A low-cost NFT with recycled tire tubes for tomato cultivation

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Abstract: Due to urbanization and the increasing world population, people are facing various challenges, such as growing food demand, limitations in soil for agriculture, and the disposal of waste materials. The generation of waste tire tubes is one of the rising issues. Utilizing waste tire tubes for agriculture could be a great solution. However, many novel growing methods, such as the nutrient film technique (NFT), require expensive materials. This study aims to evaluate the growth, yield performance, and fruit quality of hybrid tomatoes (Umagna) cultivated in different hydroponic systems, including an NFT system made with recycled tire tubes. The results of this study demonstrate that tomato plants were grown using two different methods: the open bag system (OBS) and the NFT system. Plant growth parameters varied among the treatments, including plant height, number of leaves, and days to first flowering. The average number of fruits per plant was higher in the NFT system. Plant height exhibited the highest mean values in the NFT system until the second inflorescence stage, while OBS recorded the highest plant height at the end of the experiment period. The growing method had a significant effect on the total fresh matter content. The dry matter content of roots and leaves was significantly higher in the NFT method. This study shows that the NFT system provides the opportunity to produce higher tomato yields compared to those obtained by conventionally used OBS.

Keywords: nutrient film technique, open bag system, hydroponics, soil cultivation technique.

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1 Introduction

Today most of the urban areas are more likely to towards modern methods of agriculture. Where cultivable land and water are severely depleted and fresh vegetable production is a major challenge (Cámara et al., 2022). Therefore, during the past decades, the protected cultivation system of vegetable crops has become the most efficient and to obtain quality fresh food for both domestic and export marketplaces (Campos et al., 2024).

Soilless cultivation is currently gaining popularity around the world due to quality food production and efficient resource management. Hydroponic is a novel crop-growing method under soilless cultivation. It uses an aerated, water-enriched nutrient solution and a form of mechanical support of an inert medium. There are several methods of hydroponic growing systems such as nutrient film technique (NFT), drip system, aeroponics, ebb flow, water culture, and wick system (Jones, 1983; Campos et al., 2024).

Currently, NFT hydroponic cultivation systems are widely used. This system seems to reduce the weakness of the drainage system (Cámara et al., 2022). The main principle of the NFT system is a nutrient

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solution that continuously recirculates an oxygenated nutrient solution to flow back to the tank for crop production. It enters the growing container without time control through a water pump and then flows continuously through the roots (Lakshmanan et al., 2020). In this NFT system, the plant roots are hung in channels called gullies, where a thin film of nutrient solution flows through thus keeping the roots moist but not logged. The nutrients are mixed accordingly in a primary tank from which it flows through the system continuously feeding the plants at a rate of 1 liter per minute. The system can be adjusted with automation for aeration (Cámara et al., 2022).

The NFT is mostly suitable for a variety of crop production and is ideal for short-term crops such as lettuce, leafy crops, and herbs. Larger NFT systems are suitable for long-term crop production, such as tomatoes and cucumbers (Peralta Manjarrez et al., 2023).

However, the current NFT system is associated with a few drawbacks such as the cost of systems for design and location, the need for skillful persons, and the rapid spread of a disease once it enters the system (Lakshmanan et al., 2020). One of the major problems associated with the socio-economic development of the world is waste disposal. The environmental pollution resulting from industrial wastes and waste living materials is serious problem in recent years. Waste tires and tubes are increasing more and more due to the increasing of vehicle uses. But their having short lifetime, which cause to huge quantity of tire related waste collection. Also, uncontrolled, open, waste tire fires cause serious damage to the environment, effect on soil, water, and air is a major problem (Peralta Manjarrez et al., 2023). As a result, several heavy metals can find way into soils and water, and enter the food chain and consequently living tissues of plants, animals, and human beings (Campos et al., 2024). The present study was carried out to assess the environmentally feasible, low-cost NFT using recycled tire tubes on the growth and yield performance of tomatoes under protected environmental conditions.

