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Effect of varying nitrogen levels on plant sap characteristics and growth performance of tomato (*Lycopercisum esculentum* var. baccarat)

[Kesan perbezaan tahap nitrogen terhadap ciri-ciri sap dan prestasi pertumbuhan pokok tomato (*Lycopercisum esculentum* var. baccarat)]

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Keywords: nitrate concentration, potassium concentration, biomass production, optimum yield

Abstract

Three plant parts (leaf petiole, leaf lamina and side shoot) were analysed at different ages to determine the concentration of nitrate and potassium produced in sap of tomato plants subjected to five different levels of nitrogen (100, 130, 160, 190 and 220 ppm). The experiment was arranged in a randomized complete block design with three replications and each replication consists of 10 plants which were fertilised three times a day (1,000 ml/plant/day) through drip irrigation. The sap nutrient concentration of leaf petiole, lamina and side shoot at different ages was determined using a Cardy meter. High nitrogen levels supplied to the plant resulted in higher nitrate and potassium concentration in petiole. Meanwhile, nitrate in leaf lamina and side shoot sap showed no clear trend on the effect of nitrogen treatment. Nitrogen at 190 ppm applied to tomato plants produced 6.3 kg fruits per plant which was significantly higher compared to the other treatments. This treatment also resulted in 89.9 g per plant of leaf dry matter. Leaf petioles at 4 weeks after emergence was the best plant part to be analysed for determination of plant performance.

Introduction

The use of an optimum nitrogen level that results in high yield and good quality crops are the major goal for growers. Nitrogen is one of the most important nutrients for plant growth; it affects dry matter accumulation and partitioning in many species, such as wheat, maize, safflower and barley (Dordas and Sioulas 2008). Nitrogen application gives positive effects to leaf area development and maintenance as well as photosynthetic efficiency (Arduini et al. 2006) and dry matter partitioning to reproductive organs (Prystupa et al. 2004). Fertilisation helps plants to translocate higher amount of dry matter production which is directly related to nitrogen supply. When nitrogen is low, there is low production of dry matter, especially in leaves. This affects the production of photoassimilates and the distribution of assimilates to the reproductive organs (Muchow 1988; Elliot et al. 1997).

Two methods commonly used to analyse the nutrition status of plants for fertiliser recommendation are leaf analysis and diagnosis through visual symptoms. Foliar analysis indicates the current nutrient status within a plant before the plant shows any visible symptoms of nutrient deficiency

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(Atland 2008). It can be used to confirm or diagnose problems associated with nutrient uptake and more importantly, to prevent the development of nutrient disorders (Mooney 1992). However, foliar analysis is not sensitive enough to detect the changes which take place during rapid plant growth (Smith 1988) and the analysis is also costly and time consuming. Meanwhile, soil analysis is very useful in appraising soil acidity, soil carbon, cation-exchange capacity (CEC) and pH. It measures in detail the specific levels of nutrients in a soil but could not identify any deficiency within a plant (Atland 2008). Soil analysis cannot indicate whether plants growing in the soil are able to take up a nutrient. Results from soil analysis are often contradictory with the plant behaviour (Lucena 1997) because nutrient reserved in the soil does not mean nutrient uptake by the plant.

Incorrect diagnosis of nutrient deficiency in the field can lead to crop failure as well as costly and ineffective corrective treatments. Plant analysis which can reflect the immediate status of the crop such as analysis of the conducting tissue, especially of expressed sap, has been proven to be suitable to diagnose nutrient deficiency (Martin-Prevel et al. 1987) in a very short time. According to Smith (1988), plant sap analysis can be used to anticipate potential imbalance situation.

Plant parts, age, time of day and temperature might influence plant sap nutrients (Hochmuth et al. 2008). In tomato, plant sap analysis is typically done on petioles because they are easily identifiable succulent organs and yield usable volumes of sap (Hochmuth et al. 2008). The time of day of sample collection and the length of time between sample collection and extraction were both shown to affect sap nutrient levels (Smith 1988).

The objective of the experiment was to determine the concentration of plant sap nutrients (nitrate and potassium) of different parts of the tomato plant at different ages as influenced by different nitrogen levels to highlight the optimum level for plant growth and yield.

