4.84^{a}	4.96^{abc}	0.62^{bcd}	4.42^{bcde}	4.62^{cd}	0.77^{def}
BPMRC	150 kg N ha^{-1}	4.87^{a}	4.88^{bcd}	0.49^{e}	4.55^{abc}	4.69^{abc}	0.82^{bcd}
	180 kg N ha^{-1}	4.74^{ab}	4.73^{cd}	0.69^{ab}	4.91^{a}	4.78^{abc}	0.86^{ab}
	210 kg N ha^{-1}	4.72^{ab}	5.26^{a}	0.61^{cd}	4.83^{a}	4.99^{ab}	0.91^{a}
$LSD_{0.05}$		0.30	0.33	0.08	0.37	0.32	0.07
Mean	BS	4.53^{b}	4.80^{b}	0.68^{a}	4.22^{c}	4.35^{b}	0.75^{a}
	BPM	4.71^{a}	4.84^{ab}	0.59^{bc}	4.78^{a}	4.81^{a}	0.83^{b}
	RC	4.80^{a}	5.02^{a}	0.64^{ab}	4.46^{b}	4.64^{a}	0.77^{a}
	BPMRC	4.78^{a}	4.96^{ab}	0.60^{c}	4.76^{a}	4.82^{a}	0.86^{b}
	$LSD_{0,05}$	0.17	0.19	0.04	0.21	0.18	0.04
	150 kg N ha^{-1}	4.69^{a}	4.86^{a}	0.61^{a}	4.51^{a}	4.57^{a}	0.80^{a}
	180 kg N ha^{-1}	4.71^{a}	4.86^{a}	0.64^{a}	4.55^{a}	4.61^{a}	0.80^{a}
	210 kg N ha^{-1}	4.71^{a}	4.99^{a}	0.62^{a}	4.61^{a}	4.80^{a}	0.81^{a}
	$LSD_{0,05}$	0.15	0.16	0.04	0.19	0.16	0.03

Note: Values followed by different letters within a column indicate significant differences at the 5% level.

increases in the number, size, and chemical components of tomato fruits, which are determined by carbohydrate accumulation in tomato fruits.

The positive effect of the BPM on improving tomato fruit size may be attributed to the benefits of plastic mulch on rapid vegetative growth, as well as in the higher water and nutrient use efficiencies, which lead to an increased sufficient assimilation area and subsequently, increased fruit size (Helaly *et al*., 2017). In terms of the RC, high air and soil temperature conditions under the RC at the early stages of plant growth (**Figure 2**) could have led to N loss by nitrification and volatilization into the atmosphere, resulting in the reduction of soil N, which was related to the reduced fruit size compared to BPM. It also explains the lower fruit dry weight under the RC and BPMRC treatments in the winter (**Table 2**) when the air temperature increased dramatically under the RC and higher thermal differences between outside and inside the RC at the early stages of tomato production in were recorded (**Figure 2**). In our study, the higher fruit size and quality of plants grown in soil covered by BPM and RC and higher N applications might be due to the possible increases of N efficiency and the N absorption capacity of plants as a result of better root development under the favourable soil micro-environment and increased translocation of carbohydrates from the source to the growing point (Wang *et al*., 2018b). Helaly *et al*. (2017)