2 Materials and method

2.1 Experimental site details

This study was conducted under a non-temperature-controlled polythene-covered greenhouse at the Serene International Sri Lanka (Pvt) LTD, Malpotha, Mirahawaththa during the period from August 2020 to December 2020. The experimental field belongs to the Agroecological zone of the Upcountry intermediate zone, IU_3. Serene Company was located at 6.9019° N latitude and 80.9079° E longitude and an altitude of 1,017 meters above sea level.

2.2 Experimental treatments

Treatments were arranged with 7 replicates. Tomatoes were grown in coco peat as OBS (Treatment 1), and NFT (Treatment 2) (Fig. 1). The OBS consisted of seven equal-sized grow bags (Black and white color). Each bag was filled with fresh coco peat [EC (Electrical Conductivity) - < 0.5 mS cm^{-1}, pH- 5.5-6.5]. Each pot contained one tomato plant. Every replicate was connected to an irrigation nozzle for fertigation (Fig. 2).

2.3 NFT hydroponic system

The NFT hydroponic system consisted of a plastic bucket and recycled tire tubes. A plastic bucket of 50 L was used as a nutrient tank. It had inlet and outlet facilities connected to the tire tube channel. A tire tube channel was created with two recycled tire tubes (9.00” R 20”), which surface painted white, connecting them as half circles. Corrosion resistance wire (SCW-01, 1.5 mm) was used to bear the tube channel structure joining them, as a spring (Fig 3 and 4). A part of the tire tube was laid on top of the spring to build smooth water flow in the channel. A submarine water pump (RS-1400, 25 W) was used to supply nutrients to the system while an air pump (RS-081, 3 W, 2.5 L min^{-1}) aerated the nutrient tank. The water flow slope was 1 ft for 100 ft. and the flow rate was 1 L min^{-1}. The system was fixed on a table 1m above the ground surface. The solution collected from the Channel system as used nutrient solution collects and recirculates again through the system using a PVC

(1/2”) line. There were seven holes in the tire tube Channel structure. Net pots filled with coco peat were placed in each hole. One tomato plant was established on each hole. The water level in the nutrient tank was adjusted at a depth of 0.45 m to maintain the water volume of 30 L. The desired level of water in the system was maintained by regular supplementation of water and nutrient solution.

