The effect of animal manure extracts as a source of nutrients on growth, yield, and quality of hydroponically grown tomatoes (*Solanum lycopersicum* L.)

By

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Declaration

I, **Ayanda Luthuli**, 216045582, hereby declare that the research presented in this thesis is my original work. I confirm that this work does not include any information or data from others unless properly acknowledged/ cited. The data from this study has not been submitted to any institution for the purpose of obtaining a degree.

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General abstract

Tomatoes rank as the second most vital vegetable crop in the world, they are grown globally except Antarctica. They are highly nutritional as they contain vitamins and antioxidants that benefit human health. The cultivation of these fruits is however costly due to the overuse of chemical fertilizers since their nutrient formulations are very expensive. Thus, this study assessed the potential of animal manure extracts on the growth of tomatoes under hydroponic production system. The first experiment evaluated the nutrient concentrations of fresh manure and vermicompost from three different sources (chicken, cow and goat) and to further optimize nutrient extraction by passive and active extraction methods. The second experiment investigated how extracts from animal manure influenced growth, leaf gas exchange and chlorophyll fluorescence of tomatoes (cv. CLX 532) grown in the soilless hydroponic system. The third experiment assessed the impact of animal manure extracts on yield, physiochemical and nutritional quality of tomatoes grown in soilless hydroponic cultivation.

The findings showed that, over the composting period, cow manure increased all nutrients, goat manure increased N, P, Ca, Mg, Zn, Cu and Mn; while chicken manure enhanced P, Ca, Mg, Zn, Cu and Mn. Aerated compost tea had a higher nutrient content than non-aerated compost tea, chicken-based compost tea (N, P, K, Ca, Mg, Zn, Mn, Cu and EC), cow-based compost tea (P, Mg, Cu and Zn) and goat-based compost tea (P, K, Ca and Mg). Therefore, pre-composting before vermicomposting is highly recommended. Furthermore, using the active extraction method (aerated) increased the nutrient availability in the animal-based compost tea.

The findings for the second experiment showed that applying goat manure extract (GME) and chicken manure extract (CHME) boosts plant height, stem diameter, fruit number, intercellular CO_2 rate (*Ci*), intrinsic water use efficiency (*WUEi*), maximum fluorescence (*Fm*) and non-photochemical quenching (*qN*) while cow manure extract (CME) increased stomatal conductance (*gs*), maximum quantum efficiency of photosystem II (*Fv/Fm*) and electron transport rate (*ETR*). The findings for the third experiment showed that the application of CHME enhanced the number of fruits, shoot mass, TSS, TA, TSS/TA, BrimA, colour index and firmness, CME affected shoot mass, while GME affected TSS/TA, BrimA, firmness and phenolics concentration. Furthermore, fruits fertigated with the commercial fertilizer were rich in macronutrients, whereas those fertigated with animal manure extract (AME) had elevated levels of micronutrients. Based on these findings, animal manure extracts could serve as an alternative source of nutrients in the soilless production of tomatoes, especially CHME and

GME. They improved growth, yield, leaf gas exchange, chlorophyll fluorescence and overall fruit quality.

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Preface

This thesis is a collection of individual manuscripts, each chapter functioning as an independent entity, which has led to some unavoidable repetition between chapters.

Table of contents

Table of Contents

List of tables

List of figures

Chapter 1

General introduction

1.1 Background

The current population globally is reported to surpass 7 billion and stats estimate that it will exceed 9 billion in 2050 (Lutz and KC, 2010). Approximately 48% of the world's population resides in urban areas, in Africa about 47% of people currently live in cities (Ekpenyong, 2015; OECD and Commission, 2020). There is a shortage of funds to support infrastructure development to accommodate the needs of the growing population, moreover, achieving food security is a growing concern for developing countries (Matuschke and Kohler, 2014).

Due to urban development, a high number of people are moving to the cities in search of jobs and economic freedom, which increases the urban population. This increase in population causes an up rise in food demand and other social issues such as limited land for human settlement, and poor provision of essential services, for example, water and sanitation. In South Africa, the current unemployment percentage is reported to be at 30.8% which results in poverty, food insecurity and malnutrition in children, and pregnant and breastfeeding women (Tacoli, 2013).

Urban agriculture has been seen as a possible solution to address the unemployment and food security challenges. However, urbanization is one of the challenges of agricultural production because it plays a role in decreasing cultivable land, reducing water availability for farming, and increasing the cost of transportation from production land to urban markets. More farmers lost their land ownership because of the increasing purchases of property investment (Putra et al., 2020). In cities, growers have no legal land ownership due to the pending new construction and infrastructure projects. Furthermore, much of the cultivable land has health hazards such as when crops are grown in hygienically dubious conditions on dump sites, on the premises of sewage works or next to the road (Maisonet-Guzman, 2011).

Climate change is another major challenge in agricultural production, which negatively affects growth and development of crops, performance of the livestock, water availability, aquaculture yields, and the functioning of ecosystem services in all areas. Furthermore, these effects are anticipated to exhibit significant geographic disproportionate, particularly affecting areas which are reliant on rainfall for irrigation (Tacoli, 2013).

In addition, crop diversity loss, urban sprawl and unsustainable agricultural practices also affect crop yield. One of the main contributing factors is unsustainable methods of producing crops, about 30% of arable soil is expected to experience erosion by 2050 (Maisonet-Guzman, 2011). In developing countries, farmers commonly grow their crops in marginalised conditions where extreme natural events such as droughts or floods occur more often (Matuschke and Kohler, 2014). However, several attempts have been made to counteract the aforementioned problems and some recommendations made involve the use of hydroponics systems.

Hydroponic crop production is regarded as one of the innovative cultivation technologies offering solutions for known agricultural constraints such as land scarcity and soil degradation. It is a technique for cultivating plants in soil-less conditions, either by using an artificial medium (sand, gravel, sawdust, vermiculite etc.) or completely submerging plant roots in a nutrient solution (Jan et al., 2020; Jensen, 1997). Hydroponic production is suitable for the production of many crops including vegetables, fruits, herbs and ornamental crops with limited land and crop cultivation can be done all year round without being limited by season (Charoenpakdee, 2014; Sheikh, 2006). The use of hydroponic systems is advantageous because; it circumvents soil-borne diseases, enables vegetable cultivation in areas with soil infertility and improves yield and quality (Mowa et al., 2018). Furthermore, it eliminates pests, fungi and weeds without the use of pesticides and herbicides, reduces health risks and time required for planting, and reduces harvest time (Atmadja et al., 2017).

