Original Research Article

Effect of Different Nitrogen Concentration on Plant Growth, Yield and Quality of Sweet Potato (*Ipomea Batatas*) Cultivated in Soilless Culture System

.

ABSTRACT

The soilless culture system effectively promotes plant growth by facilitating water and nutrient uptake by plant roots. To increase sweet potato production (Ipomoea batatas), we developed containerized planting in which tuberous roots were grown in solid substrates in the polybags supplied with a nutrient solution through an irrigation system. This study was conducted to investigate the effect of different nitrogen concentrations on sweet potato plant growth performance, yield, and tuber quality cultivated using a soilless culture system. The experimental setup included five treatments (T1-T5) with different levels of N (0-50-150-200-250 mg L^{-1}), which were mixed in the nutrient solution, while P and K levels were held constant at 150 and 200 mg L^{-1} respectively. After three months of cultivation, there were significant differences between treatments in terms of plant growth performance, yield and tuber quality. Plants cultivated in the 250 mg L^{-1} of N showed the highest growth rate including plant height, shoot and leaves fresh weight, number of tillers, SPAD values, number of leaves, and diameter of tillers compared to other treatments. Data also revealed that the highest tuber yield was obtained from plants treated with 200 mg L^{-1} of N. Tuber harvested from the treatment of 200 mg L^{-1} of N showed the best quality in terms of Brix value, moisture content and tuber shape and length. Therefore, planting sweet potatoes using a soilless culture system is recommended with the application of 200 mg L^{-1} of N to obtain the optimum plant performance in terms of growth, yields, and tuber quality.

Keywords: Sweet potato; yield; nitrogen; fertilizer; tuber.

1. INTRODUCTION

Sweet potato (Ipomoea. Batatas (L.) Lam.) is a plant that belongs to the family Convolvulaceae that produces nutritious tuberous roots. Sweet potato is an important tuberous root cultivated in temperate and tropical zones [1]. Sweet potato storage roots contain relatively high amounts of carbohydrates [2]. The main problem in cultivating sweet potato in Malaysia is that the current average tuber yield grown using the conventional method is still low at 9 mt/ha compared to 20-30 mt/ha targeted. Self Sufficiency Rate (SSR), which has not yet reached 100% for sweet potatoes (75.1%), has forced Malaysia to import (Import Dependence Rate (IDR)) sweet potatoes (26.3%) [3]. Vast open market opportunities and high domestic demand for the commodity require a sustainable and high-yielding system of cultivation. Therefore, it is necessary to develop cost-effective methods for the efficient cultivation of sweet potatoes.

Soilless cultures such as hydroponics and aeroponics are increasingly adopted as major technological components in agriculture to replace conventional soil farms [4]. There is potential to increase the growth and yield of sweet potatoes using soilless system based on a significant increase in yields of ginger, chilies, rockmelons, tomatoes, and other leafy and fruity vegetables grown on various substrates [5]. Sweet potato is a horticultural crop that needs heavy fertilization to obtain high growth levels and increased yield. The sweet potato plant responds well to the application of fertilizers. Efficient fertilizer uses in heavy fertilizer plants such as sweet potato is critical for sustainable agricultural production. Soilless culture system is a cultivation technique that applies nutrient solution directly to the plant's root zone thus increasing the minerals use efficiency.

Fertilizers are widely used in agriculture to increase crop production. Nitrogen (N), Phosphorus (P) and Potassium (K) are nutrients, which individually and/or together maintain the growth, yield, and quality of the plants. Among chemical fertilizers, nitrogen (N), phosphorus (P), and potassium (K) are the major elements required for supporting plant growth and development in sweet potato [6]. In the soilless culture system, fertilizers are supplied as ions form in the nutrient solution [7]. Several formulations of essential macro and micronutrients have been developed to enhance nutrient uptake and plant growth in the soilless culture system [8]. N is required for chlorophyll formation and it influences stomatal conductance and photosynthetic efficiency [9]. Sufficient supplies of fertilizers for crops can improve the performance and yield of plants but also determine plant quality [10]. In a soilless culture, different concentrations of macronutrients were tested and results indicated that plants respond differently [11]. Therefore, the present investigation was conducted to study the effects of N on the growth, yield and tuber quality of sweet potatoes grown using a soilless culture system. The main objective was to determine the optimum N concentration for sweet potato cultivation using a soilless culture system.