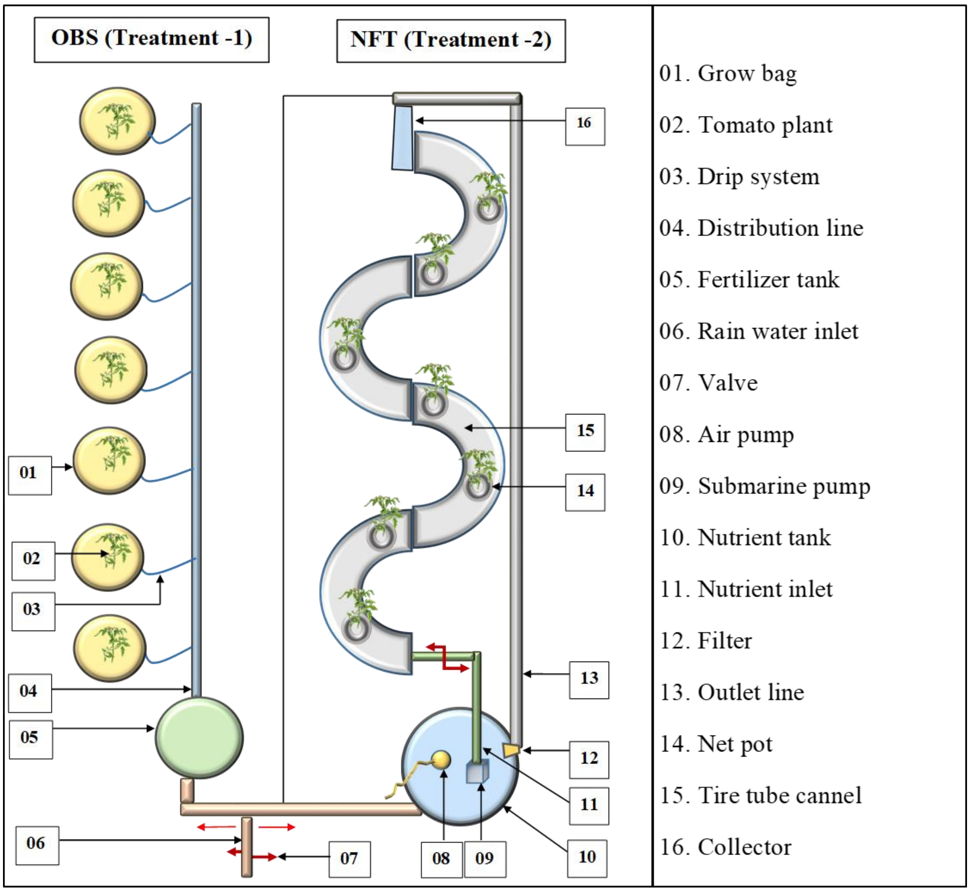

Figure 1 Design of the experiment

Figure 2 Open bag system

Figure 3 Inside of the NFT Channel

Figure 4 Tire tube made NFT system and OBS (left, right)

2.4 Plant establishment agricultural practices

The Umagna variety was cultivated in a media-based OBS and NFT. In each treatment, seven seedlings were planted. Tomato seedlings were directly planted in grow bags filled with coco peat. Tomato seedlings were established in seven net pots before transfer to NFT. Net pots with plants were placed in the hole of the channel and fertigation practices were done using a wick attached to the bottom of the net pot. Air temperature and inside of the tire tube temperature were measured three times a day using a digital thermometer (FY-10 LCD). Once at 9.00 AM, 12.00 PM and 3.00 PM. Using a pH meter, placed at a height of 1.5m from the floor surface. The potting space between the two plants was 45 cm. The plants in OBS and NFT was irrigated with a nutrient solution containing Albert's solution during the vegetative stage. With the appearance of bunches, the nutrient formulation was changed.

The same EC and pH values were maintained in fertilizer according to the growth stage wise to feed the plants. The volume of the nutrient solution lost by evapotranspiration was completed with rainwater and nutrient solution daily. Until it reached the initial volume of 30 L per experimental plot. Harvest started at 71 days after transplanting (DAT) and ended at 91 DAT. Fruits were harvested at the red stage. Red means that more than 90% of tomato surface in aggregate, is red. The fruits were classified according to Baltazar et al. (2008) in Table 1.

Table 1 Size classes of tomato fruits (Baltazar et al., 2008)

Class	Weight (g)
Giant	>100
Big	>80 up to 100
Medium	>65 up to 80
Small	>50 up to 65

2.5 Measurements

The weight of fresh matter, fruit diameter, height, width, and length were evaluated in the first 6 fruits per plant. Soluble solids (ºBrix), EC, and pH were evaluated in two fruits of the bunch showing 100% of the red surface.

The plant height was recorded from the fourth week after transplanting and thereafter on a fortnightly basis until the plants reached nearly 2 m in height. The number of leaves was also counted on each plant on a fortnightly basis.

The number of flowers per plant was counted on a fortnightly. Days to flower were recorded as the number of days from sowing until 50% of plants reached peak flowering. Other parameters, including the number of flowers per inflorescence, number of fruit set per truss, and first harvest date, were recorded throughout the growing stage. Tomatoes were harvested after 85 days from sowing. The total number of harvested fruits per plant at harvest time on each replicate was counted each time and the mean was calculated. The yield in terms of total harvested fruit weight was recorded in grams on each replicate during each harvest. A summation of the several harvests was recorded and the mean was worked out. Evaluating the weight, fruits were categorized as marketable (>50 g) and non-marketable (<50 g).

Fruit length of seven randomly selected fruits from the replicates was measured from base to the tip of the fruit and expressed in millimeters. The width of same fruits was measured taking circumference and dividing in into two and expressed in millimeters. The fruit diameter of the same selected fruits was measured by using a 15 cm ruler and expressed in millimeters.

In the last harvest, the stem diameter (measured in the region just above the first bunch and below the first leaf in the position above it) was measured using a Vernier caliper.