Table 3. Effects of cover methods and N levels on tomato fruit quality

Treatments		Spring season			Winter season		
Cover methods	Nitrogen levels	Brix value (%)	Fruit dry weight (g fruit^{-1})	% of fruit dry weight	Brix value (%)	Fruit dry weight (g fruit^{-1})	% of fruit dry weight
BS	150 kg N ha^{-1}	4.94^{a}	3.24^{e}	4.65	4.18^{cde}	3.83^{abcd}	5.26
	180 kg N ha^{-1}	4.89^{a}	3.86^{cd}	4.92	4.10^{e}	4.22^{a}	5.16
	210 kg N ha^{-1}	5.16^{a}	4.28^{abc}	4.39	4.16^{de}	4.13^{a}	4.62
BPM	150 kg N ha^{-1}	4.17^{b}	3.31^{e}	4.67	4.30^{abcd}	3.66^{bcde}	4.67
	180 kg N ha^{-1}	4.80^{a}	3.96^{bcd}	5.12	4.35^{abc}	4.01^{ab}	4.50
	210 kg N ha^{-1}	4.31^{b}	4.48^{a}	4.85	4.25^{bcde}	3.93^{abc}	4.95
RC	150 kg N ha^{-1}	4.18^{b}	4.21^{abc}	5.31	4.13^{de}	3.62^{bcde}	5.04
	180 kg N ha^{-1}	5.18^{a}	3.96^{bcd}	4.34	4.38^{ab}	3.59^{cde}	4.64
	210 kg N ha^{-1}	4.97^{a}	4.37^{ab}	4.79	4.26^{bcde}	3.57^{cde}	4.57
BPMRC	150 kg N ha^{-1}	5.01^{a}	3.58^{de}	4.48	4.36^{abc}	3.44^{de}	4.00
	180 kg N ha^{-1}	5.19^{a}	4.53^{a}	5.01	4.46^{a}	3.67^{bcde}	4.79
	210 kg N ha^{-1}	5.07^{a}	4.27^{abc}	5.42	4.35^{abc}	3.30^{e}	4.74
$LSD_{0.05}$		0.44	0.46	-	0.18	0.42	-
Mean	BS	5.00^{ab}	3.79^{b}	4.65	4.15^{c}	4.06^{a}	5.02
	BPM	4.43^{c}	3.91^{ab}	4.88	4.30^{ab}	3.87^{a}	4.70
	RC	4.77^{b}	4.18^{a}	4.81	4.26^{b}	3.59^{b}	4.75
	BPMRC	5.09^{a}	4.12^{a}	4.97	4.39^{a}	3.47^{b}	4.51
	$LSD_{0.05}$	0.26	0.27	-	0.19	0.24	-
	150 kg N ha^{-1}	4.58^{b}	3.58^{c}	4.78	4.24^{a}	3.64^{b}	4.74
	180 kg N ha^{-1}	5.01^{a}	4.08^{b}	4.85	4.32^{a}	3.87^{a}	4.77
	210 kg N ha^{-1}	4.88^{a}	4.35^{a}	4.87	4.26^{a}	3.73^{ab}	4.72
	$LSD_{0.05}$	0.22	0.23	-	0.09	0.21	-

Note: Values followed by different letters within a column indicate significant differences at the 5% level.

also reported that more matter accumulation products partitioned in tomato fruits was reflected in higher fruit sizes, dry matter, and Brix values.

Effects of cover methods and N levels on yield contributes and fruit yield

No significant differences were found among the average fruit weights under the different N rates in both seasons **(Table 4)**. In the spring, number of fruits significantly increased under increased N rates from 150 to 180 kg N ha^{-1}, and then statistically decreased under further N increases. The highest fruit yield was observed under the 180 kg N ha^{-1} addition (45.23 tons ha^{-1}), which was not statistically different from the other N treatments. In the winter, the results showed that N additions beyond 180 kg N ha^{-1} did not lead to significantly increases in yield attributes and fruit yield of tomato. The highest number of fruits (33.62 fruits plant^{-1}) and fruit weight per plant (2.68 kg plant^{-1}) were recorded under the 210 kg N ha^{-1} application, which were similar to the 180 kg N ha^{-1} treatment. The highest fruit yield was observed under 180 kg N ha^{-1} with a value of 49.94 tons ha^{-1}.

The effects of the cover methods on the yield attributes were found to be significant. In the spring, the BPM and BPMRC treatments had significantly higher yield attributes compared to the other treatments. The highest yield was

Table 4. Effects of cover methods and nitrogen levels on tomato yield contributes and fruit yield