2. MATERIAL AND METHODS

2.1 Study area

The experiment was conducted at MARDI Serdang, Selangor, Malaysia, from April 2021 to Jun 2021. A side-netted rain shelter of 30 m long x 10 m wide x 4.5 m high was used in the study. All structures were made of galvanized steel frames and insect repellent net (0.1 x 0.1 mm^2) side cladding. The entrance into the shelter was through double doors to reduce the chance of insect entry.

2.2 Planting materials

Sweet potato var CB1 was used in the study. Stem cuttings were used as plant material for the cultivation of sweet potatoes. 30 cm long stem cuttings with 5-7 leaves are taken from a 2.5-month-old sweet potato plant. The stem cuttings were treated with Benomyl and copper solution before planting. As growing media, 100% of coir dust was used. The growing media were filled into 60 cm x 60 cm black polyethene bags. One cutting was planted (7 cm deep) in each polyethene bag. Each polyethene bag was placed randomly on four irrigation lines under the side-netted rain shelter and individually irrigated with a nutrient solution via a dripper on the surface of the growth medium.

2.3 Treatments and experimental design

The experimental design used was a complete randomized block design with three replications. Each treatment plot consisted of 50 plants. There were five N concentration levels involved in the experiment. The fertilizer used was formulated by the Malaysian Agricultural Research and Development Institute (MARDI) based on the needs of the plant tubers with the modification of nitrogen concentration according to treatments [12]. Five treatments (T1-T5) had varying levels of nitrogen (N), which was mixed in nutrient solution (0-50-150-200-250 mg L^{-1}), while phosphorus (P) and potassium (K) levels were held constant at 150 mg L^{-1} and 200 mg L^{-1}, respectively. NH_4NO_3 was used as a N source in the experiment. NH_4NO_3 content was calculated and mixed into the nutrient solution. The nutrient solution was prepared as a 100 L stock solution. All the fertilizers used were water-soluble. The nutrient solution pH values were adjusted to 5.5 – 6.5 range before being applied to plants.

2.4 Irrigation set-up

The irrigation solutions were prepared in a 1,500-litre tank. Stock A and stock B were added into the tank at a 1:1 ratio until the needed electricity conductivity (EC) was achieved. The EC of the fertigation solution was between 1800 mS and 2600 mS. The irrigation duration was 3 minutes and an identical amount of fertiliser solution was applied to all polyethene bags. The irrigation scheduling was automatically implemented by a digital timer, three times per day in the first three weeks (0700 h, 1000 h and 1700 h) and six times per day after four weeks (0700 h, 0800 h, 1000 h, 1100 h, 1200 h and 1700 h) until the end of cultivation periods. The daily irrigation volumes per plant were 675 ml in the first three weeks and 1,350 ml after four weeks until the end of the cultivation periods. If necessary, routine horticultural practices for pest, disease, and weed control were done using biopesticides.

2.5 Parameters measurements

The growth of the sweet potato plants was measured by measuring the main stem length, stem diameter, number of lateral shoots, vegetative biomass, SPAD value and Brix value. The sweet potato plants were randomly selected and the tubers were harvested after three months of planting to determine the yield and growth of tubers. The weight was measured immediately after harvest to prevent desiccation and water loss from the tubers.

2.6 Statistical analysis

Data obtained were subjected to statistical analysis using analysis of variance (ANOVA) procedures to test the significant effect of all the variables investigated using SAS application (version 9.2. SAS Institute, Cary, NC, USA). Means and standard deviation (SD) of replications were determined using analysis of variance (ANOVA) and Duncan's Multiple Range Test (DMRT) was used to determine the significant differences between treatments. The statistical significance level was set at 0.05 for all tests.

