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# Circulation Culture of Tomato for Efficient Nutrient Uptake and High Yield in Tropical Greenhouses

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***ABSTRACT**. The rate of nutrient uptake and resultant yields of tomato (Lycopersicon esculentum Mill), grown in protected culture at different rates and methods of water and fertilizer applications were tested in a tropical environment. The experiment was conducted in a naturally ventilated glasshouse under hot and humid conditions where the mean daytime temperature and evapo-transpiration rate (ET) in the greenhouse were 29±3.7 °C and 65.6±4.7 mm/day, respectively. The standard irrigation method (T1) was subjected to changes by adjusting supply volume to 150 % of ET (T2 and T4) and doubling the standard volume together with drainage collection and re-circulation (T3). Standard soluble inorganic fertilizer dosage (in T1 and T2) was adjusted to T3 by doubling the dosage of essential plant nutrients, except N and Ca from the early fruit development (12 weeks after planting). Inorganic fertilizer dosage was completely replaced with phospho-compost and foliar application of plant extracts (T4). Plant and medium samples were tested for N, P and K compositions. Electrical conductivity and pH drifts in media and leacheate were also determined. Results revealed the necessity of excess irrigation from the flower initiation stage of tomato preferably in the form of circulation culture. Significantly high N and P nutrition together with adequate K improved the fruit growth and yield. Overall yields were below the recorded averages due to hot, humid and overcast conditions. Further improvements are needed for K nutrition in the circulation culture of soluble fertilizers and for N nutrition in phospho-compost supplemented plant nutrient supply.*

***Key words:** Evapo-transpiration, hydroponics, phopho-compost, water uptake rate*

## INTRODUCTION

Year-round cultivation of greenhouse crops is an integral part of commercial horticulture in every climatic region of the world. Apart from the main attributes of protected culture such as minimizing pest incidences and protection from extreme weather, enhanced root functioning through hydroponic culture greatly contribute to growth and yield advancements of greenhouse crops. Making the availability of plant nutrients in the hydroponic medium by adjusting pH and electrical conductivity (EC) of the nutrient feed is a very skillful task for the grower. It has been made easy in automated fertigation systems that are programmed to operate based on the demand parameters. Apart from the growth stage, the other major determinant of the rate of plant nutrient uptake of a species is the climate based evapo-transpiration rate (ET).

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Although basic research evidences are available to identify the growth stage and weather based rates of water and nutrient uptake rates of greenhouse crops, there are gaps in the available information on their performances under extreme environmental conditions such as humid-hot conditions in the tropics.

Even though, Sri Lankan greenhouse vegetable growers mainly use the commercial complete fertilizer, Albert's (CIC / Unipower, Sri Lanka) in coco-peat based hydroponic systems, their mean yields are yet far below the targets set forth under tropical climatic conditions (Perera, 2004). As a result, low cost and more effective sources of fertilizer and methods of fertigation have been successfully tried out lately (Ranawaka *et al.*, 2006; Weerakkody *et al.*, 2007). Previous work on improving fertilizer use efficiency revealed that adjusted K:N and N:P ratios and high dosages of Albert's fertilizer increased the growth rate, total yield and the marketable yield of tomato (Ranasinghe & Weerakkody, 2006) while high EC increased the uptake concentration of some plant nutrients (Jang & Nukaya,1997; Weerakkody *et al.*, 2008). Other work on improving fertilizer use efficiency indicated that circulation of the drainage collection as the most promising fertigation method under mild weather and tropical conditions (Weerakkody *et al*., 2007). Meanwhile, water deficit hinders pedicel sap flux, imposing water and mineral limitations on leaf photosynthesis and fruit respiration of most crops (Araki *et al.*, 1998; Kitano *et al*., 1998). On contrary, irrigating more than 75 % of ET reduces the harvesting index of tomato (Rummun *et al*., 2003). Therefore, water management in hydroponic culture needs careful maneuvering for better crop performances.

Meanwhile, application of organic manure has been proven for increased yield, reduced water requirements, resistance to pest and disease attacks and reduced use of inorganic inputs in field vegetable cultivations (Smith, 2007). Particularly "phospho-compost" (having an organic matter composition of 19 %), made by mixing powdered rock phosphate in to the composting process, is one of the widely used organic manure despite its low potential in hydroponics due to low solubility characteristics (Jayawardane, 1976; Permaratne, 2002). In a follow-up research, amendment of "phospho-compost" to coco peat medium could save part of the liquid fertilizer feed by attaining comparable yields for tomato under greenhouse conditions (Herath *et al.*, 2008).

