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Canopy Achitecture, Biomass and Fruit Production of *Solanum nigrum* L. as Determined by Nitrogen Application

Edi Santosa[1*], Marcella Putriantari[1], Hajime Nakano[2], Yoko Mine[2], and Nobuo Sugiyama[2]

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ABSTRACT

Demand on fruits of *Leunca* (*Solanum nigrum* L.) is increasing in Indonesia due to a rapid expansion of ethnic restaurants, especially Sundanese restaurants. Most fruits come from semi-intensive cultivation in intercropping system, leading to low productivity. In order to improve productivity, nitrogen experiment was carried out at field of Leuwikopo Farm of Bogor Agricultural University, Bogor-Indonesia, during rainy season from December 2013 to April 2014. Four levels of nitrogen, i.e., 0, 60, 120, and 180 kg N ha^{-1}, were arranged in a randomized complete block design with four replicates. The results revealed that canopy architecture, dry matter and fruit production, and fruit quality were highly affected by nitrogen application. Increasing nitrogen levels increased biomass and fruit production. Plants treated with nitrogen at level of 60 kg ha^{-1} produced ideal height for local labor and stable weekly fruit production than other levels. Hence, N fertilizer is essential for achieving high productivity of *S. nigrum*.

Keywords: canopy shape, fruit load, indigenous vegetable, leunca, ranti kebo

ABSTRAK

Permintaan buah Leunca (<u>Solanum</u> <u>nigrum</u> L.) terus meningkat di Indonesia sejalan dengan perkembangan restoran etnis khususnya restoran Sunda. Sebagian besar buah leunca berasal dari tanaman sampingan secara tumpangsari, sehingga produktivitas rendah. Dalam rangka meningkatkan produktivitas, percobaan pemberian nitrogen dilakukan di Kebun Percobaan Leuwikopo IPB, Bogor pada musim hujan Desember 2013 sampai April 2014. Nitrogen diberikan empat taraf yaitu 0, 60, 120, dan 180 kg N ha^{-1}, yang disusun dalam rancangan acak kelompok dengan empat ulangan. Hasil menunjukkan bahwa bentuk kanopi, produksi bahan kering dan produksi buah serta kualitas buah dipengaruhi oleh pemberian nitrogen. Peningkatan dosis nitrogen meningkatkan bahan kering dan produksi buah. Tanaman dengan perlakuan 60 kg N ha^{-1} menghasilkan tinggi yang ideal bagi pemanen, dan hasil mingguan yang stabil dibandingkan dengan taraf yang lebih besar. Oleh karena itu, pemupukan nitrogen penting dilakukan untuk meningkatkan produktivitas leunca.

Kata kunci: beban buah, bentuk kanopi, leunca, ranti kebo, sayuran tradisional

INTRODUCTION

Black nightshade (*Solanum nigrum* L) in Indonesia is called *leunca* in Sundanese or *ranti kebo* in Javanese. It grows in fields and homegardens, in intercropping system (Santosa *et al*., 2015). Traditionally, the green mature fruits are consumed locally by Sundanese (Santosa *et al*., 2015) and the leaves are locally consumed as leafy vegetables by Javanese, like in African countries (Ondieki *et al*., 2011; Gokavi *et al*., 2014). With the growing of Sundanese restaurant, demand for fruit is increasing (Santosa *et al*., 2015). There have been many studies on medicinal and functional properties of fruits and leaves of *S. nigrum* and its relatives including glycoalcaloids, glycoproteins, polyphenol compounds and polysaccharides (Ravi *et al*., 2009; Karmakar

[1]Faculty of Agriculture, Bogor Agricultural University, Jl. Meranti Kampus IPB Darmaga, Bogor 16680, Indonesia
[2]Faculty of Agriculture, Tokyo University of Agriculture, Funako, Atsugi, Kanagawa 243-0034, Japan
Emai: edisang@gmail.com (*Corresponding author)

et al., 2010; Mohy-ud-din *et al.*, 2010; Jain *et al.*, 2011; Sudhanshu, 2012; Gogoi and Islam, 2012). However, there was few studies on the management for high fruits yield in *S. nigrum* in Indonesia.