3. RESULTS AND DISCUSSION

3.1 Effect of nitrogen on plant growth performance

Previous reports showed that soilless plants have different growth characteristics compared with soil grown plants [13]. The responsiveness level of soilless culture grown sweet potato to the nutrient concentration might be different from that of soil grew sweet potato plants [14]. Table 1 shows the results of plant growth parameters for main stem length, stem diameter, number of lateral shoots, vegetative biomass and SPAD value. These results indicated that there were highly significant ($p < 0.05$) differences among the N treatments tested. T5 or N concentration at 250 mg L^{-1} recorded the highest value in plant main stem length (380 cm) compared to other concentrations tested. The plant's main stem length increased from 0 mg L^{-1}, 50 mg L^{-1}, 150 mg L^{-1}, 200 mg L^{-1} to 250 mg L^{-1} of N. As expected, the lowest plant main stem length was observed in the 0 mg L^{-1} or control treatment (88 cm) with a 76.84% reduction in the plant main stem length. There was 11.32% to 76.84% increment in plant height obtained in 250 mg L^{-1} N level compared to other treatments tested. The highest vegetative biomass was observed in 250 mg L^{-1} (3800 g) of N followed by 200 mg L^{-1} (3550 g), 150 mg L^{-1} (3350 g), 50 mg L^{-1} (2450 g) and 0 mg L^{-1} (850 g) of N concentration. The study revealed that N at 250 mg L^{-1} resulted in the optimum vegetative biomass. There was a 6.58% to 77.63% increment in vegetative biomass obtained in 250 mg L^{-1} of N level compared to other treatments. Plant main stem length and vegetative biomass increased proportionally with N concentration. The highest plant main stem length was also found to have the highest vegetative biomass. Results revealed that plant height attributes contributed to the vegetative biomass, since higher plant height resulted in higher vegetative biomass. A study on tuber volume growth using a hydroponics system showed that tuber growth rates of the plants with higher leaves numbers were significantly higher than the rate of the plant with lower leaves numbers [15].

The physiological parameter indicated that SPAD values were significantly different at $p < 0.05$ among the N treatments. The highest SPAD values were obtained from plants supplemented with 250 mg L^{-1}, 200 mg L^{-1}, 150 mg L^{-1}, 50 mg L^{-1} and 0 mg L^{-1} of N concentration respectively. The higher N concentration increased the SPAD value and sweet potato leaves tend to be darker green in colour. Previous studies had shown that there was a significant correlation between SPAD values and the contents of chlorophyll and N in plant leaves, but the optimum N application determined the plant growth and yield [16]. Meanwhile, Sarker et al. (2015) stated that deficiency of N fertilizer resulted in lower chlorophyll in leaves, resulting in earlier plant death. There was a significant difference in a number of lateral shoots between each treatment at $p<0.05$. The highest number of tillers was obtained from 150 mg L^{-1} followed by 250 mg L^{-1}, 200 mg L^{-1}, 50 mg L^{-1} and 0 mg L^{-1} of N concentration level, respectively. However, there were no significant differences in a number of lateral shoots between 50 mg L^{-1} and 0 mg L^{-1} of N concentration level. Application of N at 150 mg L^{-1} resulted in an increased number of lateral shoots (35% - 65% increment) compared to other treatments. The highest stem diameter was obtained in plants treated with 200 mg L^{-1}, followed by 150 mg L^{-1}, 250 mg L^{-1}, 50 mg L^{-1} and 0 mg L^{-1} respectively. Nutrient concentration supplied to plants appears to be more favourable for plant growth and storage root development [18].

The positive effects of N fertilization in plants have been widely studied, on the morphological and physiological characteristics. The form of nitrogen source has been shown that affects the growth, yield, fruit quality, and chemical composition of plants [19]. As expected, 0 mg L^{-1} of N level produced plants with the lowest main stem length (cm), stem diameter (cm), number of lateral shoots, vegetative biomass (g) and SPAD value, due to N deficiency. Plant treated with 0 of N exhibited major N deficiency symptoms and plants treated with 50 mg L^{-1} of N showed minor N deficiency symptoms. Lowering the concentration level below 50 mg L^{-1} could cause N deficiency in the sweet potato plant cultivated using soilless culture system. Sweet potato showed high tolerance to N up to 250 mg L^{-1} as plants supplemented with 250 mg L^{-1} didn't exhibit any N toxicity symptom. Therefore, the present study suggests that the optimum N concentration to grow sweet potatoes using soilless culture system is 200 mg L^{-1} to obtain high plant growth performance. However, application of N within the range of 150 – 250 mg L^{-1} is more advisable for sweet potato cultivation using soilless culture system.