In the present work, different rates of water and plant nutrient supply, through different sources and methods, were compared with the standard dosage and supply method of Alberts fertilizer for greenhouse tomato under tropical greenhouse conditions, aiming improvements in the rate of nutrient uptake and the yield.

## MATERIALS AND METHODS

The experiment was conducted at the Dodangolla Experimental Station of the University of Peradeniya, which is located in the Mid-country Intermediate Zone (580 m from the sea level and 1450 mm of annual rainfall). The mean maximum and minimum temperatures are 29 $^{o}$C and 20.5 $^{o}$C, respectively. The experiment was conducted in drip fertigated grow-bag culture in a Venlo type glasshouse with partial environment control. The early part of the cropping season was overlapped with the North-eastern monsoon, resulting relatively mild weather. As a result, the mean daytime temperature in the glasshouse ranged within 23.4-30.3 $^{o}$C during vegetative stage of the crop while it was within 23.5-41.5 $^{o}$C during reproductive stage of the crop. The daytime relative humidity (RH) was relatively high at early stages of crop growth (65–71 %) but rather lower at late stages (60–62.5 %). F1 hybrid, Volcano

(Seminis Korea Inc.) was grown in grow-bags, filled with coco peat and sand (1:1) mixture and at the crop density of 1.4 plants/$m^2$.

The experiment was conducted as a Randomized Complete Block Design (RCBD) with four treatments and three replicates. First three treatments were fertigated daily with a fully soluble complete fertilizer, Albert's (CIC, Colombo) at either different dosages of fertilizer or different irrigation volumes at a given growth stages of tomato, causing a variable EC in the supply solution. The standard dosage and irrigation volume (T1) was subjected to changes by irrigating 150 % of the evapo-transpiration (0.91±0.15 mm/day) in T2 and doubling the standard volume of irrigation together with circulation of the drainage collection (with pH adjustments) several times a day in T3 (Table 1). Additionally, the dosage of plant nutrients was doubled during reproductive stage (12 – 20 WAP) of T3, except for the dosage of $Ca(NO_3)_2$. Hence the K : N ratio of the standard dosage was altered from 1.2 : 1 to 1.8 : 1 and the N : P ratio was altered from 3.3 : 1 to 2.1 : 1, during the reproductive growth of T3. Based on the composition of N, P and K in the Albert's fertilizer (11.8, 3.54 and 13.7 g per 100 g, respectively) and the dosages applied (Table 1), on average, both T1 and T2 received 75 mg of N, 22 mg of P and 82 mg of K /plant per day whereas T3 received 86 mg of N, 34 mg of P and 125 mg of K. In the fourth treatment (T4) the growing medium was amended with phospho-compost at the rate of 1 kg in two splits, based on the early work (Herath *et al.,* 2008) while irrigating a volume similar to T2 (Table 1). In addition, an aqueous extract of *Gliricedia sepium* leaves (at the dilution rate of 100 g/l and at the rate of 5 ml/plant per day) was applied as a foliar spray for T4 plants (Lakmini *et al.* 2007). The available N, P and K composition of phospho-compost is reported as 0.15, 1.66 and 1.92 %, respectively (Menike, 2004) while the N and K contents of the *G. sepium* leaf extract is 1.8 and 2.18 %, respectively (Smith, 2007). Based on these composition data, P and K supply to T4 was more or less similar to the standard dosage of Albert's fertilizer but in case of N, it was 50-65 % lower.