S. nigrum belongs to the group of *Solanum nigrum* complex that spreads throughout tropical and temperate regions up to an elevation of 3 048 m (Edmonds and Chweya, 1997). Edmonds and Chweya (1997) describes *S. nigrum* is an annual plant growing to a height of 70 cm; flowers are medium, corolla stellate and white in a sub-umbellate inflorescence; 5-20 flowered cymes, fruiting pedicels reflexed or erecto-patent; fruit is a ovoid-globose 6-10 mm in diameter, and purplish-black dull at maturity.

Here, canopy architecture, biomass and fruit production of *S. nigrum* from different nitogren level are evaluated. N level has been known to determine plant architecture of Solanaceae family members (Etissa *et al*., 2013; Bvenura and Afolayan, 2014; Gokavi *et al*., 2014; Putriantari and Santosa, 2014). Plant architecture is important because it determines crop production (Ravi *et al*., 2013) and management (Sarlikioti *et al*., 2011; Degri, 2014) especially on weed control and easiness to harvest. Hence, the objective of this research was to determine the effect of nitrogen application on plant architecture, biomass and fruit production of *S. nigrum* in order to improve production in intercropping system.

MATERIAL AND METHODS

A field experiment was conducted at Leuwikopo Farm, Bogor Agricultural University, Bogor, Indonesia, during rainy season from December 2013 to April 2014 (21−30 rainy days per month) using soil of latosol Darmaga type. Daily rainfall ranged from 0.2–103.3 mm, temperature 24.6−33.5 ^{0}C, and relative air humidity 79−89%. Dolomite ($CaCO_3$) at a rate of 1 t ha^{-1} was incorporated during land preparation (2 weeks before planting). Soil after dolomite application had pH (H_2O) 4.5 with 0.95% organic carbon (Walkley and Black), 0.10% total N (Kjeldahl), 5.6 ppm P (Bray I), 15.2 and 3.2 me kg^{-1} exchangeable Ca and K, and 26.1% base saturation, 1.93 ppm Fe, 2.88 ppm Cu, 4.67 ppm Zn, and 56.63 ppm Mn. Goat manure (pH 7.6, 0.12% total N, 60.9 ppm P, and 23.8 me kg^{-1} K) at a rate of 10 t ha^{-1} was applied approximately 0.6 kg per plant at one week before planting.

Seeds of *S. nigrum* were collected in November 2013 and sowed immediately in a green house. On December 17, 2013 (5 weeks after sowing), they were transplanted into field. Non-surviving plants were replaced by supplementary seedlings within a week after planting.

Four levels of nitrogen (N) were applied, i.e., 0, 60, 120 and 180 kg N ha^{-1}. Plots were arranged by a randomized complete block design with four replications. Cultivation and sampling methods followed Putriantari and Santosa (2014). Briefly, plants were arranged at double rows at a distance of 50 cm × 70 cm on planting bed that suit 20 plants. Seedling height was 15±2 cm. One third and two third of the total amount of N were applied by side-dressing one and six weeks after transplanting (WAP), respectively. Together with first N application, phosphorus (P_2O_5) and potassium (K_2O) fertilizers were applied at a rate of 120 kg ha^{-1} each. Ten plants were randomly selected for measurement in each experimental unit. Plants were protected using insecticides profenofos (Curacron®) and propineb (Antracol®). Irrigation water was applied if rainfall for three consecutive days less than 2 mm.

Plant height was grouped into short (< 100 cm), medium (100–135 cm) and high (>135 cm) for easiness of harvest based on average height of woman worker. Canopy shape was evaluated by dividing canopy width to it height, i.e., columnar (ratio < 0.5), oval-globe (0.5–1.0), broadly-round (1.1–1.5), and spreading (> 1.5), number of flower reaching anthesis, number of inflorescences and inflorescences with fruits proper stage of harvest were measured weekly. Destructive sampling of extra three plants was carried out at 6 WAP (before second N application) and 12 WAP. Plant parts were separated and oven-dried to constant mass at 80 ^{0}C for 3 days. Fruits were classified into small (< 3 mm), medium (3–7 mm) and large (>7 mm). Data were analyzed by ANOVA. Duncan's Multiple Range Test (DMRT) was conducted to detect significant differences between treatments.