Materials and methods

Seeds of tomato, *Lycopersicon esculentum* var baccarat, a lowland variety, were germinated in cocopeat. After 25 days, the seedlings were transplanted into polybags measuring 16 cm x 16 cm containing a mixture medium of cocopeat, rice husk charcoal and perlite in a ratio of 7:3:3. The polybags were arranged in a double row system, at a distance of 0.5 m within rows and 1.3 m between rows. Five nitrogen levels were used as treatments as shown in *Table 1*. A Randomized Complete Block Design (CRBD) was used with three replications and each replication contained 10 plants. Plants were fertilised three times a day with a total of 1,000 ml/plant/day using drip irrigation.

Leaf petioles, leaf lamina and side shoots were tagged after emergence in order to obtain the right samples at different ages. The side shoots were sampled at 4, 7, 10, 13 and 16 days while the leaf petiole and leaf lamina were sampled at 2, 3, 4, 5 and 7 weeks after emergence. The sap samples were taken at two production stages, 8 and 12 weeks after transplanting. To extract the sap, the leaf petioles and leaf lamina were squeezed using a garlic press and their sap nitrate and potassium readings were determined using the Cardy meter (Horiba Cardy Meter) which was calibrated before each determination.

Destructive sampling was done at 4 week intervals at 4, 8, 12 and 16 weeks after transplanting. Root and shoots were

Table 1. Nitrogen fertigation levels used as treatments

Treatment	Nitrogen concentration (ppm)
T1	100
T2	130
T3	160
T4	190
T5	220

harvested for leaves, stems and root dry mass. Samples of leaves, stems and roots for each treatment were dried separately in the oven at 70 °C. After 5 days, weights of the samples were determined using the weighing balance (SmartWeigh, Model SQW-3). Yield data were collected at week 6 until week 12 after transplating.

The data were subjected to analysis of variance (ANOVA) and tested for significance using Least Significant Difference (LSD) by PC-SAS 9.3 software (SAS Institute Cary NC 2001).

Results and discussion

Petiole sap nitrate and potassium

The results indicated that the concentration of nitrate in petiole sap were proportional to the applied nitrogen when analysed at 8 and 12 weeks after transplanting. The sap nitrate also varied with the plant age. At 8 weeks, the nitrate concentration was high, ranging between 300 and 600 ppm (*Figure 1a*) but after 12 weeks (*Figure 1b*) the reading dropped to only 170 – 330 ppm. Nitrate concentration increased with the increasing petiole age. Petiole sap nitrate concentration varied greatly according to the different nitrogen treatments. When sampled at 8 weeks after transplanting, application of nitrogen levels at 220 and 190 ppm resulted in 486.7and 378.3 ppm of nitrate concentration respectively, from 4-week old emerging leaf petioles (*Figure 1a*). Meanwhile application of 100 ppm N gave the lowest nitrate sap concentration (323.3 ppm). Similarly, when sampled at 12 weeks after transplanting, nitrogen at 220 and 190 ppm also showed high nitrate concentration (*Figure 1b*) producing 256.7 ppm and 241.3 ppm of nitrate in petiole sap respectively.

Potassium sap concentration in petiole varied with time following the same pattern when applied at 220, 190 and 130 ppm nitrogen during the first 8 weeks (*Figure 2a*) after transplanting. After 12 weeks of transplanting (*Figure 2b*) the pattern changed when the potassium sap concentration did not increase with increasing N level. At both 8 and 12 weeks after transplanting, application of nitrogen at 220 and 190 ppm resulted in high potassium concentration meanwhile application of 100 ppm N gave lower potassium concentration. In general, potassium sap concentration in petioles at 8 and 12 weeks ranged from 2,000 ppm to 4,500 ppm. Coltman (1987), Hochmuth et al. (1993) and Hochmuth (1994) reported that mineral concentration in petiole tissues sensitively reflect the adequacy of mineral concentrations availability in many vegetable crops. High level of nitrogen fertiliser applied to the plant produced high sap nitrate and potassium concentration as well as higher fruit yield. This finding was similar to that reported by Schenk (1988) who found that increasing nitrogen supply increased nitrate sap concentration and yield of saintpaulias.