**Table 1. Fertigation treatments (per plant per day) of greenhouse tomatoes in grow-bag culture**

| | | **Growth stage** (*weeks after planting*) | | | | |
|---|---|---|---|---|---|---|
| **Fertigation treatment** | | **Early Vegetative** (*2 – 4*) | **Late Vegetative** (*4 – 8*) | **Flowering & Fruit set** (*8 –12*) | **Early Fruit growth** (*12 – 16*) | **Late Fruit growth** (*16 - 20*) |
| **T1** | Water (ml) | 500 | 500 | 800 | 1000 | 1000 |
| | Alberts (g) | 0.2 | 0.4 | 0.6 | 0.8 | 0.8 |
| | EC (mS/cm) | 0.29 | 0.51 | 0.45 | 0.51 | 0.51 |
| **T2** | Water[1] (ml) | 795 | 817 | 985 | 1462 | 1456 |
| | Alberts (g) | 0.2 | 0.4 | 0.6 | 0.8 | 0.8 |
| **T3** | Water (ml) | 1000 | 1000 | 1600 | 2000 | 2000 |
| | Alberts (g) | 0.2 | 0.4 | 0.6 | 1.2[2] | 1.2[2] |
| | EC (mS/cm) | 0.14 | 0.29 | 0.22 | 0.35 | 0.35 |
| **T4** | Water[1] (ml) | 705 | 618 | 714 | 929 | 1021 |
| | Phospho-compost[3] (g) | 500 | 00 | 500 | 00 | 00 |

[1] 150 % of evapo-transpiration [2] At 1:2 ratio of Ca $(NO_3)_2$: Rest of the plant nutrients
[3] As a single application per growth stage

Evapo-transpiration was estimated by applying lysimeter data in the soil water balance equation (Schwanki, 2007; Van Meurs & Stanghelini, 1992) for ET based water application (150% of ET) for T2 and T4. Foliar application of $Ca(NO_3)_2$ at the rate of 0.5 g $L^{-1}$ was applied across the treatments during the stage of fruit development to avoid blossom-end rot (BER). The basic crop management practices, beginning from nursery to harvesting were done according to the procedures described by Ontario (2002) and Weerakkody *et al*., (2008). The plants were maintained as two stems (main stem and side shoot). The fruits were thinned-out, keeping 4 fruits per cluster. The medium was flushed-out fortnightly to avoid the risk of mineral toxicity.

Plant growth was determined in terms of shoot and root growth parameters, determined in frequent intervals of the vegetative growth while yield characteristics were determined during reproductive stage and at harvesting. The plant nutrient compositions were determined as an estimate of plant nutrient uptake while nutrient analysis of medium and leachate (in T3) samples were determined to support it (Hochmuth, 2001; Van Ranst *et al.*, 1999). pH and EC measurements were taken in the medium and leachate samples in weekly intervals. GLM (General Linear Model) procedure was followed by Duncan's New Multiple Range Test (DnMRT), using Statistical Analytical Systems (SAS, 1990) for testing treatment effect and separating treatment means, respectively.

## RESULTS AND DISCUSSION

### Nitrogen uptake

Leaf nitrogen compositions in all the fertigation treatments gradually reduced with plant growth but increased again at the late fruit development stage, 20 weeks after planting (WAP). The leaf N levels of the treatments with Alberts fertilizer (T1 – T3) were well within the range specified for tomato at all four stages of plant growth (Bryson & Barker, 2002; Hochmuth *et al*., 2004) (Fig. 1). Therefore, supply of nitrogen and the conditions governing its uptake in the standard fertigation schedule and method (T1) appeared to be satisfactory throughout the crop growth at high ET rates (hot and dry weather). At higher EC of the solution, roots uptake water at a higher rate, enabling passive uptake of almost all plant nutrients (Sonneveld, 2000; Weerakkody *et al.* 2010). Even though the EC was lower in ET based fertigation treatment (T2) and circulation culture (T3) (0.29 - 0.51 mS/cm), the leaf N compositions did not significantly increased over the standard dosage (T1) up to 12 WAP. This could be an effect of low nutrient pressure on root hairs during the absorption process under low EC in the hydroponics solution as described in earlier reports (Jang & Nukaya, 1997). Accordingly, at late fruit development (20 WAP), elevated EC contributed for the highest leaf N composition in T3 (Fig. 1).