RESULTS AND DISCUSSIONS

Plant Architechture

Nitrogen application significantly increased plant height (Figure 1). Plant height of 100–135 cm was desirable because it was easy to harvest. Thus, N application at rate 60 and 120 kg ha^{-1} produced the ideal plant height in present experiment. Application of N larger than 120 kg ha^{-1}, increased number of plant with ideal height by about 11% than control. Ondieki *et al*. (2011) has stated that plant height of *S. americanum* increases by 48% with compost application at level of 8 ton ha^{-1}; and Gokavi *et al*. (2014) stated that NPK at a rate of 125:75:75 kg ha^{-1} to *S. nigrum* increased plant height as compared to without fertilizer.

Plants received 180 kg N ha^{-1} significantly produced wider canopy and higher leaf area index (LAI) (Table 1). However, many branches bent downward due to high fruit load of plants received high N level, resulted in variation on plant heigt as shown in Figure 1.

Level of N determined canopy shape (Table 1). In absence of supplement N fertilizer, canopy shaped globe. The canopy expanded into broadly-round at 60 kg N ha^{-1}, and spreading at 120 kg N ha^{-1} or more. It was likely that changing in canopy shape was due to increasing in canopy width. Consequently, wider plant spacing should be adopted when high N fertilizer was applied. According to Jiang *et al*. (2013), root formation is important in determining planting distance. In present study, total root length was 379.9 cm, 978.2 cm, 1024.8 cm and 1198.3 cm from plants treated with 0, 60, 120 and 180 kg N ha^{-1}, respectively. Putriantari and Santosa (2014) have noted that maximum individual root length in *S. americanum* is 66–71 cm, irrespective of N application.

Increasing canopy width for plant receiving N application could be explained by increasing number of node, increasing internode length, and increasing branch number. Morphologically, *S. nigrum* plant produced single primary stem; followed by 1–2 secondary branches, and many tertiary and quarterly branches types dependent on N level. Primary stem had of 12–13 internodes, irrespective of N levels. In the present study, secondary branch located on top of primary stem was considered; but the branches grew along primary stem, i.e., 0–2 on control and 10–11 on N treated plants, were excluded from analysis because they are commonly removed by farmers. Plants with supplement N produced two secondary branches on top of primary stem, and 80% plants of control produced the same amount. The rest of no N plants produced single secondary branch.

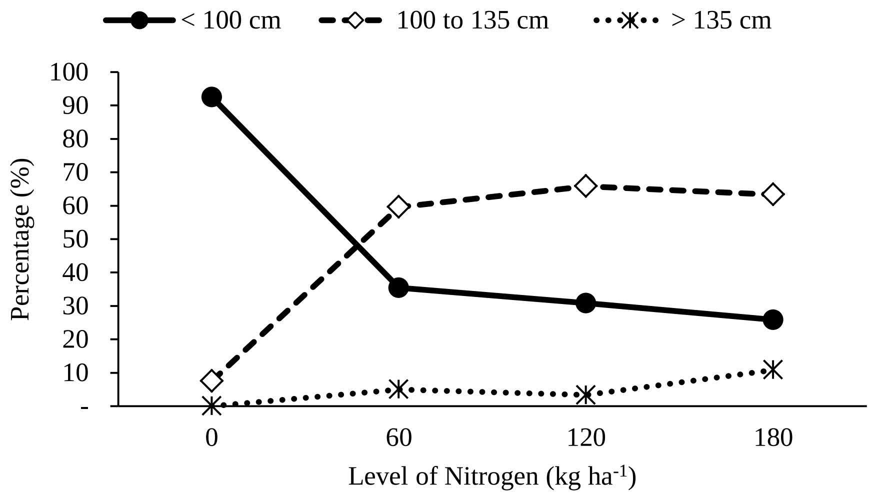


Figure 1. Percentage of *S. nigrum* plant based on height group from different N levels. Height was grouped as short (<100 mm), medium (100 to 135 cm) and tall (>135 cm).