Fruit firmness was measured with a hand penetrometer [Fruit pressure tester, Model: FT 327 (200 g-20 Kg), with 0.7 mm × 0.92 mm of probe's size]. Fruit firmness was determined on three fruits per treatment. Fruit firmness (kgf/cm^2) was recorded at the equatorial surface for each individual fruit using a destructive technique. Fruits were harvested at the red stage. The firmness readings were taken at harvest day.

The TSS was determined by calculating the average TSS for the three fruits per treatment for each replicate. The total soluble solids (TSS) content was measured using a hand-held refractometer [Model SKU: MT- 032 (Brix, 0-32%). The final value was obtained by determining the average of the replicate for each treatment.

The pH and EC contents of fruit juice were measured using an EC/pH meter [Model: PCTEST-35]. Determination was done by calculating the average pH and EC for the three fruits per treatment for each replicate. The final value was obtained by determining the average of the replicate for each treatment.

Fresh leaves, fresh stem and fresh root were weighed using a weighing balance scale, (SF-400, 10000 g ×1 g). Dry matter content of the plant was determined by drying samples in an oven at 60°C, until a constant weight is obtained. The average monthly water consumption for each open bag method and NFT hydroponic method were recorded.

3 Statistical analysis

Data were analyzed using Minitab 19.1 statistical software with a two-sample t-test.

4 Results

4.1 Plant Growth parameters

As seen in Table 2, the growth method and DAT have an effect on plant height. Although the plants in the NFT exhibited the highest plant height up to 56 days, during the last two weeks, the OBS recorded the highest plant height. There was no significant difference in the number of leaves. The NFT took the fewest days (43 days) to reach the first flowering stage. Additionally, the NFT recorded the highest number of flowers per plant.

Table 2 Effect of days after transplanting on plant height (cm)

	Days after transplanting (DAT)			
Treatment	28	42	56	70
1-OBS	64.43	112.86	137.57	166.86
2-NFT	70.71	121.43	140.14	160.29
LSD	0.003	0.020	ns	0.014

Note: LSD= least significant difference, ns= non-significant

4.1.1 Number of leaves

Both treatments had a significant difference in a number of leaves per plant. Highly significant variations of 28 DAT, 42 DAT, and 56 DAT were observed (Table 3). NFT had a high number of 7, 11, and 15 leaves. Also, 70 DAT, treatments had significant differences in a number of leaves per plant. But comparison means of OBS, tomato plants showed that higher number of leaves per plant in NFT with 19 and 18 leaves respectively.

Table 3 Effect of days after transplanting on number of leaves

	Days after transplanting (DAT)			
Treatment	28	42	56	70
1-OBS	6	10	14	19
2-NFT	7	11	15	18
LSD	<0.001	0.031	0.002	0.042

Note: LSD= least significant difference

4.1.2 Days to first flowering

The treatment 1-OBS had taken 46 days from sawing to first flowering (Table 4). However, the treatment 2- NFT hydroponic system took significantly less days (43) than OBS to obtain the first flowering. It will be the most economically important factor for the commercial production of tomato fruits. Also, the first harvest was obtained from NFT, three days earlier than OBS.

4.1.3 Number of flowers per plant

The number of flowers is presented in (Table 4). As can be seen in the table, the Number of flowers per plant in treatment 1-OBS and treatment 2-NFT had significant differences. Maximum number of flowers per plant (16) recorded in hydroponic NFT. As a result, NFT had increased total yield.

Table 4 Plant growth parameters

Treatment	Days to first flowering	Number of flowers/plant
1-OBS	46	14
2-NFT	43	16
LSD	<0.001	0.001

Note: LSD= least significant difference

4.2 Yield parameters

4.2.1 Total yield per treatment

Table 5 contains the average values of total yield per plant. However, the NFT showed a comparatively higher yield than treatment OBS. At the harvesting stage, a comparatively higher yield per plant (1459.0 g) was obtained in NFT, and a lower yield per plant (1258.0 g) was noticed in the OBS.

4.2.2 Number of fruits per plant

In this study, NFT was increased tendency towards a high number of fruits per plant at NFT compared to OBS (Table 5). The maximum number of mean fruits was recorded in NFT. Therefore, growing method have a significant effect on average number of fruits per plant compared to other treatments.