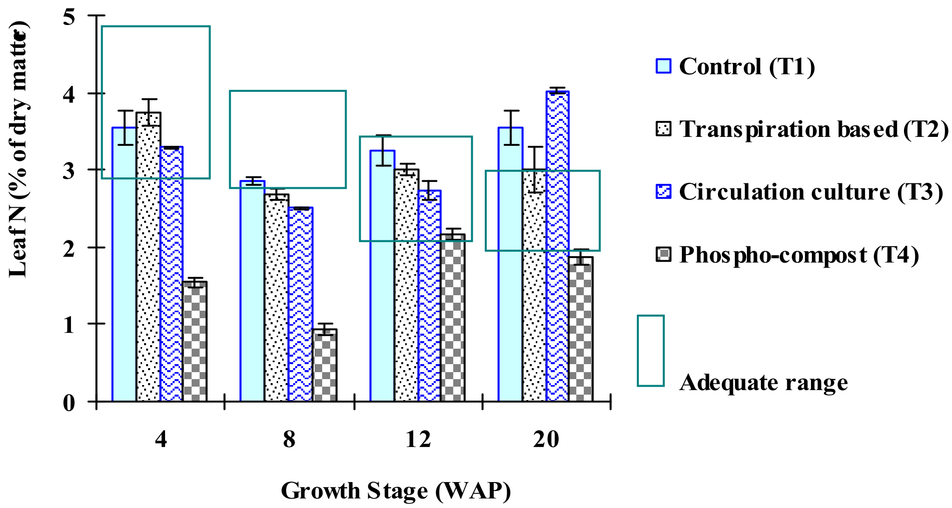


**Fig. 1. Leaf nitrogen composition of tomato under different fertigation methods**

[Vertical bars represent the S.E. of treatment means (n = 4)]

This could be a general trend of rapid nutrient uptake (Terabayashi *et al*., 2004). Reports on similar work have also shown rapid nutrient uptake from the solutions having a high EC under warm weather (Bryson & Barker, 2002; Burns *et al*., 2004; Nakano *et al*., 2006). Nevertheless, the increased K: N ratio during 12-20 WAP in T3 appeared to be favourable for N uptake. Meanwhile the phosho-compost treatment (T4) continued to be the lowest in leaf N throughout the crop growth.

On average, the N compositions of stems (0.77±0.22-1.68±0.69) and roots (0.99±0.2-1.05±0.26) were 20–60 % lower than leaf N levels at respective growth stages. Their treatment differences were not significant throughout the growth, except the lower root N levels found in T4 (Table 2). Compared to the N supply (75 mg/plant), analysis of medium and leachate at the end of 24 hour irrigation cycle at the flowering stage (8 WAP) proved evidences of N depletion in the root environment (Table 3). This can be further assured by comparing medium and the leachate N contents with the critical levels specified for peat grown tomato at flowering (30 mg/kg) by Bryson and Barker (2002). The medium N was always much lower than the leachate N in all the treatments. Eventhough medium N in T4 was comparable with other treatments, lower leachate N testifies for the low solubility of nitrogen in phospho-compost. Hence, significantly lower level of leachate N in T4 implies the severity of strain underwent by the plants in phospho-compost based medium, justifying for comparatively low N uptake (tissue contents) and resultant plant growth and yield retardations (as described later in the paper).

**Table 2. Variability of stem and root nutrient compositions of tomato (in g 100/g) with fertgation method, at two growth stages**

| | N | | P | | K | |
|---|---|---|---|---|---|---|
| | 4 WAP | 12 WAP | 4 WAP | 12 WAP | 4 WAP | 12 WAP |
| **Stem** | | | | | | |
| T1 | 1.97±0.28[a] | 1.35±0.45[a] | 0.5±0.010[a] | 0.32±0.04[a] | 4.75±0.00[a] | 1.57±0.07[a] |
| T2 | 2.1±0.13[a] | 0.89±0.03[a] | 0.52±0.01[a] | 0.36±0.02[a] | 4.83±0.17[a] | 1.56±0.10[a] |
| T3 | 2.01±0.13[a] | 0.79±0.06[a] | 0.58±0.03[a] | 0.39±0.00[a] | 4.83±0.30[a] | 1.32±0.10[a] |
| T4 | 0.65±0.04[b] | 0.68±0.07[a] | 0.53±0.03[a] | 0.37±0.02[a] | 4.5±0.140[a] | 1.63±0.10[a] |
| **Root** | | | | | | |
| T1 | 0.76±0.14[b] | 1.18±0.08[a] | 0.1±0.030[a] | 0.37±0.00[a] | 0.39±0.12[a] | 0.18±0.08[a] |
| T2 | 1.18±0.06[a] | 1.24±0.04[a] | 0.15±0.04[a] | 0.29±0.00[b] | 0.57±0.06[a] | 0.22±0.04[a] |
| T3 | 1.13±0.05[a] | 1.13±0.10[a] | 0.12±0.02[a] | 0.19±0.03[c] | 0.46±0.01[a] | 0.34±0.03[a] |
| T4 | 0.90±0.01[b] | 0.66±0.3[b] | 0.06±0.03[a] | 0.26±0.00[b] | 0.22±0.10[a] | 0.57±0.08[a] |

*Means with same letters are not significantly different with each other.