A study done by Jan et al. (2020) reported that according to growers, with hydroponics they can produce harvests any time of the year, in less space with a controlled growth environment, anywhere, in a short period allowing them to have high yield and productivity without being limited by climate and weather conditions. However, the utilization and adoption of hydroponic systems by growers and farmers have been reported to face some resistance due to high capital investment for installations and the high requirements of inorganic fertilizers.

Contrary to the use of synthetic fertilizers, the use of organic waste is becoming popular and has gained momentum worldwide including in countries such as Thailand where liquid fertilizers are produced from agricultural residues and industrial wastes (Phibunwatthanawong and Riddech, 2019b). These fertilizer nutrients are produced through fermentation utilizing organic wastes as carbon substrates and they consist of vital nutrients for plants and helpful microorganisms that facilitate the recycling of organic material (Phibunwatthanawong and Reddech, 2019b).

Liquid manure is applied to boost growth and yield in crops because of the enhanced nutrient availability and the improved soil chemical and physical properties (Dordas, 2008; Matsi, 2011). Its effectiveness as fertilizer depends on the following factors; animal species, diet, digestibility, protein and fibre content, animal age, housing, environment and stage of production (Lorimor, 2000). However, different types of manure have different impacts on plant production for example; chicken manure extract contains N-indole-3-acetic acid, gibberellins, cytokine, and humic acid which stimulates seedling growth (Tikasz et al., 2019). The organic nutrient solution from goat manure improves plant growth and yield performance of tomato crops, produces bigger and fleshier tomato fruits (Mowa et al., 2018), and increases the vegetative performance of tomato plants and reproductive growth (Mowa, 2018).

1.2 Problem statement

Although the hydroponic system is regarded as the suitable solution to overcome the challenges of land scarcity, soil degradation and inefficient use of water, most hydroponic systems use inorganic solutions as fertilizers which are applied via fertigation. The leaching of nutrients, through runoff irrigation is reported to be the main contributor to serious environmental pollution hence destroying the balance of the ecosystem (Charoenpakdee, 2014). Phibunwatthanawong and Riddech (2019a) reported that chemical fertilizers have health risks related to its consumption as a result of the buildup of harmful chemicals in fruits and vegetables. In addition, the higher use of inorganic fertilizers in hydroponic systems comes at a hefty cost for the farmers since the nutrient formulations of these fertilizers are very expensive. Commercial farmers can access these fertilizers; through closed-loop agriculture, they are also able to recycle the nutrients. However, this is a challenge for poor farmers since they cannot afford inorganic fertilizers and plants cannot survive without their applications due to the excessive use of inert growing medium which lacks essential nutrients for plant growth.

Globally, the livestock sector is rapidly developing thus the increase in animal waste production which is now becoming a serious environmental hazard. Disposal of animal waste into surface water, groundwater, soil, and air contributes to the deterioration of the country's surface waters and has many human health and ecological impacts (Copeland et al., 2006), the decomposition of organic waste leads to an unpleasant odour, dispersion of chemicals pollutants, fumes and gases into the atmosphere (Kostic et al., 2020). Moreover, methane gas can be released and may contribute to global climate change (Singh and Rashid, 2017). One of the effective ways to reduce waste disposal is to reuse the animal waste in plant production.

Due to the aforementioned issue, using organic nutrients as a fertilizer in hydroponic crop production is viewed as a possible long-term solution (Phibunwatthanawong and Riddech, 2019a). The use of liquid manure, also referred to as manure extracts or compost tea has gained increasing interest as it stimulates plant root and vegetative growth and promotes antifungal activity which reduces the severity of plant pathogens (Nartey et al., 2017; On et al., 2015). However, if they are derived from industrial waste, they may contain high concentrations of toxic metals and have high energy requirements (Tikasz et al., 2019). The cost of transporting and applying these nutrients is usually higher because they have less nutrient concentration available per unit mass, therefore they should be applied in bulk. A study by Williams and Nelson (2014) concluded that the challenge with using organic fertilizers in hydroponics systems was obtaining plant yield which is comparable to those grown with inorganic fertilizers. This was due to nutrient deficiency in some sources of manure. Furthermore, pH, EC and nutrient management is also difficult. Studies investigating the effect of liquid manure on plant growth in hydroponic systems have discovered inconsistent findings (Ingham, 2005; Leudtke and Razvi, 2010).

Additionally, most high-valued crops (tomato, pepper, cucumber and greens) grown under hydroponic cultivation systems tend to decay faster. Poor handling and transport system affect produce quality, thereby affecting postharvest losses which are 24-40% in developing countries and 2-20% in developed (Faried et al., 2022). Tomato crops have a short life span due to higher water content and respiration during their ripening period. Thus, the imperative to increase the quality of food available globally in a sustainable manner should encourage more research on agricultural approaches, to increase the nutritional composition of fresh fruits and vegetables while prolonging shelf life (Ceglie et al., 2016).

1.3 Justification

The use of hydroponic system is supposed to help small scale farmers utilize the limited land available to optimize plant production by intensifying agriculture. Furthermore, hydroponically produced crops have higher and more nutritional value (Andrian et al., 2019; Tikasz et al., 2019). Integrating animal manure extract and hydroponics offers small scale farmers an affordable alternative source of nutrients that can optimize tomato plant growth, yield and nutritional quality. The use of animal waste extract as alternative to inorganic fertilizers also helps to reduce environmental pollution.

Tomato is a tropical fruit which means it is a warm season crop, it can survive some cold but it cannot tolerate to extremely low temperatures. However, we are in subtropical zone where our winters are very cold ranging from 16- 25℃. Under protected hydroponic cultivation farmers are able to produce tomatoes all year round irrespective of seasons, crops mature quicker, and there is high germination and plant growth (Pattnaik and Mohanty; Sheikh, 2006). Thus, there is a need to integrate hydroponics systems with animal manure extract for small scale farmers to optimize tomato production sustainably.