Table 1. Leaf area index (LAI), ratio and width of canopy, total shoot length and longest branch of *S. nigrum* cultivated with different N levels

N level (kg ha^{-1})	LAI^x	Canopy Shape^x	Canopy Width (cm) $^{x, y}$	Total Shoot Length (cm) ^{z,}*	Number of Internode*
0	0.92 d	1.00 d	93.0 c	753.3 d	268.5 d
60	1.76 c	1.34 c	147.8 b	1314.9 c	456.1 c
120	2.91 b	1.59 b	177.3 ab	1675.6 b	524.1 b
180	3.29 a	1.96 a	221.5 a	2182.0 a	744.6 a

Values in each column followed by different letters are significantly different by DMRT at the 5% levels; ^{x} at 12 WAP; ^{y}Horizontal distant from the tip of a branch to the tip of opposite branch; .^{z}Lateral branch longer than 20 mm were counted; * at 16 WAP.

Every branches grew out from axillary buds that were formed at nodes. Extension growth of secondary, tertiary and quarterly branches were marked by increasing N levels. For example, the longest secondary branches in plants treated with 0, 60, 120 and 180 kg N ha^{-1} were 51.3, 83.8, 92.8 and 121.3 cm at 12 WAP, respectively. Most plants treated with 120 kg N ha^{-1} or lower produced single branch on each node; and 180 kg N ha^{-1} plants had two or more branches on each node. As a result, total shoot length control plants was about one third of those in plants received 180 kg N ha^{-1} (Table 1).

Table 1 indicated that number of internode increased by 69.9% and 177.3% of plants at N level of 60 and 180 kg N ha^{-1}, respectively relative to control. Maximum internode length, irrespective on the type of branch, was 14–18 cm in plants received 60 kg N ha^{-1} or higher, and 10–12 cm in control plants at 12 WAP. Increasing number of branch and internode length on *S. nigrum* by increasing level of nutrient have been studied (Ondieki *et al*., 2011; Nyagari *et al*., 2016).

Dry Matter Production and Its Partitioning

Dry mass production was affected by N level (Table 2), in line with finding by Opiyo (2004). Fruit load as represented by the ratio dry mass of fruit to leaf was the highest in plants of 0 kg N ha^{-1} at 6 WAP, and 60 kg N ha^{-1} at 12 WAP. A decrease in this ratio in control plants at 12 WAP suggests that fruit production in *S. nigrum* was not solely dependent on N availability. In 180 kg N ha^{-1} application, on the other hand, plants allocated more assimilate to develop leaves and stem, irrespective plant age (Table 2).

The ratio of root dry mass to total dry mass was almost the same among treatments at 6 WAP, but it decreased in plants received 180 kg N ha^{-1} at 12 WAP. It appears that plant tended to translocate more dry mass into roots as compared to above-ground parts when N availability was insufficient; inline with result of Bvenura and Afolayan (2014).

Inflorescence and Fruit Production

An inflorescence emerged from the middle of internode; thus number of inflorescences was determined by number of node. Two distinct peaks of flowering and fruit set were observed on weekly basis (Figure 2). The second peaks were higher on the number of flowering than the first peaks in all treatments. Regardless of N level, the number of flowers decreased in 8 WAP and 9 WAP at which time the amount of rainfall was decreased, i.e., 116.7 mm and 8.2 mm per week, respectively (Figure 2A). On the other hand, the number of fruits decreased sharply in 11 WAP or two weeks after the driest week (Figure 2B). Thus, the effect of rainfall on *S. nigrum* flowering was likely within a week while its effect on fruiting was apparent two weeks later. Although supplemental irrigation was regularly applied, the amount of water was unlikely to be adequate due to high transpirasion rates.