## Phosphous uptake

Similar to the trend observed with respect to leaf N compositions, leaf P compositions also gradually reduced with plant growth but without a marked increase in the latter part of reproductive development. All fertigation treatments maintained the leaf phosphous compositions within or near the favourable range for tomato throughout the crop growth (Hochmuth *et al*., 2004). The Circulation treatment (T3) contained the highest leaf P levels from flowering to late fruit growth (8–20 WAP) (Fig. 2). Therefore, the availability of P and the conditions governing its uptake in T3 appeared to be satisfactory. As reported by Nukaya *et al*. (1995) and Kim *et al*. (2008), the uptake concentration of P is less than K and $NO_3$-N. Therefore, the reason for higher rate of P uptake in T3 might not be due to active uptake but due to improved availability of P within the root zone, as a result of repeated flow (circulation) through the growth medium (Weerakkody *et al*., 2007).

Meanwhile relatively high P composition of phospho-compost (T4) have been able to keep the leaf P composition within the favourable range throughout the time unlike some other treatments which falls below at certain growth stages (Fig. 2).

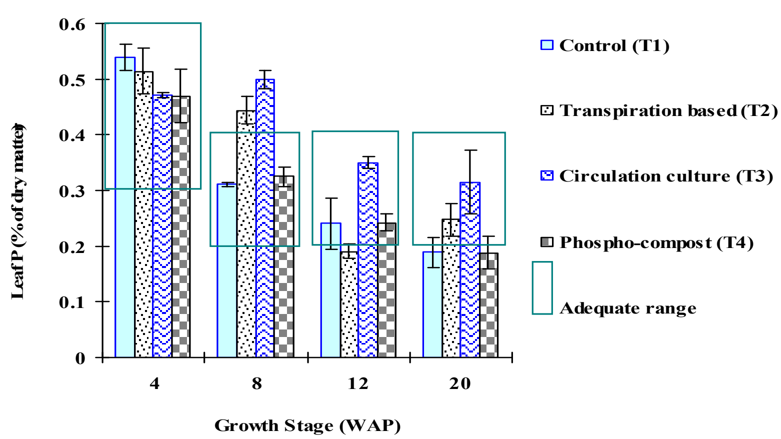


**Fig. 2. Leaf phosphorus composition of tomato under different fertigation methods**

[Vertical bars represent the S.E. of treatment means (n = 4)]

**Table 3. Nutrient contents in coco-peat medium and the leachate at flowering stage (8 WAP)**

| Treatment | Medium (mg/kg) | | | Leachate (mg/l) | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| Standard dosage (T1) | 0.12 | 4.43[a] | 122.2 | 2.2 [a] | 4.49 [a] | 81.5 [a] |
| ET based (T2) | 0.22 | 3.01 [ab] | 100.0 | 1.9 [a] | 3.62 [a] | 56.5 [b] |
| Circulation (T3) | 0.25 | 5.42 [a] | 133.3 | 2.36 [a] | 1.89 [b] | 96.8 [a] |
| P-compost (T4) | 0.22 | 2.03 [b] | 133.3 | 1.31 [b] | 3.69 [a] | 102.4[a] |

On average, the P compositions of stems (0.2±0.05 - 0.53±0.03) were highly fluctuating around the leaf P levels at different growth stages while it was always 25–50 % lower in roots (Table 2). Root P compositions gradually increased along with crop growth, from 0.11±0.04 to 0.28±0.07 until early fruit growth stage. Similar to N, P content in the medium and the leachate at the flowering stage were much lower than the supply concentration (for T1–T3) at the end of 24 hr fertigation cycle. Critical P levels in the cocopeat medium (30 mg $kg^{-1}$), given by Bryson and Barker (2002) indicates a depletion of P in the medium after 24 hours, similar to the fate of N. Hence, roots might have undergone a strain during last few hours of the fertigation cycle with respect to uptake of N and P. The medium P concentration in T4 was significantly lower than the other treatments but it was not considerably low compared to the P composition in phospho-compost (Table 2). Meanwhile, leachate P in T3 was significantly lower, probably due to rapid uptake as shown in leaf P data. Unlike the case of N, P contents of the medium and the leachate were at a similar range.