Lamina sap nitrate and potassium

In the leaf lamina sap, low nitrogen level supplied to the plant resulted in high nitrate concentration (*Figure 3a*) at 8 weeks after transplanting. Application of nitrogen at 100 and 220 ppm produced 283.3 and 238.3 ppm sap nitrate respectively at 4 weeks after emergence. These results were similar with those obtained by MacKown et al. (2000) who reported that lamina $NO3^-$ concentration diminished with increasing amounts of N fertiliser. During the second production stage (12 weeks after transplanting), high nitrogen level supplied to the plant resulted in high nitrate concentration. Nitrogen applied at 190 and 220 ppm produced 210.3 and 201.5 ppm sap nitrate concentrations respectively, at 4 weeks after emergence (*Figure 3b*). The optimum N level for tropical tomato is probably at about 190 ppm. At 220 ppm, the level is probably toxic to the plants, thus it is not accumulated in the lamina as similarly indicated by MacKown et al. (2000).

Sap potassium concentration in the lamina varied with time following the same pattern as nitrate sap concentration at 8 weeks and 12 weeks after transplanting.

Results at 8 weeks after transplanting indicated that application of 100 and 220 ppm N produced 4,083.3 and 2,333.3 ppm potassium concentration (*Figure 4a*) respectively. At 12 weeks after transplanting, application of 190 ppm N produced the highest sap potassium concentration (3,800 ppm) while 160 ppm N produced the lowest sap potassium concentration (2,300 ppm) (*Figure 4b*). Lamina sap potassium concentration at week 8 was higher than week 12. This result shows that the lamina sap potassium concentration is higher at bloom (8 weeks) than at harvest (12 weeks) as reported by Wolpert et al. (2005), indicating greater translocation of K from the leaves to the fruit at that stage.

Side shoot sap nitrate and potassium

Results on nitrate concentration of side shoot sap at early cluster (8 weeks) of transplanting showed that low level of nitrogen (100 ppm) supplied to the plant produced lowest nitrate concentration (*Figure 5a*), producing only 180 – 270 ppm from day 4 to day 16 of side shoot emergence. In contrast, at 12 weeks after transplanting, the sap nitrate concentration of 100 ppm N was the highest (*Figure 5b*). This was probably due to the slower growth rate at 12 weeks age allowing accumulation of the absorbed N. Side shoot sap potassium concentration did not show any significant difference when subjected to different nitrogen levels at both 8 weeks (*Figure 6a*) and 12 weeks (*Figure 6b*) after transplanting. The growth rate of side shoots are comparatively faster than leaves, thus preventing differential accumulation of both N and K, furthermore, both elements are naturally very mobile within the plant tissues.

Stem, leaf and root dry masses

The stem dry mass of the plants gradually increased up to 12 weeks after transplanting (*Figure 7*). There was no significant difference among treatments. However, at week 12 after transplanting, plants fertilised with 190 ppm nitrogen had the highest stem dry weight (68.2 g per plant) while those that received 100 ppm nitrogen had the lowest (51.0 g per plant) stem dry mass. These results were similar with findings of Yurtseven et al. (2005) who reported that gradual increase in dry matter content of tomato plant organs was observed with increasing nitrogen levels. After 12 weeks, the tomato vine is long (not shown in data), which slows down the translocation of water and nutrients from the root to the leaves and therefore reduces plant biomass as well as yield reduction.

The leaf dry mass also showed similar pattern as stem dry mass (*Figure 8*). There was increment of values for all treatments with time and the peak value was found at week 12. Application of 190 ppm N gave 89.9 g per plant of leaf dry mass while 100 ppm gave only 62.5g per plant. However, statistical analysis showed that there was no significant difference among the treatments. Similar results were also reported by Mohammad et al. (1989) and Jefing et al. (1992). They showed that low rates of nitrogen gave less leaf dry weight and higher rates of nitrogen gave higher leaf dry weight.

Figure 9 shows that the roots were well developed up to week 12 after transplanting. After week 12, the root dry mass in all treatments decreased as the nutrient was transported intensively for fruit development. At week 12, root dry mass of plants fertilised with 160 ppm N was 10 g per plant while those receiving 220 ppm N was only 7.5 g per plant. Again this indicated that 220 ppm of N was excessively high and gave negative effect on plant biomass. However, there were no significant differences among all treatments. Reina-Sanchez et al. (2005) reported that reduction of plant dry mass would consequently result in yield reduction.