4.2.3 Average weight of fruit

Both treatment's average fruit weight mean values are comparatively equal. Therefore, the OBS and NFT showed nearly similar average fruit weight that was not statistically significant (OBS= 117.8 g, NFT= 120.29 g) (Table 5).

4.2.4 Number of marketable fruits per plant

The average number of marketable fruits per plant is outlined in Table 5. The results demonstrated that the growing methods did not have a significant effect on average number of marketable fruits per plant. Therefore, both treatments had an equal number of marketable fruits per plant (10 fruits/plant).

Table 5 Effect of different treatments on tomato yield

Treatment	Total yield / plant (g)	Number of fruits / plant	Average weight of fruit (g)	No of marketable fruits
1-OBS	1258.0	10	117.8	10
2-NFT	1459.0	12	120.29	10
LSD	ns	0.041	ns	ns

Note: LSD= least significant difference, ns= non-significant

4.3 Fruit quality parameters

4.3.1 TSS, pH, and EC values of fruit juice

TSS, pH and EC, fruit diameter, width, length, and firmness were investigated under quality parameters. The OBS method recorded a higher value of pH (5.04) (Table 6). The OBS recorded (9.17 mS cm^{-1}) and the treatment NFT recorded 9.25 mS cm^{-1} of EC value.

Table 6 Influence of growing method on the fruit chemical parameters

Treatment	pH	EC mS cm^{-1}	TSS
1-OBS	5.04	9.17	4.07
2-NFT	4.91	9.25	4.32
LSD	0.026	0.006	ns

Note: LSD = least significant difference, ns= non-significant

4.3.2 Fruit diameter, width, and length

In this experiment, comparison means of fruit width per plant recorded that maximum fruit width related to NFT (99.61 mm) that had not any significant difference with OBS (98.19 mm). Types of growing methods had not significantly influenced fruit firmness. Fruits from OBS were firmer than fruits from NFT, but not significant (Table 7).

Table 7 Influence of growing method on the fruit yield parameters

Treatment	Fruit diameter (mm)	Fruit width (mm)	Fruit length (mm)	Fruit firmness (kgf/cm²)
1-OBS	56.01	98.19	91.64	2.52
2-NFT	56.50	99.61	91.41	2.45
LSD	ns	ns	ns	ns

Note: LSD= least significant difference, ns = non-significant

4.4 Fresh matter content and dry matter content of plants

A comparison of means showed that the fresh weight of roots of NFT had a significant difference than OBS. The maximum total fresh weight of roots was noted in NFT (65.0 g) (Table 8). There was no statistically significant difference in the fresh weight of the stem, fresh weight of leaves, and total fresh weight of the plant in both tested treatments. Table 9 shows the dry matter content of tomato plants. As can be seen in the table, the treatments had significant difference on average dry matter weight of plant roots.

NFT and OBS recorded 8 g and 6 g respectively. Maximum dry weights of roots (8 g), stem (24 g), and leaves (19.71 g) were recorded in the NFT. However, there was no statistically significant difference in the dry weight of stem and dry weight of leaves in the tested treatments. Concerning the total average dry weight of the plant, the maximum average weight (51.71 g) was observed in NFT. However, there was no significant difference in average total dry matter content per plant within Treatments.

Table 8 Fresh matter content of Tomato plants

Treatment	Fresh weight of roots (g)	Fresh weight of stem (g)	Fresh weight of leaves (g)	Total fresh weight of plant (g)
1-OBS	41.0	139.4	138.7	319.1
2-NFT	65.0	136.6	138.0	339.6
LSD	0.001	ns	ns	ns

Note: LSD= least significant difference, ns= non-significant

Table 9 Dry matter content of Tomato plants

Treatment	Average dry weight of roots (g)	Average dry weight of stem (g)	Average dry weight of leaves (g)	Total dry weight of plant (g)
1-OBS	6.00	21.86	18.14	46.00
2-NFT	8.00	24.00	19.71	51.71
LSD	0.031	ns	0.031	ns

Note: LSD= least significant difference, ns= non-significant

Table 10 Total yield, total fertilizer addition and fertilizer use efficiency (FUE) caused by growing methods