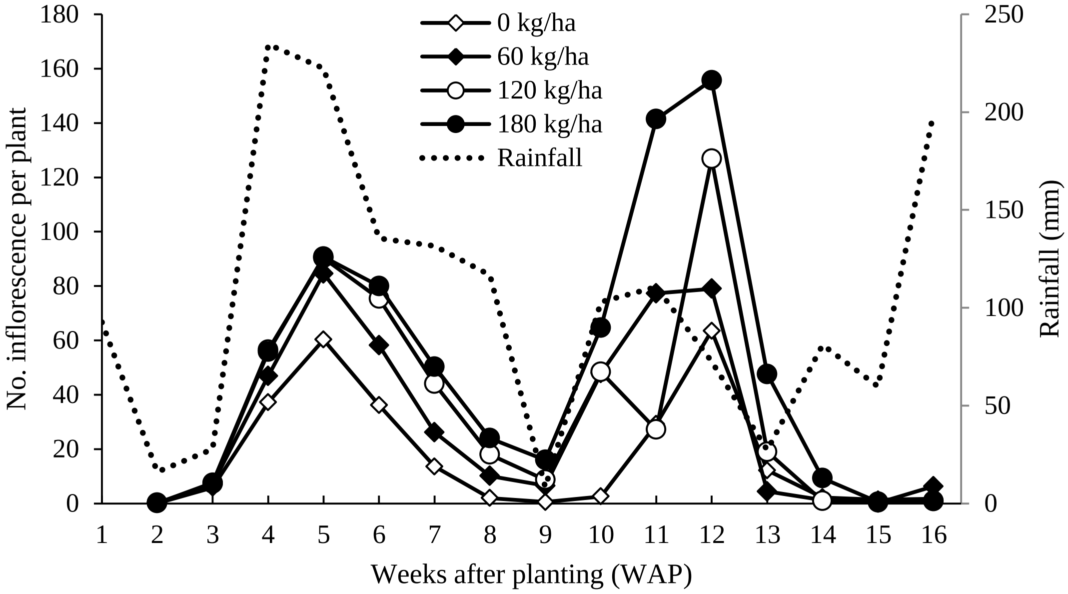
Table 2. Dry mass (DM) plant parts and its ratio of *S. nigrum* cultivated under different N levels at 6 and 12 WAP

Plant Part	Level of Nitrogen			
	0 kg N	60 kg N	120 kg N	180 kg N
	................................6 WAP................................			
Leaves DM (g)	5.10 c	9.91 b	12.20 b	17.76 a
Roots DM (g)	2.71 c	5.82 b	7.58 ab	8.07 a
Shoots and branches DM (g)[y]	8.15 c	19.53 b	22.36 b	30.21 a
Flower DM (g)	0.33 d	0.52 c	0.77 b	0.91 a
Fruits (all size) DM (g)	2.91 b	3.85 a	4.37 a	5.21 a
Ratio Fruit DM to leaf DM (gg^{-1})	0.57 a	0.39 b	0.36 b	0.29 c
Ratio Root DM to total DM (gg^{-1})	0.16 b	0.17 b	0.19 b	0.15 b
Ratio Fruit DM to total DM (gg^{-1})	0.15 a	0.10 b	0.09 b	0.08 b
	...............................12 WAP...............................			
Leaves DM (g)	1.43 c	4.27 bc	8.29 ab	14.57 a
Roots DM (g)	4.23 b	10.35 a	11.87 a	13.28 a
Shoots and branches DM (g)[y]	18.84 c	41.07 b	55.47 ab	71.16 a
Flower DM (g)	0.30 c	0.86 b	2.02 a	2.35 a
Fruits (all size) DM (g)	0.20 b	4.43 a	3.81 a	5.28 a
Ratio Fruit DM to leaf DM (gg^{-1})	0.14 c	0.61 a	0.46 b	0.36 b
Ratio Root DM to total DM (gg^{-1})	0.20 a	0.19 a	0.17 ab	0.14 b
Ratio Fruit DM to total DM (gg^{-1})	0.01 b	0.07 a	0.05 a	0.05 a