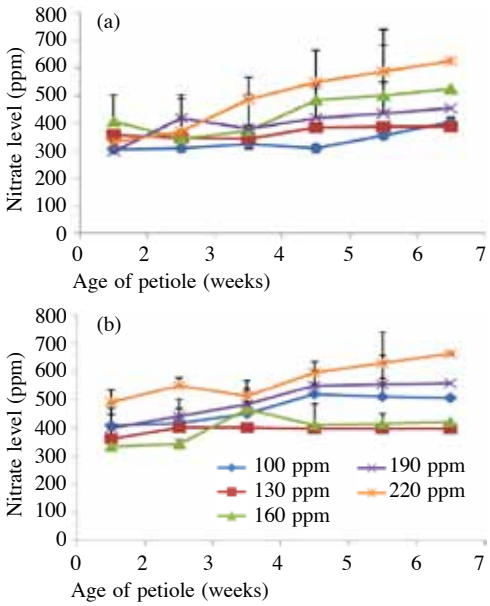

Figure 1. Effect of different levels of nitrogen on nitrate levels in petiole sap at (a) 8 weeks and (b) 12 weeks after transplanting

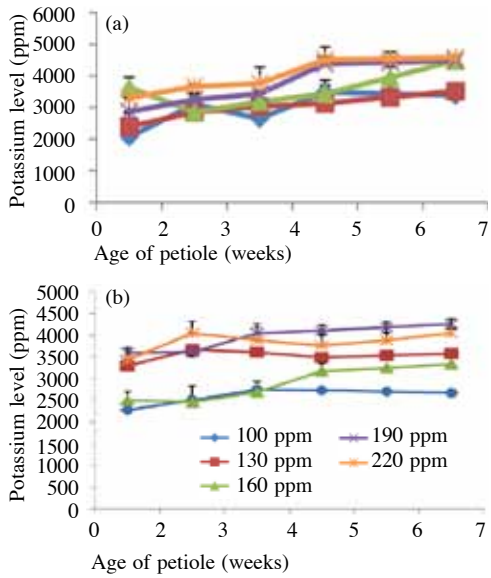

Figure 2. Effect of different levels of nitrogen on potassium levels in petiole sap at (a) 8 weeks and (b) 12 weeks after transplanting

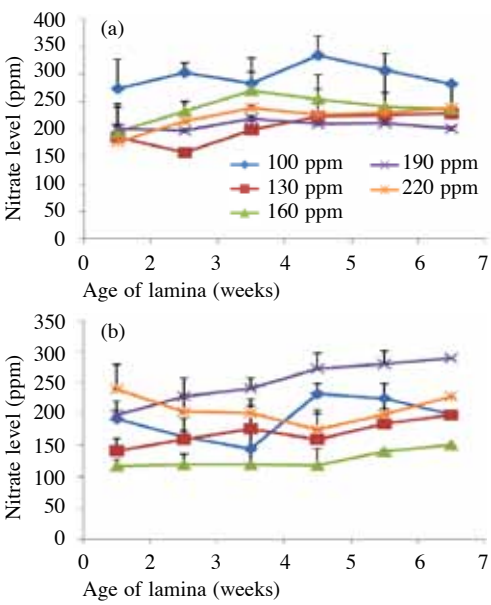

Figure 3. Effect of different levels of nitrogen on nitrate levels in lamina sap at (a) 8 weeks and (b) 12 weeks after transplanting

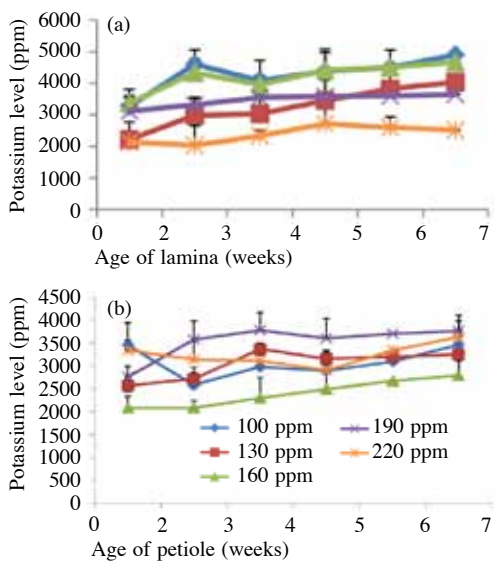

Figure 4. Effect of different levels of nitrogen on potassium levels in lamina sap at (a) 8 weeks and (b) 12 weeks after transplanting