1.4 Aim

This study aims to evaluate the feasibility of using animal manure extract as a liquid/soluble fertilizer for hydroponically produced tomatoes and to determine their effect on growth, quality and yield performance of tomatoes.

1.4.1 Objectives

i. To assess how the conversion of solid manure to liquid extracts can be improvised by trying different extraction methods and the effect it has on nutrient composition and availability in animal manure extract.

ii. To investigate the effect of animal manure extracts on the growth, leaf gas exchange and chlorophyll fluorescence of tomatoes (CLX 532) grown in the soilless hydroponic system.

iii. To evaluate the effect of animal manure extracts on yield, physicochemical and nutritional quality of tomatoes grown in soilless hydroponic cultivation.

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Chapter 2

The use of animal manure for soilless crop production: A review

Abstract

The worldwide cultivable land is currently 0.2 ha per capita and is projected to decline to 0.15 ha in 2050. The forecasted decrease will largely be due to urbanization, industrialization, climate change, natural disasters, and unlimited use of chemicals for agricultural purposes which compromises soil fertility and quality. Alternative cultivation methods such as a hydroponic system have become crucial in ensuring sustainable food production. Under a hydroponic system, the plants are cultivated with a nutrient-rich water and fertilizer solution essential for their growth. The fertilizer which is used as a source of nutrients is dissolved in water to form an appropriate concentration and supplied to the plants via irrigation. One major benefit of a hydroponic system is that it ensures higher productivity and yields without being limited by climate and weather conditions. However, there are still unresolved challenges with the use of chemical fertilizers in hydroponic systems such as the discharge of already-used nutrient solutions which negatively affect the environment. Although significant research progress has been made with regard possible reuse of nutrient solutions to control pollution. However, the integration of animal manure extracts into hydroponic systems remains underexplored because many types of manure yet to be utilized. A considerable number of studies have shown that animal manure extracts enhance plant growth and increase crop yield. This could benefit small-scale farmers since animal manure is abundantly available and affordable. This study aims to highlight different methods of soilless culture, manure as organic fertilizers, and its composition. It will further touch on the already existing information on the use of different animal manure extracts in hydroponics systems.

Keywords: Animal manure, hydroponics/ soilless culture, liquid organic fertilizer, nutrient solution

2.1 Introduction

The hydroponic system is the technology of plant cultivation in a nutrient solution with or without the use of any inert medium such as gravel, vermiculite, rockwool, peat moss, saw dust, coir dust, and coconut fibre to give structural support (Jensen, 1997; Sharma et al., 2018). It is commonly used to produce vegetables and ornamental crops (Charoenpakdee, 2014).

The hydroponic system offers various benefits, including the elimination of weeds, and other soil-borne diseases thus reducing health risks due to the limited use of herbicides. It is also regarded as the most efficient technology because it decreases the time for planting since there is no need to prepare the ground before planting, thus resulting in reduced harvest time and higher crop yields (Atmadja et al., 2017). However, hydroponic systems have a high use of inorganic fertilizers. The adverse effect of using these chemical fertilizers is two-fold, namely financial and environmental. The high use of organic fertilizers in hydroponic system comes at a high price for farmers since the nutrient formulations of these fertilizers are very expensive (Phibunwatthanawong and Riddech 2019; Mowa, 2018). The release of used nutrient solutions to the environment leads to pollution, thus resulting in an imbalance in the ecosystem (Charoenpakdee, 2014). A study by Setiawati et al. (2019) reported that when the nutrient concentration is very low the plant will have a nutrient deficiency while extremely high concentrations lead to toxicity.

There is a growing awareness among individuals regarding their health and the environmental impact of using chemicals in food production, thus, there is a shift towards organically-produced food. The organic food market is rapidly growing because organic food is perceived as environmentally friendly, more nutritious and healthy compared to inorganic food (Charoenpakdee, 2014; Mditshwa et al., 2017). For this reason, some farmers have shifted to organic production because it reduces the cost of production, particularly if there is a reliable local source of nutrients (Charoenpakdee, 2014). However, organic fertilizers are not readily available to farmers, moreover, if they are not properly used and handled, they can cause serious environmental problems (Singh, 2012). These environmental problems include the contamination of water bodies and the reduction of oxygen content in water, making it unsafe for consumption, and the death of aquatic animals (Aderinoye-Abdulwahab and Salami, 2017).

Organic fertilizers have important plant nutrients and microorganisms including both beneficial and potentially pathogenic. A study done in Brazil by Antoneli et al. (2019), reported that the use of animal manure had a beneficial effect on the fertility of the soil, organic matter content, and crop production. **Table 2.1** shows a list of previously published reviews on the soilless production of crops. However, there is limited information on the use of manure in soilless culture. This review aims to outline and understand soilless culture, and the effect of animal manure on soilless crop production. The suitability of animal manure extracts and their impact on hydroponically grown vegetables will also be highlighted.

Table 2.1: Previously published reviews on soilless production of horticultural crops.

Review title	Citation
Seawater potential use in soilless culture.	(Atzori et al., 2019)
Do soilless culture systems have an influence on the product quality of vegetables.	(Gruda, 2009)
A review on the science of growing crops without soil (soilless culture) A novel alternative for growing crops.	(Hussain et al., 2014)
Soilless culture system to support water use efficiency and product quality.	(Putra and Yuliando, 2015)
A review on the effect of different soilless growing media on vegetable production.	(Saurabh et al., 2019)
Application of soilless culture technologies in the modern greenhouse industry.	(Savvas and Gruda, 2018)

2.2 Soilless culture

The term soilless culture defines the technique of growing plants without the use of soil as a medium where the inorganic nutrients are delivered via fertigation (Putra and Yuliando, 2015). The fertilizer comprising vital nutrients is dissolved into the irrigation water at the appropriate concentration, thereby creating a nutrient solution. This practice originated in 1666 when Boyle tried to grow plants using nothing but water and later reported that one species of *Raphanus aquatic* survived for 9 months (Olympios and Choukr-Allah, 1999). Currently, it is a routine cultural practice to provide a nutrient solution via fertigation or liquid fertilization to plants to optimize crop nutrition, not only in soilless culture but also in greenhouse-grown crops. (Putra and Yuliando, 2015). The soilless culture is often used for producing high-quality and less minimally processed vegetables because the technique is easy to use, cost-effective and resource-saving (Conversa et al., 2021). In soilless culture, the plant roots may grow on substrates that are irrigated with nutrient solution regularly or directly in a nutrient solution without any solid phase. Soilless systems are classified based on leachate management as either open- or closed-loop systems (Baudoin et al., 2013).