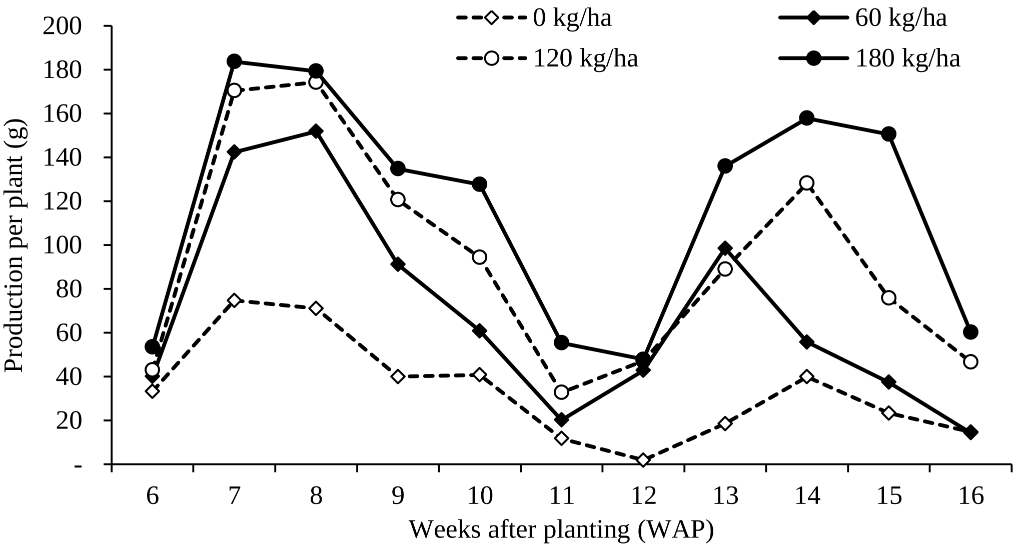
Values in each row at the same plant part followed by different letters are statistically different by DMRT at the 5% levels. [y]Petioles, pedicel and calyces were incorporated to shoot and branches dry mass calculation.

During a period with much precipitation, i.e., 4–6 WAP (Figure 2A), 36.2–90.8 inflorescences reached anthesis in a plant on average. The number of inflorescences reaching anthesis gradually decreased, and attained minimum values 9 WAP. Thereafter, it increased gradually to return the values of 4 WAP. The periods between February 11 and 21, and between March 9 and 16, 2014 were the driest periods with no adequate consecutive rainfall (0−2.5 mm per day). Some plants received 120 and 180 kg N ha^{-1} wilted at midday, but recovered in the afternoon by irrigation. Due to more frequent wilting at 14 WAP and later, the number of flowers decreased to nearly zero in plants treated with 120 and 180 kg N ha^{-1} (Figure 2). N application decreased the ratio of root dry mass to total dry mass (Table 2), leading to the imbalance between transpiration and water absorption. This suggests that an adequate irrigation is needed along with N application for achieving high productivity.

The number of fruits set per plant per week significantly increased with the increase in plant age and N levels (Figure 2B). The number of flowers on an inflorescence ranged from 4−13, irrespective of N levels. However, the percentage of inflorescences with 4 flowers or more increased by N application. Since flower drop was rare, it was likely that the number of fruits on each inflorescence was determined by the number of flowers. In general, N application at rate 60−180 kg N ha^{-1} increased the number of fruits by 169−235% at 6 WAP, and 1824−2194% at 12 WAP as compared with control. Since plants produced flowers and fruits continuously, plant carried flowers and fruits with different age or size at a time. Therefore, farmers harvested the fruits once or twice a week.



(A)



(B)

Figure 2. Weekly number of inflorescence reaching anthesis (A) and fruit production (B) of *S. nigrum* as affected by different N levels.

Fruit Quality

Small-, medium- and large-sized fruits mixed in the harvest because the fruits were harvested on the basis of an inflorescence. Consumers like medium and large-sized fruits at dark green stage. Fruits at black stage was allowable less than 10%, because the black fruit was considered as over-matured by consumers. The percentage of black fruits at harvest of 10 WAP were 49.9% in plants treated with 0 N kg ha^{-1}, while 30.3–36.5% in other N levels. Nevertheless, number of over-matured fruits was unlikely affected by N levels in other harvesting times. Thus, harvesting time and N level are important on the fruit quality.