**Potassium uptake**

Leaf potassium composition of fertigation treatments were within or near the range specified for tomato (Hochmuth *et al*., 2004) only during 4 WAP and 20 WAP. K reserves in leaves appeared to be depleting to cater to the demand from reproductive boom of the plant during 8–12 WAP. The treatment differences in leaf K were not significant, except at 8 WAP, where the differences were in the order of T1 and T2 > T3 > T4 (Fig. 3). Even though circulation culture have catered to the high N and P demand during flowering and fruit growth relatively well, its contributions to the K demand was not significant. This is contradictory with the earlier reports where a major portion of K and $NO_3$-N uptake were active from a hydroponics solution with low EC (Nukaya *et al*., 1995). However, the reports on the low priority received by cations (i.e. $K^+$) over anions in the process of penetrating through membranes of root tissues (Halvin *et al*., 2005) support this result.

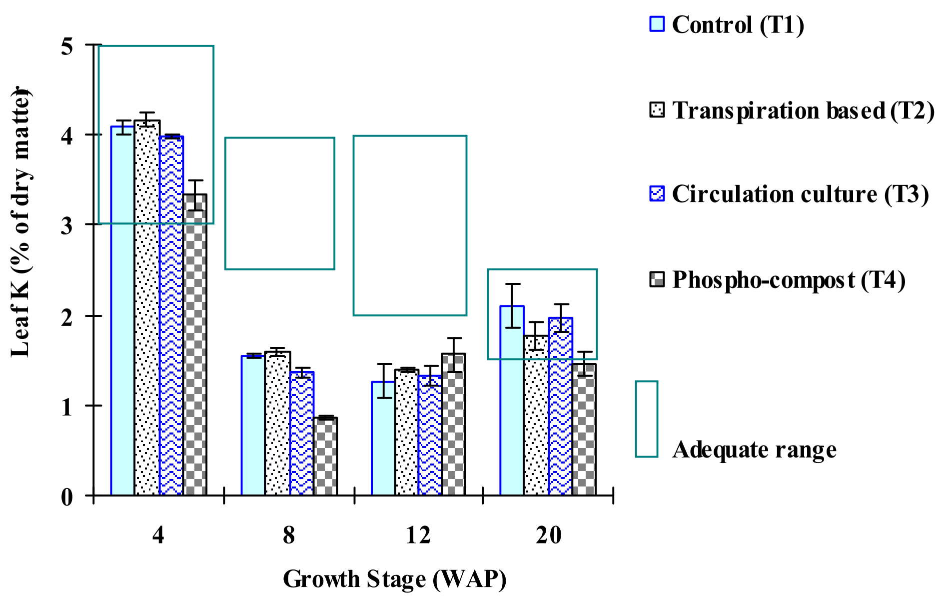


**Fig. 3. Leaf potassium composition of tomato under different fertigation methods**

[Vertical bars represent the S.E. of treatments means (n = 4)]

Meanwhile, the effect of elevated dosage of fertilizer and K:N ratio in circulation culture during 12–20 WAP has been limited to increase in leaf N, showing a deviation from the general trend of macro nutrient uptake (Nakano *et al*., 2006; Weerakkody *et al*., 2010) and particularly K uptake (Klaring *et al*., 1999; Kim *et al*., 2008). Therefore, unlike the early stages, low leaf K contents at 20 WAP could not be a sole effect of low uptake rate but be attributed to partitioning of K into fruit sink, as testified by the yield data.

Treatment differences in stem and root K compositions were not significantly different. Stems contained more or less the same K composition to leaves while roots contained only 25–40 % of the leaf K compositions at any given stage of plant growth (Table 2). K contents in the medium and the leachate were much higher compared to N and P contents at the flowering stage (Table 3). In contrast to N, and P, the medium and leachate K levels did not show a notable reduction from the daily supply (82 mg/plant) within a 24 hour period, indicating lower uptake rate as well as partial adherence to cation exchange sites. Low leachate K contents (30–50 %) compared to the medium K contents testifies for low mobility of K in the medium. However, yet the medium and leachate K contents were much lower than the critical level specified for K in cocopeat grown tomatoes at flowering (300 mg/kg, Bryson & Barker, 2002), leading to the suggestion for more intensive K fertigation in Alberts fertilizer based methods.