An open-loop system is when water and nutrients are provided similar to soil culture and excess nutrients and water are allowed to run to waste thus lowering water-use efficiency and polluting groundwater supplies with salts (Goddek et al., 2019). The leachate may be collected and reused as a fertilizer or lost causing damage to the environment (Baudoin et al., 2013). The attraction of this technique is its similarity to the soil as a growing medium and many comparable methods have been developed using various inert media such as rock wool, sand, vermiculite, perlite and pumice (Putra and Yuliando, 2015). Tognoni and Pardossi (1998) mentioned that an open-loop system may exploit saline water as there is no risk of progressive salt accumulation in the root zone if enough drainage is maintained.

In closed-loop systems, the drained nutrient solution is restored into the system and reused. The routine control of nutrient solution is required in this system, the plants utilize water more efficiently compared to an open-loop system because of less water and nutrient loss to the environment (Tüzel et al., 2019). This system uses less substrate thus decreasing environmental pollution from its disposal (Goddek et al., 2019). In addition, a closed-loop system requires technical expertise as it is more sensitive to operational errors, especially in spring because the nutrient concentration in the solution may rise as temperatures and solar radiation increase (Putra and Yuliando, 2015). The recycled nutrient solution must be treated to restore its initial nutrient element composition and to remove any alien substances. Furthermore, root-borne diseases can be easily transmitted thus, it is essential to sterilize the solution (Putra and Yuliando, 2015). Sterilization is the process of disinfecting the recirculating nutrient solution to eliminate pathogens (Ehret et al., 2001). It can either be by physical methods (heat treatments, UV radiation, membrane filtration, and slow sand filtration) or chemical methods (Ozone, hydrogen peroxide, sodium hypochlorite, chlorine dioxide, copper-silver ionization and active carbon adsorption) (Van Os, 2009). Ahn et al. (2021) reported that microbial management in the closed-loop soilless culture system could be conducted more efficiently than in the open-loop system without any water and fertilizer losses to the ecosystem. Both open and closed-loop systems can be implemented using different types of techniques depending on whether the soilless culture method used is a water or gravel culture.

2.2.1 Water culture

Water culture is a method of growing plants with or without a solid substrate. In this method, plant roots are submerged in a solution that contains minerals that are important for plant growth (Sharma et al., 2018). In water culture, a large volume of solution is always in contact with the roots thus providing enough water and nutrients needed by the plant (Jan et al., 2020; Sheikh, 2006). There are different types of water culture, these include deep water culture, nutrient film technique, float hydroponics and aeroponics.

2.2.1.1 Deep water culture

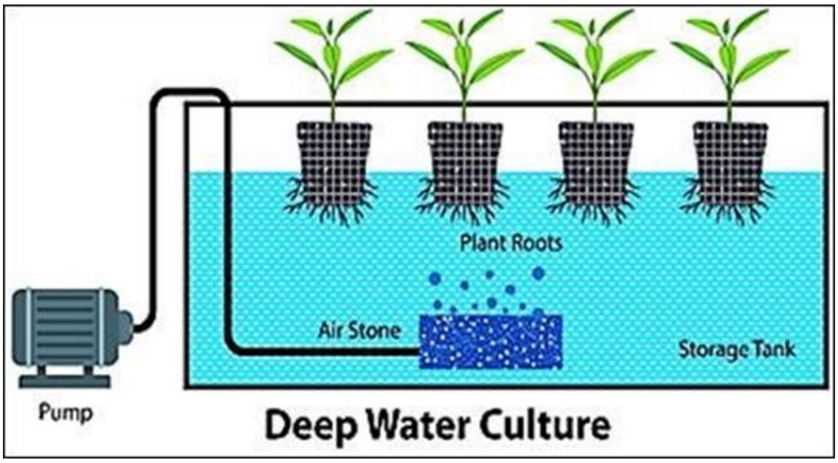

Figure 2.1: A diagrammatic representation of deep-water culture (Source: Bhagawati, 2020).

Deep water culture (DWC) was the first soilless technique proposed for commercial purposes in the year 1929 by Professor W.F. Gericke. In this method of cultivation, a bucket full of the hydroponic nutrient solution is covered with a net-like material and a cloth with a sheet of sand to provide support for the plants; the roots are completely submerged in the nutrient solution (Bumgarner and Hochumuth, 2019). The downside of this system is the lack of oxygen at the root level which is caused by the restricted water exchange area, relative to the solution volume and the low oxygen diffusion coefficient in water (Baudoin et al., 2013). This challenge can be solved by using an air pump to provide oxygen to the nutrient solution by recycling the deep water culture system (Savvas et al., 2013). This system is most suitable for the cultivation of larger plants that produce fruits, especially cucumbers and tomatoes (Sharma et al., 2018).

2.2.1.2 Nutrient film technique

Figure 2.2: Nutrient solution flows through the root system of lettuce in the gullies (NFT) (source: Mahakur, 2023).

The nutrient film technique (NFT) is a cultivation technique where plants are grown in PVC pipe-like growing channels that have a soluble fertilizer pumping through watertight passages such as gullies, troughs, or gutters where the roots of the plants are positioned. The nutrient solution is placed into a large reservoir where it is pumped into the planting channels with the thin water stream ensuring enough oxygenation of the roots (Baudoin et al., 2013). The nutrient film system is well suited for the production of both short-term crops (lettuce, leafy crops and herbs) and long-term crops (cucumber and tomatoes) (Mohammed and Sookoo, 2016). Furthermore, it is the best method for the protection of the degradation of natural resources.

In NFT, the channels are on a slope (1%-2%) hence plant roots are not completely submerged in water (Savvas et al., 2013). When delivered into the channel, the nutrient solution travels down the incline, passing over the plant roots to supply the appropriate nutrients. while keeping the roots completely submerged (Bumgarner and Hochmuth, 2019).