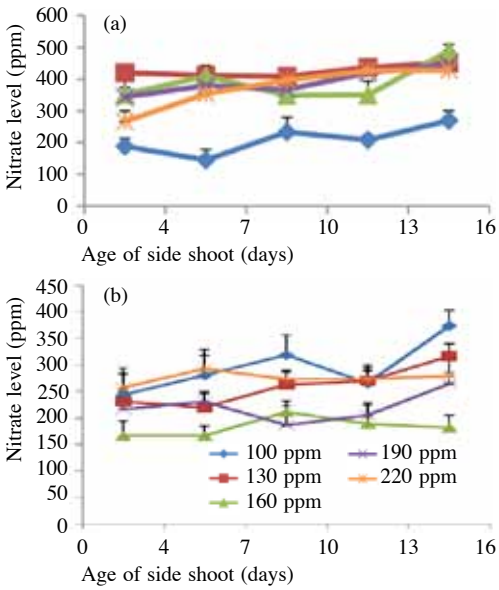

Figure 5. Effect of different levels of nitrogen on nitrate levels in side shoot sap at (a) 8 weeks and (b) 12 weeks after transplanting

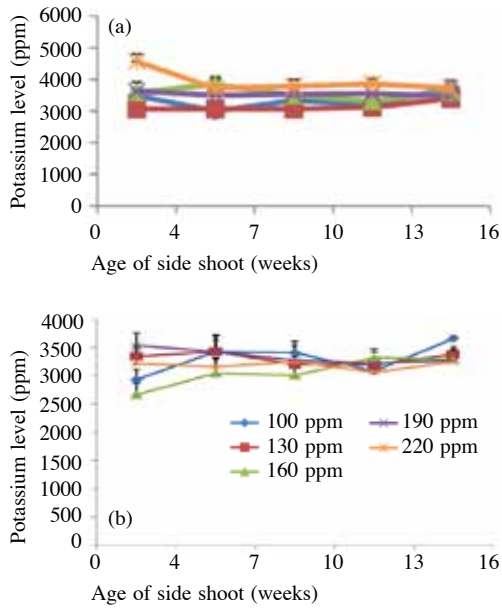

Figure 6. Effect of different levels of nitrogen on potassium levels in side shoot sap at (a) 8 weeks and (b) 12 weeks after transplanting

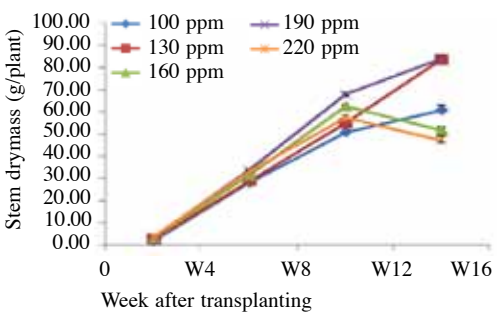

Figure 7. Effect of different levels of nitrogen in stem dry mass at week 4, 8, 12 and 16 after transplanting

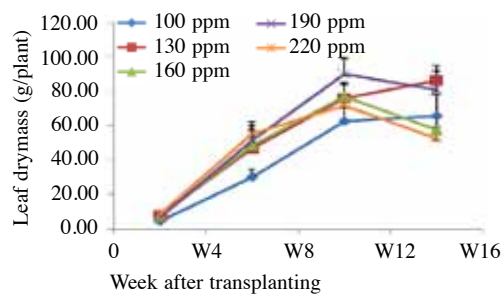

Figure 8. Effect of different levels of nitrogen in leaf dry mass at week 4, 8, 12 and 16 after transplanting

Effect on yield

Increasing application of N from 100 to 190 ppm resulted in increasing yield (*Figure 10*). Application of nitrogen at 190 ppm resulted in highest fruit weight (6.3 kg per plant) and it was significantly higher compared to the other treatments. Plants supplied with 160 ppm N produced 5.54 kg fruits per plant and was not significantly different with 220 ppm N, indicating negative effect of excessive N at the latter. Those fertilised with 100 and 130 ppm N produced only 3.74 kg and 4.80 kg fruits per plant respectively. Applying low level of nitrogen resulted in lower fruit weight because very low nitrogen concentration reduced the size, colour and the yield of tomato fruit (Dorais et al. 2001).