Treatments		Spring season				Winter season			
Cover methods	Nitrogen levels	Fruit weight (g fruit^{-1})	Number of fruits	Fruit weight per plant (kg plant^{-1})	Fruit yield (tons ha^{-1})	Fruit weight (g fruit^{-1})	Number of fruits	Fruit weight per plant (kg plant^{-1})	Fruit yield (tons ha^{-1})
BS	150 kg N ha^{-1}	79.30^{cd}	24.35^{c}	1.93^{d}	37.22^{de}	79.79^{bc}	25.93^{e}	2.07^{d}	43.75^{cde}
	180 kg N ha^{-1}	81.89^{abcd}	27.36^{bc}	2.24^{bcd}	42.27^{bcd}	71.96^{de}	29.62^{bcde}	2.13^{d}	48.62^{bcd}
	210 kg N ha^{-1}	77.51^{d}	25.55^{bc}	1.98^{cd}	42.64^{bcd}	68.39^{e}	34.86^{abc}	2.38^{bcd}	37.50^{e}
BPM	150 kg N ha^{-1}	79.99^{bcd}	28.6^{bc}	2.28a^{bcd}	43.40^{bc}	77.51^{cd}	28.33^{bcde}	2.20^{cd}	49.20^{bcd}
	180 kg N ha^{-1}	84.88^{ab}	31.44^{ab}	2.67^{ab}	41.13^{cd}	82.59^{abc}	33.60^{abcd}	2.77^{ab}	49.49^{abc}
	210 kg N ha^{-1}	86.72^{a}	28.37^{bc}	2.46^{abc}	50.90^{a}	81.87^{abc}	35.01^{ab}	2.85^{ab}	58.27^{a}
RC	150 kg N ha^{-1}	82.78^{abc}	26.59^{bc}	2.20^{bcd}	43.83^{bc}	80.07^{bc}	33.67^{abcd}	2.71^{abcd}	46.85^{cd}
	180 kg N ha^{-1}	79.34^{cd}	29.33^{abc}	2.33^{abcd}	50.2^{a}	86.02^{ab}	28.13^{cde}	2.42^{bcd}	44.68^{cde}
	210 kg N ha^{-1}	83.73^{abc}	28.55^{bc}	2.38^{abcd}	35.46^{e}	87.22^{a}	27.27^{de}	2.37^{bcd}	45.38^{cde}
BPMRC	150 kg N ha^{-1}	83.26^{abc}	28.21^{bc}	2.35^{abcd}	47.57^{ab}	80.32^{bc}	27.53^{de}	2.21^{d}	40.53^{de}
	180 kg N ha^{-1}	79.17^{cd}	34.88^{a}	2.76^{a}	47.33^{ab}	82.01^{abc}	37.77^{a}	3.09^{a}	56.98^{ab}
	210 kg N ha^{-1}	85.28^{a}	28.07^{bc}	2.39^{abcd}	49.5^{a}	83.02^{abc}	37.35^{a}	3.10^{a}	51.58^{abc}
$LSD_{0.05}$		5.09	6.04	6.04	4.31	6.43	6.82	0.53	8.90
Mean	BS	79.57^{b}	25.75^{b}	2.05^{b}	40.71^{c}	73.38^{c}	30.14^{b}	2.19^{b}	43.29^{c}
	BPM	83.87^{a}	29.47^{a}	2.47^{a}	45.14^{ab}	80.66^{b}	32.31^{ab}	2.61^{a}	52.32^{a}
	RC	81.95^{ab}	28.16^{ab}	2.3^{ab}	43.17^{bc}	84.44^{a}	29.69^{b}	2.50^{a}	45.64^{bc}
	BPMRC	82.57^{a}	30.39^{a}	2.5^{a}	48.13^{a}	81.78^{ab}	34.22^{a}	2.80^{a}	49.70^{ab}
	$LSD_{0.05}$	2.94	3.48	0.29	2.49	3.71	3.94	0.31	5.14
	150 kg N ha^{-1}	81.34^{a}	26.94^{b}	2.19^{b}	43,00^{a}	79.42^{a}	28.87^{b}	2.30^{b}	45.08^{b}
	180 kg N ha^{-1}	81.32^{a}	30.75^{a}	2.50^{ab}	45.23^{a}	80.64^{a}	32.28^{a}	2.60^{a}	49.94^{a}
	210 kg N ha^{-1}	83.31^{a}	27.63^{b}	2.30^{a}	44.63^{a}	80.13^{a}	33.62^{a}	2.68^{a}	48.18^{ab}
	$LSD_{0.05}$	2.54	3.02	0.25	2.15	3.21	3.41	0.27	4.45

Note: Values followed by different letters within a column indicate significant differences at the 5% level.

observed in the BPMRC treatment (48.13 tons ha^{-1}), followed by the BPM treatment (45.14 tons ha^{-1}). In the winter season, the plants grown in the uncovered plots were recorded with the lowest yield parameters and yield. Therein, there was no difference among the three cover methods in fruit weight per plant, but the values were significantly higher than in the BS treatment. The maximum fruit yield was reached in the BPM covered plots with the value of 52.32 tons ha^{-1}.