	OBS	NFT
Total yield per treatment (kg)	8.85	10.21
Mineral fertilizer addition (kg)	0.826	0.542
FUE (kg kg^{-1})	10.71	18.83

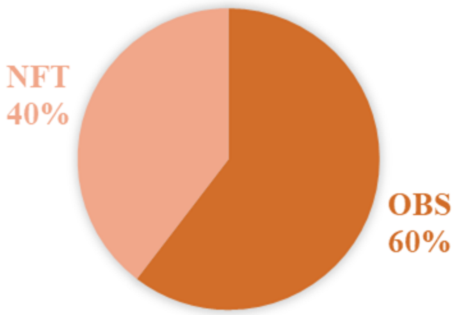

Figure 5 Fertilizer usage during experiment

4.5 Fertilizer use efficiency (FUE)

As can be seen in Table 10, the addition of total fertilizer into the NFT is reduced by 34.40%. Compared to plants grown in the OBS. The FUE was improved by 75.81% in service of the NFT system (fig. 5).

5 Discussion

5.1 Plant growth parameters

Different substrates have direct or indirect effects on plant growth and development (Gutiérrez et al., 2012; Mielcarek et al., 2023). Wang et al. (2007) stated excess water results in the tomato plant being too high and thin. The OBS showed a significant height of plant growth (OBS-166.86 cm). Therefore, the results of this research agree with the literature findings. In this research, the NFT recorded the lowest days to first flowering and first harvest which mean favorable conditions for production. The reduction of the vegetative growth period, survival of the plants in adverse conditions are resulted in a delay in flowering, fruit development and fruit maturity, and final harvest (Mielcarek et al., 2023). Cooper (1977) states optimum vegetative growth and the increase in branch length are essential to flower clusters development in a tomato plant. Although genetically and physiologically phenomena also affect flower clusters occurring. As well as pruning of the plant side shoots, nutrient availability and uptake by plants of different kinds and strengths of the solutions also influence the number and pattern of the flower clusters in tomatoes (Campos et al., 2024). The results of this research agree with the literature findings. NFT recorded a high number of flowers/plants (16). Byari and Al-Sayed (1999) stated that the reduction in stem diameter is due to increased time of irrigation intervals between successive irrigations. It means plants were under water stress. Zhai et al. (2010) reported that stem diameter increased with plant growth, and the final stem diameter is larger in treatments with more irrigation water applied. The results are agreed with the finding of this research because NFT recorded the maximum girth which was high in nutrient and water availability.

5.2 Yield parameters

Sonneveld (2000) and Cámara et al. (2022) stated that the EC threshold value determines the reduction in yield; after this point, a linear decrease in yield parameters. There were no significant differences in total yield among growth methods. The low air temperature decreases the fruit set formation in tomato plants. Currently, most of the greenhouse tomato growers use several practices to increase the fruit setting, fruit development, and accelerating maturity. Mostly the indeterminate type varieties are bred in greenhouse or hydroponics cultivation (Mielcarek et al., 2023). Also, if lower truss is there and not harvested, it causes to weakly growth of the upper part and even matures very late. Collins et al. (2022) stated that tomatoes grown in the NFT and conventional systems and, both are compared to good quality with commercial yields. Therefore, NFT systems crops can be cultivated simply by measuring the pH and electrical conductivity of the nutrient solution.

The NFT recorded a comparatively higher yield than OBS (1459.0 g) with a significantly higher number of fruits per plant (12 fruit/ plant). Research conducted by Preedy and Watson (2008) reported to the fact that the reduced number of fruits was due to the high application of Ca: Mg ratio fertilizers. Beardsell et al. (1979) reported that a combination of mixtures possesses both aeration and water-holding characteristics respectively which may contribute to crop yield. Lack of elasticity causes to increase in the incidence of tomato fruit cracking among cultivars. It causes product failure in the marketplace (Logendra et al., 2001; Sainju et al., 2003; Collins et al., 2022).

Dorais et al. (2001) reported that fruit weight was affected when the EC threshold was above 4 dS m^{-1}, and when the EC value was above 8 dS m^{-1}. It also causes to reduction in the number of fruits. In this research there was no rapid EC change reported on average fruit weight.