## Residual nutrients in the medium

The EC of the medium (coco peat) determined at the end of 24 hr irrigation cycle during the stages of flowering and fruit set were much lower than the set level in T1 and T2 (from 0.51 to 0.08 mS/cm) but it was more or less the same in the leach ate, indicating a well balanced nutrient and water uptake. However, the change in the medium EC of circulation culture (T3) after 24 hours (from 0.29 to 0.12 m/cm) was lower than T1 and T2 while the leachate EC has increased (to 0.56 m/cm), indicating accumulation of mineral ions in the medium with circulation of the nutrient solution. Furthermore, the uptake balance has been on the side of the water compared to overall mineral uptake. Relatively high N and K in the medium and leachate of T3 (Table 3) together with its complementary ions (data not presented) support this result.

Meanwhile the leachate EC of phospho-compost treatment (T4) was significantly lower (0.28 mS $cm^{-1}$) than soluble fertilizer (Albert's) applied treatments. This may be a consequence of low rate of nutrient release from pohspho-compost. Meanwhile, retardation of early vegetative growth in phospho-compost treatment (T4) mainly due to low N availability (30 mg/plant per day) could have given arise to low demand for water. Thus, low rate of water uptake together with the low EC in the leachate could be the main reasons behind the low rate of plant nutrient uptake from the phospho-compost based medium, despite the fact that the compositions of P and K in the leachate were comparable with the other treatments.

Meanwhile, pH values of the leachate showed a general drift towards alkalinity 24 hrs after fertigation, causing possible low availability of P and other micro elements (Schwarz, 1995) at least towards the end of the 24 hour fertigation cycle. The drift towards alkalinity is much higher in the phospho-compost treatment (8.17), compared to Albert's treatments (7.67+0.3). Lower P contents in the leachate of T4 (Table 3) support this fact.

**Fruit yield and yield components**

Based on the reports on varietal trials, the variety Volcano bears nearly 26 marketable fruits with an average weight of 140 g, giving a marketable yield of 2-3 kg per plant under favourable greenhouse climatic conditions in the wet zone of Sri Lanka (Ranasinghe & Weerakkody, 2006; Wahundeniya *et al*., 2006). In contrast, this research performed much lower fruit number (13-15 per plant) and lower mean fruit weight (78 -110 g), contributing to a marketable yield of 1.2–1.5 kg/plant from the Albert's treated plants at the end of the harvesting period (20 WAP). The treatment having a limited water supply (T1) was at the lower extreme while transpiration based water supply (T2) and excess water supply through circulation (T3) were at the upper extremes of the yield and fruit size charts (Fig. 4). For instance, relatively small fruit formation and low yield of standard fertigation (T1) compared to ET based fertigation (T2) can be attributed to under-irrigation in T1 (with respect to ET) where tissue compositions of N, P and K between the two treatments were not significantly different in almost all the growth stages.

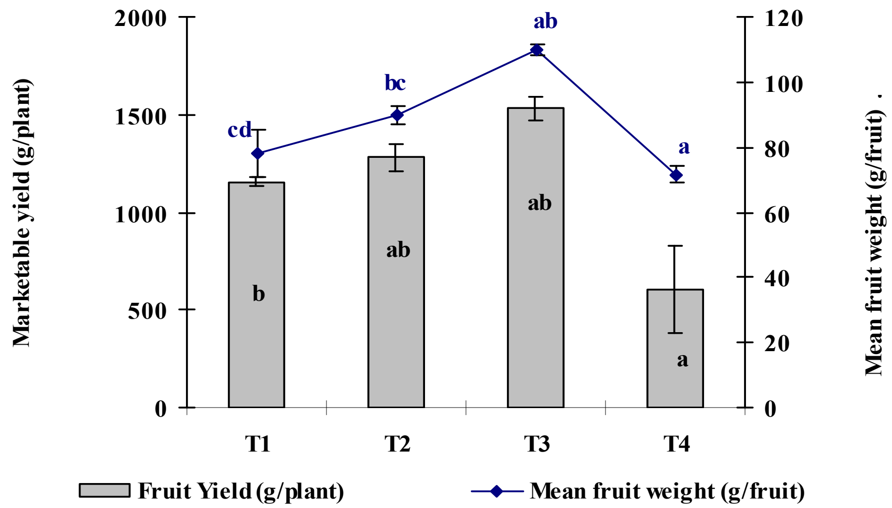


**Fig. 4. Marketable yield and fruit size of tomato under different fertigation methods**

[The same letter within one yield parameter indicates statistical similarity among treatments (DMRT/P<0.05). Vertical bars represent the S.E. of treatment means (n = 4)]