The interaction between the N levels and cover methods dramatically affected the tomato yield attributes and fruit yield. Generally, within the N treatments, higher yield attributes were observed in the covered plots in both seasons. In the spring, a higher N addition (180-210 kg N ha^{-1}) in the covered plots led to significant increases in fruit yield as compared to the other treatments, and the highest fruit yield was recorded in the treatment of BPM + 210 kg N ha^{-1} (50.9 tons ha^{-1}), which was on par with the treatments of RC + 180 kg N ha^{-1} and BPMRC + 210 kg N ha^{-1}. In the winter, the addition of 180 and 210 kg N ha^{-1} to the BPMRC plots resulted in significantly higher values for the number of fruits and fruit weight per plant than those in the other treatments. The combination of BPM with a 210 kg N ha^{-1} application gave the highest fruit yield of 58.27 tons ha^{-1}.

Kirimi *et al.* (2011) and Rashid *et al.* (2016) suggested that high N levels were able to set many fruits per plant but resulted in smaller fruits. In our study, higher N fertilizer led to significant increases in the number of fruits but did not result in fruit weight increases. Non-statistical differences of fruit weights under higher N rates could be due to the vigorous plant growth, which caused the plants to transport photosynthetic products to the vegetative parts of the plants instead of the tomato fruits. Besides, minerals and carbohydrates should be partitioned for a larger number of fruits per plant, which also results in reduced fruit weights (Kirimi *et al.*, 2011). In terms of fruit yields, the 210 kg N ha^{-1} addition did not statistically increase the fruit weight per plant and fruit yield compared to the 180 kg N ha^{-1} application in both seasons. These results are in agreement with the study of Elia *et al.* (2007), who showed that the fresh mass and total fruit yield significantly rose when N rates increased from 0 to 200 kg N ha^{-1}, while further increases of the N rate resulted in a decreasing trend.

The role of plastic mulch in crop yield increases has been supported before. Filipovíc *et al*. (2016) and Wang *et al.* (2018a) reported that crop yields with plastic mulch (PM) were higher because of the higher solar radiation and soil temperatures during the early growth stages and the slightly higher water use efficiency of the soil under the mulch, which maintained a root-zone temperature closer to the optimum for longer periods of time compared to BS. Filipovíc *et al.* (2016) indicated that the highest soil temperature was observed when the soil was covered with BPM, which could increase the near-surface soil temperature by up to 6°C and provided other benefits for crop growth during the growing season. Besides, mulches were able to maintain soil moisture, reduce soil water loss, and improve soil water storage mainly because of their ability to reduce soil evaporation, control weeds, and reduce nutrient leaching (Fan *et al*., 2017; Wang *et al*., 2018a; Wang *et al*., 2019; Tarara, 2000). These led to improved root growth and nutrient absorption capacity, which are associated with higher yields and greater biomass of tomato.

In the current study, the BPM alone or with the RC significantly increased the yield attributes and fruit yield under all of the N fertilizer rates tested in this study. These results are in line with the study of Wang *et al.* (2018a). In addition, it was found that the presence of the RC did not statistically increase fruit yield compared to the BS treatment in both seasons. This may be related to the N source (urea) used in this experiment. According to Kirimi *et al.* (2011), urea can easily cause excessive N losses particularly under conditions of high soil pH, high temperature, and excessive soil drying and wetting. In our study, under the RC covered plots, high temperatures at the early growth stages after transplanting (**Figures 2A, 2B**) could have led to N loss, which further led to reduced numbers of fruits per plant and fruit weight. However, the BPM was able to reduce N loss into the environment due to the reduction of N volatilization and denitrification (Tarara, 2000), so the BPM increased N use efficiency, and led to a higher soil N content and N recovery efficiency (Wang *et al.,* 2018b). Under these conditions, tomato roots could be stimulated and recover N more efficiently from the BPM than in the BS. This could be the reason for the observed increases of tomato yield attributes and fruit yield in the plots treated with a higher N application and using BPM with or without the RC.

Conclusions

Soil covering by BPM and RC led to increases in the air temperature and humidity, soil temperature, and moisture in the micro-climate surrounding the plant canopy, and therein, the combination of BPM with RC resulted in higher values of soil and air characteristics. The cover methods interacting with the higher N application led to significantly increased plant heights and number of leaves per main stem. Using cover materials (BPM, RC) alone or in combination dramatically increased the fruit size, fruit quality (Brix value), yield components, and fruit yield compared to the uncovered plots. There were no statistical differences in fruit size and weight under the different N levels, however higher N led to improved tomato yield attributes and fruit yield. The combination of cover methods and N rate led to significantly different yield components and fruit yield of tomato. Plots mulched by BPM combined with a 210 kg N ha^{-1} addition gave the maximum fruit yields with 50.9 tons ha^{-1} in the spring and 58.3 tons ha^{-1} in the winter.

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