5.3 Fruit quality parameters

Concentrations of high ammonium in the solution can reduce TSS and increasing in macro elements concentration in nutrient solution result to increasing of TSS of fruits. The flavor is the most important quality aspect for the consumer of fresh fruits, and a balanced proportion of sugar/acid is essential. For a better fruit flavor, high levels of sugars and acids are required. Low sugar and high acid content can result in an astringent/sour taste. As well as several tomato cultivars with a high juice pH generally had lower Brix value and indicating that the acidity of these fruit was lower. And also, Dorais et al. (2001) reported that greenhouse-grown brix value varied from 4.7 to 5.1. However, this result disagrees with research finding because the values of this research were recorded as NFT = 4.32, OBS= 4.07.

This research showed that NFT tomatoes are more acidic than OBS tomatoes. Gava et al. (2009) stated that foods are classified into three categories: low acidity (pH >4.5); acid (pH 4.0 - 4.5), and very acid (pH < 4.0). Sakiyama and Stevens (1976) stated that to environmental effects on fruit acidity are comparatively different. Opiyo (2005) reported under shading conditions fruits grown in protected environments result to lower photosynthetic activity of the tomato plant. It causes lower acidity and lower carbohydrate accumulation in the fruits occur. Azarmi et al. (2010) reported that higher EC values caused an increase in TSSs and organic acids, parameters determining the taste of tomatoes.

Mazuela et al. (2012) reported that plant-growing media used in soilless culture has little effect on fruit width and size of the fruit. This research also showed little effect on fruit width.

Azarmi et al. (2010) stated that hydroponically grown tomatoes' average fruit diameter they grew (not mention the name of the cultivar) remained around 53.5 mm. These results agree with the findings of this research. (NFT-56.50 mm, OBS-56.01mm).

Campos et al. (2024) reported that the firmness of the tomatoes ripened on the vine was significantly higher, by 15.5%, than the firmness of the tomatoes ripened off the vine. In this research, the tested tomato variety was a vine type.

5.4 Fresh matter content and dry matter content of plant

Tindall et al. (1990) stated that root-zone temperature is effect to growth of tomato plant. Carbon distribution to the roots, root growth, water and nutrient uptake, leaf area expansion and carbon dioxide exchange rate were decreased by low root-zone temperature. Additionally, Harmanto et al. (2005) reported that root growth and root activity were improved by root-zone cooling, leading to the ensuing promotion of shoot growth. It is important to the morphological and physiological mechanisms that determine the effects of temperature on roots. In other cases, shoot growth increases when the nitrogen supply is increased, and root growth decreases at the same time. It directly affects to final dry matter content of tomato plants. Anyway, due to the same environmental condition, there were no significant differences in total fresh and dry matter content.

5.5 Production cost of hydroponic systems

The conventional NFT system for 100 plants typically costs between $210 and $315. This cost includes structural items such as NFT channels, which range from $150 to $200, electronic items like the pump ($25 to $45), plumbing materials ($20 to $40), and the growing medium, which adds $15 to $30 to the total. While this setup provides a reliable solution, it can be expensive for smaller or resource-constrained growers.

In contrast, a system utilizing waste tire tubes as a replacement for NFT plastic channels offers a more affordable alternative. The total cost for this setup is approximately $70 to $185, with structural items (waste tire tubes) ranging from $0 to $50, electronic items (pump) priced at $25 to $45, plumbing materials at $20 to $40, and the growing medium costing $15 to $30. Additionally, mechanical items like a corrosion-resistant coil add $10 to $20 to the cost. This method not only reduces expenses but also promotes a more sustainable and eco-friendly approach to hydroponic farming.

6 Conclusion

This study highlights the potential of utilizing recycled tire tubes in hydroponic systems like the NFT to address agricultural challenges. Results indicate that the NFT system outperforms the OBS in terms of tomato yield, plant growth, and dry matter content. By repurposing waste materials for sustainable agriculture, the study offers a practical solution to resource limitations while promoting higher productivity.

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Conflicts of Interest

The authors declare no conflict of interest.

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