Table 3. The number and fresh mass of fruits according to fruit size of *S. nigrum* plants cultivated under different N levels harvested at 6 and 12 weeks after planting (WAP)

N Level ($kg\ ha^{-1}$)	Small (< 3 mm)		Medium (3–7 mm)		Large (> 7 mm)	
	6 WAP	12 WAP	6 WAP	12 WAP	6 WAP	12 WAP
	...Number of Fruits^{y}...					
0	54.3 b	9.8 b	39.3 a	5.0 b	51.8 a	2.8 b
60	142.5 a	197.5 a	47.3 a	69.0 a	55.3 a	56.8 a
120	153.0 a	177.0 a	70.8 a	96.8 a	43.0 a	45.5 a
180	185.8 a	212.5 a	89.3 a	109.3 a	67.0 a	62.3 a
	...Fresh Mass Index of 100 Fruits (g)...					
0	2.5 a	3.5 a	9.9 b	16.1 a	56.2 a	40.0 b
60	4.4 a	3.6 a	20.9 ab	15.7 a	58.7 a	50.5 ab
120	4.3 a	3.0 a	27.3 a	14.0 a	68.8 a	63.1 a
180	3.8 a	3.9 a	17.7 ab	16.0 a	60.2 a	54.4 ab

Value in each column followed by different letters are significantly different by DMRT at the 5% levels; ^{y}Fruits were categorized based on diameter.

Distribution pattern of fruit size and weight in each harvesting time were affected by N application (Table 3). In harvest of control plants without N application, the percentages of small-, medium- and large-sized fruits at 6 WAP were almost the same, i.e., 37, 27 and 36% of total fruit, respectively. N application increased the percentage of small fruits; the percentage of small fruits was 54–55% of total fruits harvested at same date from 180 kg N ha^{-1}. In this experiment, the fruits became mature within less than a week after they attained full size. It implied that at high N fertilizer, more frequent harvesting should be considered.

N application at rate 120 kg ha^{-1} increased fresh masses index of the 100 fruits of medium-sized at 6 WAP, and the index of large-sized fruits at 12 WAP (Table 3). Table 3 showed increasing number of fruit in N treated plant at 12 WAP. It indicated that the yield-increasing effect of N application in Figure 2B was due to fruit number-increasing effect.

Fruit cracking was observed in irrespective N treatment (Figure 3); it ranged from 0–5 fruits per plant for each harvesting week. Incidence of fruit cracking was initially detected as brown ring or spot around pedicels (Figure 3A). The phenomenon was unlikely due to Ca defficiency because Ca level in the soil was adequate. Rapid expansion of fruit after rainfall was considered to expand the opening at the ring or spots, leading to cracking (Figure 3B). Thus, the fruit cracking could relate to high water availability in the soil after severe drought; although Capel *et al.* (2017) stated that fruit cracking in tomato due to genetic factor.

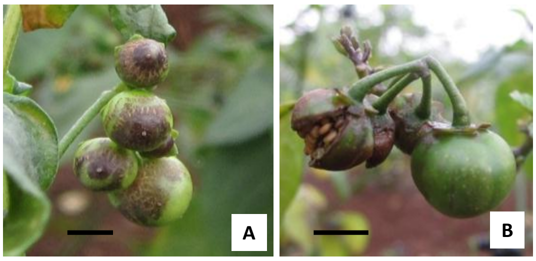


Figure 3. Brown spot (A) and fruits cracking (B) in fruits of *S. nigrum*. Bar ± 5 mm.

CONCLUSION

Application of nitrogen significantly determined canopy architecture, dry matter and fruit production, and fruit quality of *S. nigrum*. At least the amount of nitrogen fertilizer at rate 60 kg N ha^{-1} should be applied to increase fruit yield of *S. nigrum* and to maintain efficiency on labor force for harvesting.

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