This practice can be very helpful in countries with limited land resources. Compared to traditional soil production, growing crops through NFT is more flexible and allows growers to manipulate their crops more freely (Burrage, 1997). A study by Wheeler et al. (1990) reported that using NFT was a feasible method for cultivating potatoes in a controlled environment, especially with advancements in cultivation techniques and equipment.

Float hydroponic

Figure 2.3: Lettuce growing in float hydroponic (source: Sweat et al., 2004).

A float hydroponic system employs a reservoir where plants are suspended allowing their roots to hang freely within the nutrient solution (Bumgarner and Hochumuth, 2019). This system was first used in 1976 to grow lettuce (*Lactuca sativa*), cardoon (*Cynara cardunculus L*) and strawberries (*Fragaria x ananassa*) and now it is used for the cultivation of fresh-cut leafy vegetables and aromatics (Baudoin et al., 2013). This system can be cost-effectively built for home growers by using either wooden frames lined with plastic or other containers that are watertight such as buckets, tubs, and small swimming pools. Lightweight plastics with holes drilled at intervals are used to support the plants in plastic mesh pots (Savvas et al., 2013). To maintain oxygen in the nutrient solution of this system, an air bubbler or oxygen injector is required (Bumgarner and Hochumuth, 2019). Pumping the nutrient solution in this type of hydroponic system is not mendatory because the plants are floating on the nutrient solution.

2.2.1.3 Aeroponics

Figure 2.4: Aeroponics for potato seeds (mini-tuber) production (source: Challam et al., 2019).

In aeroponics, plants are grown with the roots supported in a fine mist of nutrient solution applied continuously (Sheikh, 2006). The plants are anchored in holes on polystyrene panels using polyurethane foam. Nutrients and water are delivered supplied by misting the plant's hanging roots with an atomized nutrient solution using sprayers, misters or foggers which are inserted in PE or PVC pipes placed in the unit (Baudoin et al., 2013). This method may be utilized for the cultivation of small vegetables (e.g. lettuce and strawberries), medicinal and aromatic plants (Savvas et al., 2013). Using this method is advantageous because it increases plant density, there is high water use efficiency and allows four annual cultivation cycles (Olympios and Choukr-Allah, 1999).

2.2.2 Substrate culture

Figure 2.5: Engineered wood substrate as a potting medium. (source: Jackson, 2019).

Substrate culture is a soilless system that supports the plant through a solid inorganic medium (sand, gravel, perlite, rock wool, and volcanic stones) or organic medium (peat, bark, coir, and rice hulls) (Baudoin et al., 2013). In substrate culture, nutrient solutions are supplied through irrigation and excess solution is allowed to run to waste or recirculated (Olympios and Choukr-Allah, 1999). Currently, planting on a substrate is the commonly used soilless method of cultivation to produce greenhouse peppers, cucumbers and tomatoes (Baudoin et al., 2013).

2.2.3 Advantages and limitations of soilless culture

Soilless culture provides necessary tools for handling salt stress in plants by preventing salinity levels from exceeding the tolerance threshold of crops which may adversely impact plant growth and productivity (Conversa et al., 2021). Also, there is an absence of soil-borne pathogens, moreover, the system eliminates pests, weeds and fungi without the use of herbicides and insecticides. The application of water and nutrients is more even to the plants thus decreasing the loss of nutrients and providing conditions that are almost optimal growing environment (Baudoin et al., 2013; Putra and Yuliando, 2015). Furthermore, with the soilless culture, it is possible to produce high yields and good quality in areas with poor soil fertility (Sardare and Admane, 2013). Notably, under soilless culture, there is no need to till the soil before planting and this significantly reduces operational costs for the growers (Savvas et al., 2013). Moreover, there is an improvement in initial crop yield when planted during the colder season due to elevated temperatures in the root zone during the day (Baudoin et al., 2013; Putra and Yuliando, 2015).

Although soilless culture offers various benefits as mentioned, the significant expense of installation and the technical skillset required are often prohibitive for growers (Baudoin et al., 2013). It also requires more extensive input for both construction and maintenance than traditional soil production (Olympios and Choukr-Allah, 1999) and doesn’t guarantee high-quality produce (Gruda, 2009). In a closed soilless culture, plants share the same nutrient extract which makes it easy for water-borne diseases to spread (Tüzel et al., 2019). Moreover, due to climate change, there are serious challenges in crop production. This is hindered by extremely high temperatures and limited oxygenation can easily lead to significant losses of crops under soilless production (Sharma et al., 2018). Hence, it would be ideal to practice soilless cultivation under a protected structure.

2.3 Organic fertilizers

The use of organic fertilizers as a source of nutrients for crop production is not new; about 12,000 years ago people applied animal residues, river humus, animal and human excreta to the soil to nourish plant crops (Loss et al., 2019). Back then, people depended on animal manure for fertilization of soil and upkeep of crop nutrition (Risse et al., 2006). However, due to a scarcity of animal manure in specific areas and seasons, alternative fertilizers had to be included in agricultural production.

Compared to inorganic fertilizers, organic fertilizers offer various benefits for crop and soil health. Numerous studies have demonstrated that organic fertilizers enhance productivity and crop performance (Ledum et al., 2020, Sanista et al., 2019), improve root growth and nutrient uptake (Budiyanto and Achmad, 2022; Gichaba et al., 2020) and stimulate crop yield (Usman, 2015; Uwah and Eyo, 2014). Moreover, there is consensus among crop scientists and soil nutritionists that organic fertilizers could help solve pollution caused by agro-industrial wastes and can have a positive influence on the growth of soil N-fixing bacteria (Kang et al., 2021; Siavoshi et al., 2011). A study by Siavoshi et al. (2011) concluded that organic fertilizers have a huge impact on the growth and productivity of rice, and produce better grain yield compared to inorganic fertilizers.

2.3.1 Factors affecting manure composition

The main factors that influence the nutrient composition of manure are; the type of livestock, growth stage, feeding methods, quantity of bedding or water incorporated, storage type, duration and storage conditions (Lorimor, 2015; Matsi, 2011).