Table 1: Effects of N on plant growth after three months of cultivation

Treatment	Main stem length (cm)	Stem diameter (cm)	Number of lateral shoots	Vegetative biomass (g)	SPAD value
T1	88^{e}	0.9^{e}	7^{d}	850^{e}	32^{c}
T2	268^{d}	1.3^{d}	8^{d}	2450^{d}	53^{b}
T3	294^{c}	1.95^{b}	20^{a}	3350^{c}	54^{b}
T4	337^{b}	2.52^{a}	10^{c}	3550^{b}	56^{b}
T5	380^{a}	1.79^{c}	13^{b}	3800^{a}	62^{a}

Mean values in the same column followed by the same letter are not significantly different at $p < 0.05$

3.2 Effect of nitrogen on yield

N plays a crucial role in plant growth and development, as an important nutrient for plants. The availability of N is significantly increasing vegetative growth and yield parameters of sweet potatoes than other nutrients. Six different levels of N concentration were tested and sweet potato plants responded significantly differently to these N regimes. There were significant differences in terms of sweet potato yield per plant, in response to N concentration level (Table 2). The highest tuber yield per plant was obtained from plants treated with 200 mg L^{-1} of N (3255 g). Meanwhile, 0 mg L^{-1} of N did not produce any tuber followed by 50 mg L^{-1} (1725 g), 150 mg L^{-1} (2748 g) and 250 mg L^{-1} (2500 g) in ascending order. The tuber yield per plant increased steadily from 0 mg L^{-1} until achieving the highest yield at 200 mg L^{-1} of N concentration level and started to decrease after application of 250 mg L^{-1} or higher. The decrease in the tuber yield per plant in plants supplemented with 250 mg L^{-1} of N after three months of cultivation was due to high vegetative biomass growth that led to lower growth of the underground part of sweet potato plant, in this case, is the tuber. The plant also exhibited darker green in color of leaves and showed abundant foliage at the early stages. Harvest index (HI) obtained from plants supplemented with 250 mg L^{-1} (0.66) was lower compared to other treatments. The application of N fertilizers significantly increases the tuber yield, photosynthesis product distribution, and leaf enzyme activities in sweet potato [20, 21]. Furthermore, N concentration influences the lateral root development at the early growth stage that initiates storage root formation [22].

Sweet potato plants grown without N application withered earlier and gave a poorer vegetative growth resulting in no tuber formation. The symptoms of N deficiencies appeared in plants with 0 mg L^{-1} about two weeks after sowing. The N deficiency in sweet potato plant was evident as old leaves become pale or yellow green (chlorosis). Small reddish tints gradually appeared at the leaf margin and were spreading toward the midrib or central vein of the leaf. New sweet potato leaves formed were small and overall growth is reduced and plant growth was stunted. High tuber yield per plant was noticed together with the increased number of tubers per plant and HI. Plants supplemented with 200 mg L^{-1} of N gave rise to the highest number of tubers per plant (6) and HI (0.92). Substantial increase in HI, emphasizing that the plant partitioning of photoassimilate more to the yield rather than the generation of whole-plant biomass. The lowest HI was observed from plants supplemented with 250 mg L^{-1} of N where the vegetative biomass was highest among other treatments. However, there was no significant difference between 50 mg L^{-1}, 150 mg L^{-1} and 250 mg L^{-1} of N in terms of the number of tubers yielded per plant. Plant supplemented with 150 mg L^{-1} of N gave rise to the highest average weight per tuber compared to other treatments. The concentration of 200 mg L^{-1} of N was able to give rise to the highest tuber yield per plant and the number of tubers per plant. HI data also revealed plants supplemented with 200 mg L^{-1} of

N improved plant partitioning towards the tuber compared to vegetative biomass. Plants sense the nutrient concentration and alter the biomass partitioning accordingly [23]. The concentration of N fertilizer alters the biomass partitioning of tubers and vegetative biomass in sweet potato [24]. Similar studies also showed increasing the N fertilizer concentration increases the biomass partitioning to storage roots [24]. However, at a higher N concentration resulting in the storage root biomass decreases, whereas the shoot biomass increases [24].