Nitrate concentration in the petiole reflects the balance between recent nitrate uptake by the tomato root system, and nitrate reduction in the leaf in response to crop growth. Leaf petiole aged 4 weeks was found to be the best plant part for sap sampling. Early detection could be made

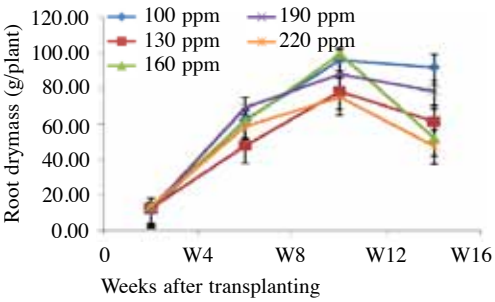

Figure 9. Effect of different levels of nitrogen in root dry mass at week 4, 8, 12 and 16 after transplanting

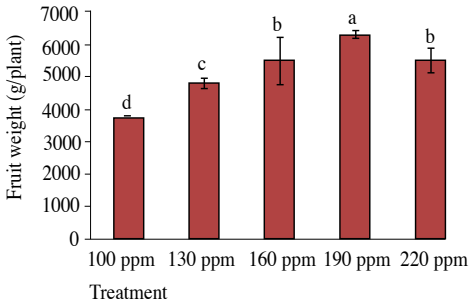

Figure 10. Effect of different levels of nitrogen on fruit weight. Means with the same letter are not significantly different using LSD at p <0.05

and the sap composition responded well to N application. It showed a strong connection between nitrate and potassium levels measured in the sap across the resulting yield. Results on nitrate and potassium concentration in lamina and side shoot showed that there was a connection between the two. The requirement of nitrogen for fruit crops such as tomatoes was relatively little until flowering begins. Then the nitrogen uptake increased reaching a peak during fruit set and early fruit bulking period. The nitrogen demand drops again as the fruit matures. Excess in nitrogen can cause reduction in the levels of other mineral nutrients in the plants such as potassium, calcium and magnesium, often resulting in the development of deficiencies and associated disorders (Johnson 2012). As fruits begin to set and grow, they form a sink into which the plant pumps large amounts of nitrogen, limiting the amount of nitrate stored in leaf petioles.

Conclusion

The higher nitrogen levels supplied to the plant resulted in higher nitrate and potassium concentrations. For biomass production, different levels of nitrogen given to the tomato plants affected stem and leaf dry masses but did not affect the root dry mass. It can be concluded that higher fruit yields were associated with higher application of nitrogen, especially at 190 ppm which resulted in significantly higher fruit yield (6.3 kg per plant) compared to other treatments.

This level of N is recommended for fertigation production of tomato in the humid tropics.

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Abstrak

Tiga bahagian pokok tomato (petiol, lamina daun dan sulur sisi) daripada sampel berlainan umur dianalisis untuk menentukan kepekatan nitrat dan kalium yang dihasilkan di dalam sap pokok mengikut aras nitrogen yang dibekalkan (100, 130, 160, 190 dan 220 ppm). Kajian dijalankan menggunakan Reka Bentuk Blok Lengkap Terawak dengan tiga replikasi dan setiap replikasi mengandungi 10 pokok yang diberi baja tiga kali sehari (1,000 ml/pokok/hari) menggunakan pengairan titisan. Sap daripada petiol daun, lamina dan sulur sisi pada umur berlainan ditentukan menggunakan *Cardy* meter. Pokok yang dibaja dengan aras nitrogen yang tinggi menghasilkan kepekatan nitrat dan kalium yang tinggi dalam petiol. Sementara itu, rawatan nitrogen tidak memberi kesan yang ketara kepada kandungan nitrat dalam sap lamina dan sulur sisi daun. Pembajaan pokok tomato dengan 190 ppm nitrogen menghasilkan 6.3 kg buah setiap pokok dan ini sangat ketara lebih tinggi berbanding dengan berat buah rawatan lain. Rawatan in juga menghasilkan 89.9 g berat kering daun setiap pokok. Petiol daun berumur 4 minggu selepas bercambah adalah bahagian pokok terbaik untuk dianalisis bagi mengesan prestasi pokok.

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