2.3.1.1 Ration composition

When livestock is fed, it retains some of the nutrients as it gains weight (Lorimor, 2015). Furthermore, some of the nutrients are preserved in milk and eggs. The remaining nutrients are excreted, and they end up as manure. The nutrient composition of manure reflects both nutrient levels and the presence or absence of specific feed additives in the animal diet (Sutton et al., 1985). For example, increasing levels of additives (copper, arsenic, sulfa drug or antibiotics) and inorganic salts (sodium, calcium, potassium, magnesium, phosphate, chloride) in swine diets can alter the levels of these elements and potentially influence the breakdown rate of organic material in manure (Lorimor et al., 2004).

Depending on the type of animal, growth stage and diet, livestock normally release 50 to 90 % of the nutrients they are fed (Lorimor, 2015). Furthermore, feeding more than the required nutrients to an animal elevates the amount that is released in the faeces and animal liquid waste (Bennett, 2006). The amount of nutrients available in the manure is directly proportional to the level of nutrients animals take in through feed.

2.3.1.2 Methods of collection and storage

The type of storage and waste handling system greatly affects the final nutrient composition (Lorimor et al., 2004). A great amount of nitrogen (N) is lost through ammonia volatilization. When manure is exposed to the sun to dry, it can also be leached by rain (Lorimor, 2015; Sutton et al., 1985; Zhang, 2002). However, comparatively little N is lost from manure in a completely covered feedlot when a manure pack or liquid pit storage system is used (Lorimor et al., 2004).

Only a small amount (5-15%) of phosphorus (P) and potassium (K) is lost with various waste handling methods, except for open lots and lagoons (Zhang, 2002). About 50-85% of the P in the waste can settle in lagoons, rendering it inaccessible in the liquid utilized for spraying crops during irrigation.

2.3.1.3 Bedding and water added

The amount and type of bedding materials influence how the manure will be handled as a liquid, solid or semi-solid. Bedding materials may be wood chips, sawdust, wheat straw, flax straw or even peanut hulls, rice hulls and recycled paper products (Lorimor, 2015). Bedding and water added to the animal manure dilute the nutrient concentration, thereby reducing its value per ton when it is applied to the land (Sutton et al., 1985; Zhang, 2002). In contrast, the buildup of the sludge can be caused by feed spillage and the lack of a proper agitation system, making the removal of liquid manure challenging. Wet feeders can reduce manure volume for storage by up to 50% as compared to conventional feeders with nipple waterers thus increasing the nutrient content in manure (Sutton et al., 1985).

2.3.1.4 Method of application

There are various methods of animal manure application such as surface broadcasting with plow-down or disking, broadcasting without incorporation, by injection (direct incorporation) under the soil surface or by fertigation (Risse et al., 2006). A study by Adekiya and Agbede (2017) discovered the highest nutrient benefits and minimal runoff when manure was applied into the soil right after application. Moreover, instant incorporation not only minimised ammonia volatilization but also allowed soil microorganisms to start composing the organic matter in the manure (Sutton et al., 1985). Thus, the nutrients became available to the crop sooner.

2.3.1.5 Time of application

Time of application is one of the factors influencing the mineralization of animal manure and nutrient availability to the crops (Loss et al., 2019). Thus, it is critical to timeously apply animal manure to ensure the immediate availability of nutrients at the time of planting (Mkhabela and Materechera, 2013). This is because the time of application influences grain yield and nutrient uptake depending on the type of manure and soil texture (Adekiya and Agbede, 2017; Kolawole, 2014). Applying animal manure 2/3 weeks before planting avoids nutrient losses that can occur before planting (Adekiya and Agbede, 2017).

2.3.2 Method of applying manure

Animal manure in its solid form can be applied by different methods. The most common methods include i) broadcasting the manure to the top layer of the soil and till the soil ii) applying in a narrow band or iii) under the soil surface (King, 2015). Spreading manure on agricultural land is a traditional practice that provides essential nutrients for plants, and increases soil fertility and soil chemical, biological and physical properties (Amanullah et al., 2007). Both soil chemical and physical properties are impacted by changes in soil biological properties due to the application of organic matter, but microbial biomass carbon is the most affected (Ksheem, 2014).

The benefits of animal manure differ depending on the type and composition of manure. Goat manure comprises 0.63-0.95% N, 0.35-0.51%P_2O_5 and 1.0-1.2% K_2O (Budiyanto and Achmad, 2022). Consequently, the application of goat manure increases nutrient supply and acts as a soil amendment to enhance the water-holding ability of sandy soil (Uwah and Eyo, 2014). A study by Sanista et al. (2019) reported that high-quality goat manure increases cactus growth performance in terms of racket numbers per plant, height and diameter.

Cattle manure is usually the lowest in nutrients compared to other types of animal manure and has a high moisture content (King, 2015). However, Adebayo et al., (2014) reported that cattle manure contained 2.06% N, 0.53% P_2O_5 and 1.71% K_2O on average. It increases water retention and availability, phosphorus, potassium and sodium contents in the 0-20 cm soil layer (Silva et al., 2006). A study by Eleduma et al. (2020) on the effect of cattle manure on maize indicated that cattle manure improved soil fertility and crop performance.

Chicken manure consists of 4.5-5.0% N, 2.5-2.98% P_2O_5, 2.04-2.33% K_2O (Richa et al.2020). While chicken manure has many benefits for the crops, the spread of disease-causing agents, the emission of greenhouse gases as well as the possibility of water contamination remain a major concern (Ksheem, 2014; Kyakuwaire et al., 2019). Chicken manure is normally applied in spring or before planting, thus storing and frequently applying chicken manure is often regarded as the sole remedy for its accumulation (Ksheem, 2014). Conversely, when animal manure is continuously applied over a long period, it rapidly increases the organic carbon in the soil, thereby improving soil structure and stimulating the binding of soil particles to prevent erosion (Singh, 2012).

Table 2.2: Nutrient concentration of different types of manure as excreted (source: Kissinger et al., 2007).