Table 3: Effects of N on tuber yield after three months of cultivation

Treatment	Tuber yield per plant (g)	Number of tubers per plant	Average weight per tuber	Harvest index (HI)
T1	nil	nil	nil	nil
T2	1725^{d}	5^{b}	345^{d}	0.70^{c}
T3	2748^{b}	5^{b}	549.60^{a}	0.85^{b}
T4	3255^{a}	6^{a}	542.5^{b}	0.92^{a}
T5	2500^{c}	5^{b}	500^{c}	0.66^{d}

Mean values in the same column followed by the same letter are not significantly different at $p < 0.05$

3.3 Effect of nitrogen on tuber quality

There were significant N concentration effects on tuber quality between treatments (Table 4). Tubers obtained from 200 mg L^{-1} of N gave a higher Total Soluble Solid (TSS) or Brix value (11.6 °Bx) compared to other treatments. Brix values from 50 mg L^{-1}, 150 mg L^{-1} and 250 mg L^{-1} of N were no significance, ranging between 10.5 – 10.83 °Bx. Tuber dry matter content from all treatments were ranging from 70.10% – 73.60% with 50 mg L^{-1} of N being the highest followed by 200 mg L^{-1}, 150 mg L^{-1} and 250 mg L^{-1} of N in descending order. Most of the dry matter in sweet potatoes consists of carbohydrates, primarily starch and sugars and to a lesser extent pectins, cellulose and hemicellulose [25]. Tuber flesh pH in all treatments ranging between 5.85 – 6.08, indicated that the flesh is slightly acidic. However, there was no significance difference between 150 mg L^{-1} and 200 mg L^{-1} of N in terms of tuber flesh pH. The shape of the tuber is tapered at the top and bottom with the middle part expanded. All treatments produced similar tuber shapes with 250 mg L^{-1} of N producing the highest tuber diameter for upper, middle and lower parts. Although 250 mg L^{-1} of N was able to produce the highest tuber diameters, it did not result in the longest tuber length. The longest tuber length was obtained from a plant supplemented with 200 mg L^{-1} of N. Good quality sweet potatoes should be smooth and firm, with uniform shape and size [26]. The N fertilizer concentration or dosage is also important for increasing the marketable sweet potato tuber yield [27]. Other than nutrients, root zone temperature and moisture also influence tuberous root enlargement in sweet potato plants [28].

Table 4: Effects of N on tuber quality after three months of cultivation

Treatment	Total Soluble Solid (Brix	Tuber dry matter content (%) (1 g)	Tuber flesh pH	Tuber diameter (mm)	Tuber length (cm)

	value)			Upper part	Middle part	Lower part	
T1	nil	nil	nil	nil	nil	nil	nil
T2	10.50^{bc}	73.60^{a}	5.64^{c}	33.59^{d}	39.40^{c}	28.54^{d}	13.52^{c}
T3	10.60^{bc}	72.48^{b}	5.82^{a}	45.50^{b}	51.16^{b}	36.88^{c}	17.80^{b}
T4	11.60^{a}	72.80^{b}	5.8^{a}	41.26^{c}	52.30^{b}	37.54^{b}	18.75^{a}
T5	10.83^{b}	70.10^{c}	5.77^{b}	47.60^{a}	54.17^{a}	39.74^{a}	17.53^{b}

Mean values in the same column followed by the same letter are not significantly different at $p < 0.05$

4. CONCLUSION

Studies revealed that sweet potato plants respond very well to 50 – 250 mg L^{-1} of N concentration. The sweet potato plant was able to grow and produced tuber when supplemented with N concentrations ranging between 50 – 250 mg L^{-1}. Plant supplemented with 250 mg L^{-1} gave the best plant growth performance based on the vegetative growth. Meanwhile, the best N concentration to obtain the highest tuber yield was 200 mg L^{-1} of N. HI data also revealed plants supplemented with 200 mg L^{-1} of N improved plant partitioning towards the tuber compared to vegetative biomass. Thus, it can be concluded that for plant growth and yield, N at 200 mg L^{-1} is the efficiency rate of application for sweet potato grown using soilless culture system. In addition, soilless culture system can efficiently utilize nutrients as supplied nutrients are not dispersed to the soil.

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