As reported by Kitano *et al*. (1998) suppressed respiration in tissues under water deficit inhibits the expansive growth and sugar accumulation in the fruits. Hence, suppressed sap flow and fruit respiration affect the fruit growth in water deficit plants. The suppression of fruit growth and resultant low yield in less water applied treatments could have been driven through reduced rate of photosynthesis in leaf tissues and moisture accumulation in fruit tissues as a consequence of low rate of uptake and transportation of water (less than the ET demand) (Moore *et al*., 1958; Waister & Hudson, 1970; Pill & Lambeth, 1980; Mitchell *et al*., 1991). Rudich *et al*. (1977) and Tan (1988) reported that water stress causes to form small fruits and reduce the fresh yield, specifically in tomato. Hence, the severe set back found in the mean fruit weight and yield of tomato in this experiment could have been heavily influenced by the water stress under tropical (hot and humid) conditions in the greenhouse.

According to the same argument, the comparative yield advancements shown by the circulation culture (T3) could have been partly influenced by extra irrigation as reported by Karlen *et al*., (1985). As discussed earlier the concentration of plant nutrients, denoted by EC of the supply solution, mainly determines the uptake rates of water and mineral ions. Hence low EC maintained in T3 might have a better tendency for the water uptake, emphasizing its influence of more water uptake for the fruit enlargement.

The rate of mineral uptake which increases leaf area and net assimilation rate (Nakano *et al*., 2006; Weerakkody *et al*., 2010), could be another contributing factor for the fruit yield. The duel role of leaf area, by increasing the rate of photosynthesis (Bhattarai, 2005) and increasing the rate of transpiration based rapid transport of mineral nutrients and water (Tan, 1988) would be the driving forces behind the synthesis and partitioning of dry matter in tomato. Based on the correlations of fruit size and yield with tissue compositions of the three macro nutrients, the contribution of P for fruit growth is more pronounced, despite the fact that its regression has been earlier identified to be nonlinear (Terabayashi *et al*., 2004). In addition, enhanced N uptake during fruit development could also have favoured this yield advancement.

Low mean harvest index (HI) is another indicator for further improvement needs in the yield. Similar to yield and fruit size records, HI of circulation culture treatment (T3) was 0.5, which was much higher than the other treatments. This is an indicator of its better crop management and high-yielding ability (Scholberg, *et al*., 2000). According to some other studies, HI starts decreasing when irrigation exceeds 0.75 fold of ET for tomato (Rummun *et al*., 2003). Therefore, the irrigation regime maintained in T3 appeared to be within the favourable range of irrigation (0.5 - 0.75 % of ET).

Phospho-compost treatment (T4) had significantly lower fresh marketable yield and fruit size than the other treatments. Apart from the water stress, this situation could also be attributed to low availability of major plant nutrients (i.e. N and K) in the growth medium. The fruit number was similar in all Albert's fertilizer treatments due to cluster pruning but T4 produced significantly lower fruit numbers per plant. Therefore, fruit weight or size would be the only reliable yield parameter.

## CONCLUSIONS

Standard fertigation of 0.2 g of Albert's fertilizer dissolved in 500 ml/plant per day provided adequate N, P and K nutrition for tomato grown in coco peat bag culture during the vegetative growth under tropical greenhouse conditions. The subsequent growth stages needed excess irrigation (800 – 1500 ml) under warm/sunny weather. Fertigation with twice high dosage of essential plant nutrients, (other than N and Ca) beginning from the early fruit development (12 WAP) in circulation culture improved N and P nutrition leading to improved fruit growth and yield. Application of 1 kg of phospho-compost/plant in two splits together with foliar spraying of *Gliricidia sepium* leaf extract could not be identified as a replacement for fully soluble fertilizer in bag culture of tomato except for the rate of P uptake. Further improvements can be suggested for K nutrition in the circulation culture of fully soluble fertilizers and for N availability in the phospho-compost based plant nutrient supply.

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