	Manure nutrient concentration, as excreted		
	N	P_2O_5	K_2O
Sources of animal manure	lb nutrients/ T manure		
Dairy cow, lactating	13.2	5.2	3.7
Beef cow, finishing	11.2	3.4	9.3
Swine, growers	16.7	6.5	8.8
Swine, gestating	12.9	8.3	10.5
Swine, lactating	15.2	10.1	11.6
Poultry, boilers	21.8	14.6	14.9
Poultry, layers	36.8	26.5	16.5
Turkey, female	30.0	19.3	15.9
Horse, intense exercise	11.9	5.9	8.9
Horse, sedentary	7.1	2.4	2.6
Sheep (lamb)*/goat	19.5	22.3	23.5

When manure is applied to the soil the nutrients go through several processes which can either speed up or slow down their availability for crop uptake (Bennett, 2006). Nitrogen is excreted in livestock and poultry urine as urea or uric acid and as urea, ammonia and organic nitrogen in faeces (Smith et al. 2011). The following is the nitrogen transformation after land application of animal manure:

i. Mineralization: This is the process whereby soil microbes change organic nitrogen by decomposing it from manure and organic matter to ammonium (Bennett, 2006). The rate at which mineralization occurs increases with soil temperature, moisture and oxygen (Smith et al. 2011).

ii. Nitrification: This is the oxidation of ammonium to nitrites and can further be oxidized to nitrate (Robertson and Groffman, 2015). Under aerobic conditions, nitrifying bacteria in the soil change ammonium to nitrite and then to nitrate in a few days (Smith et al 2011). In the process, nitrous oxide and nitric oxide gases are lost to the atmosphere. Nitrate is highly soluble and plants take it up more rapidly than ammonium which tends to be bound to clay particles in the soil where roots must reach it (Bennett, 2006).

iii. Volatilization: The transformation of liquid ammonium into ammonium gas that is released to the atmosphere, it can occur during storage as well as during application. Volatilization losses during storage are higher for open than enclosed structures and it increases with exposed surface area for open structures (Smith et al 2011). The amount of nitrogen lost through volatilization during the application of manure depends on the amount of ammonium in the manure, exposure of the manure to the atmosphere and weather conditions (Bennett, 2006).

iv. Immobilization: This is the opposite of mineralization, where inorganic nitrogen is converted to organic. As soil microorganisms decompose plant material and manure, they use carbon as a food source (Bennett, 2006). As carbon is consumed, nitrogen is also consumed making it temporarily available to plants. When high-carbon materials are incorporated into the soil, the accessibility of nitrogen for the crops may be minimized (Robertson and Groffman, 2015). When these microorganisms die, the nutrients they hold are emitted back into the soil.

v. Nitrate leaching: Nitrate has high solubility, therefore, it primarily gets washed away during rainy seasons and periods of fallow (Bennett, 2006). Thus, as the descends through the soil profile, nitrate is leached. Runoff can be an important source of nitrogen to surface waters where, along with phosphorus, it can cause large algal blooms (Gworek et al., 2021).

vi. Denitrification: This is the process where soil bacteria transform nitrate and nitrite into gaseous forms such as nitrous oxide and nitric oxide, ultimately leading to the release of nitrogen gas into the atmosphere (Bennett, 2006; Robertson and Groffman, 2015). This process occurs under anaerobic conditions (Smith et al. 2011).

2.4 Extraction of liquid manure from animal waste

2.4.1 Methods of liquid manure extraction

There are many practices used to extract nutrients from manure or compost liquid. The purpose of any of the methods is to effectively extract as many nutrients as possible from composted or fresh material, using simple equipment to minimize the cost of production (Metwally and Kishta, 2019). The succession of the extracting soluble nutrients from fresh or composted material is dependent on the initial material quality, amount of material-to-water ratio, fermentation nutrients, brewing time, aeration and filtration materials (Ksheem, 2014). The following are the most common extraction methods:

2.4.1.1 Anaerobic "passive" method

This method includes submerging the manure/compost in water and leaving it to immerse. It is advised to stir the mixture occasionally; it usually takes 7-10 days for the mixture to be brewed

(Javanmardi and Ghorbani, 2012). This method has been practised for over 100 years in European countries, and the final nutrient solution is weak compared to aerated tea. In this method, aerobic microorganisms consume oxygen from the water and after a few days, the system becomes anaerobic (Ksheem, 2014). The compost/manure in a passive extraction method can be soaked directly in water which is easier or in a sack bag. Organic waste such as chopped plant material or animal manure is added to water at a ratio of 1:25 (waste: water), left for a brief period for fermentation to take place depending on how long it takes for the soluble nutrients to leach out and the amount of oxygen consumed by aerobic microbes (Ksheem, 2014).

In a study by (Charoenpakdee, 2014), each type of animal manure (bat, pig and cattle) was dried, mixed and brewed in groundwater for one full day in a ratio of 1:50. The mixture was filtered through a thin white cloth and then diluted with groundwater (negative control) in a 1:3 ratio of solution to water, before transferring into a foam tank using a homemade hydroponic system. The manure/ compost is placed into a woven sack bag made out of hessian or burlap which efficiently acts like a crude filter (Ingham, 2005; Ksheem, 2014). This bag is soaked in water for 1-2 days to obtain a nutrient solution.

2.4.1.2 Aerobic "Bucket-bubble method" method

The equipment used and the ratio is similar to the anaerobic method of extraction, the difference is the use of an aquarium-size pump, and an air bubbler, as well as the inclusion of microbial food catalyst mediums as a source of food (e.g., simple sugar, cane syrup or sugar beet for bacteria and cellulose, humic acids or other cellulose-containing material for fungi) for 48 – 72 hours (Ingham, 2005). The pump provides the microbes with oxygen thereby maintaining aerobic conditions. The addition of oxygen to the organic liquid increases the quality of the extract by minimizing detrimental by-products like butyric acid, ammonium nitrogen, and hydrogen sulfide gas (Ingham, 2005; Ksheem, 2014). Javanmardi and Ghorbani (2012) prepared vermicompost and chicken manure teas by mixing vermicompost and chicken manure with water separately at a ratio of 1:5 (vermicompost: water) and 1:10 (chicken manure: water) and then covered the solutions in a plastic container. Water was allowed to stand for 24 hours for passive chlorine removal before mixing. The mixtures were aerated using an aquarium pump for 72 hours of brewing time in a shaded area; the solution was filtered using cheesecloth before application.

2.4.1.3 Manure/ compost leachate

Compost windrow leachate is a solution that leaks from the base of the compost heap. It is rich in soluble nutrients but may contain pathogens in the early phases of composting and additional bioremediation may be necessary to make it suitable for foliar application or spreading (Ksheem, 2014). This technique produces the highest concentration of soluble nutrients (Diver, 2002).

2.4.2 Application of liquid manure

Before applying liquid manure to the soil, there are a few things to be taken into consideration. Only the required amount of liquid manure should be applied, the rate at which the liquid manure is applied should ensure that there will be no runoff after application and the correct irrigation system and operating system should be used (Ksheem, 2014). Liquid manure can be applied in three ways, namely: under irrigated conditions (fertigation) foliar application and surface application (surface applicator) (Ingham, 2005).

i. Fertigation: the application of liquid manure during irrigation. The most used irrigation methods are centre pivot and travelling gun (Smith et al. 2011), an above-canopy sprinkler application has an advantage during effluent application by providing nutrients to crop foliage in addition to soil surface application. In dry countries such as Libya, there is a shortage of water and due to the heat, there is high evaporation. In such cases, it is important to maximize water efficiency and efficient use of nutrients by plants, therefore, sprinkler and drip irrigation systems are the preferred methods for the application of fertilizer and organic solutions (Ksheem, 2014). Subsurface drip irrigation increases water efficiency and reduces nitrate leaching and water contamination by phosphorus and nitrate (Martínez and Reca, 2014).

ii. Foliar method: in this method, the application excludes dilution, even though water is normally used as a carrier. The concentration of organisms in the tea is critical, so it is important to pay attention carefully to maintain the concentration. If the tea is diluted, insufficient coverage on the leaf surface is often experienced and might negatively affect plant growth and development (Ingham, 2005).

iii. Surface/ soil application method: to keep beneficial organisms functioning throughout the year, the soil needs to be nourished with the right set of organisms and food (Ingham, 2005). Manually, carrying liquid manure to the field can be time-consuming and costly. However, there are alternative methods where one can use large nurse tanks that can fill a tank wagon 2-4 times, pump manure to a remote storage site or directly into application equipment or deliver liquid manure directly to a field implemented by a drag-horse system or injector unit pulled by a tractor (Al-Kaisi et al., 2006). The reduced weight also allows for more flexibility in application timing.

2.5 Liquid manure extracts for growing vegetables under hydroponic conditions

2.5.1 Case studies on hydroponic crop production using liquid manure extract/ organic fertilizers

Several studies have been conducted on the use of hydroponic systems in crop production. However, the continuous use of inorganic fertilizers in hydroponic production remains a prevalent global challenge. The exorbitant cost of these fertilizers is a major concern, unfortunately, most small-scale farmers, particularly in Africa, find these fertilizers unaffordable. This leads to small-scale farmers being reluctant to make such investments when the outcomes seem uncertain (Mowa, 2018). Moreover, using high concentrations of inorganic fertilizers can cause high levels of nitrate in crops which can pose risks to human health (El-Shinawy et al., 1997; Williams and Nelson, 2014).

Owing to these challenges, recent research efforts have been focused on the potential of liquid manure as an alternative nutrient source for hydroponic production systems. A study by Mowa et al. (2018) on the use of goat manure in hydroponic reported that the formulated hydroponic nutrient solution derived from goat manure increases tomato fruit quality to high qualities compared to tomato fruits from the synthetic fertilizer. Furthermore, using aerated cow and turkey manure extract as a hydroponic solution increases growth in kale and lettuce (Tikasz et al., 2019). Based on a study by Charoenpakdee (2014), the fresh mass of lettuce produced with bat nutrient solution in a homemade hydroponic system (HHS) was 94%, which indicated that this natural source of nutrients can be used instead of chemical fertilizers for producing lettuce in HHS.

Using liquid organic fertilizer from cocoa peel and cow manure liquid fertilizer in the production of water spinach, results in unequal generative growth (Andrian et al., 2019). Furthermore, when using organic fertilizer in a hydroponic system, it is a challenge to obtain plant yield which is comparable to those grown with inorganic fertilizers (Williams and Nelson, 2014).

2.6 Summary and conclusion

Nowadays, cultivable land is becoming scarce therefore hydroponic system is a good alternative as it offers various benefits, including the minimal use of pesticides as well as year-round production even in unfavorable soil conditions. However, most hydroponic systems use inorganic solutions which are expensive and harmful to the environment as well as humans.

Livestock production is rapidly growing worldwide; therefore, there is a high production of animal waste. When this waste is not properly handled, it causes environmental pollution and has an impact on human health. More researchers are attempting to find a more affordable alternative source of nutrients for plant growth in hydroponics while simultaneously reducing environmental pollution by using animal manure. Various studies have highlighted that using liquid organic fertilizers in hydroponic systems improves plant growth and yield. Moreover, it is a cheaper and easily accessible alternative, environmentally friendly, and effectively recycles waste products, while serving as a rich nutrient source for the plants.

Soilless agriculture is gaining momentum since it improves both the preharvest and postharvest quality of crops (Frezza et al., 2011). It also allows growers to set optimal conditions and nutrient concentrations for plant growth (Chiesa et al., 2004). A study by Pace et al. (2018) reported that ready-to-use lettuces cultivated in soilless showed better microbiological and qualitative performance compared to those grown in soil. Furthermore, it enhanced the storability of lettuces and allowed the production of clean raw material which is suitable for the ready-to-use industry.

Several preharvest factors affect the postharvest quality of organically grown crops namely, climatic conditions (Mditshwa et al., 2017), seed cultivar selection (Suslow, 2000), and production system (Perkins-Veazie and Lester, 2008). However, the loss of postharvest firmness is mainly due to the lack of calcium, water content loss and metabolic changes (Mditshwa et al., 2017) and the texture is affected by nitrogen, phosphorous, potassium and calcium (Roth et al., 2007). Furthermore, poor handling and transportation can also negatively affect the quality and lead to postharvest losses which can be more than 35%, particularly in underdeveloped countries (Faried et al., 2022). Thus, there is a need to improve the quality of food through sustainable and environmentally beneficial production systems that will ensure high nutritional composition and physicochemical attributes. There is limited research on the effect of animal manure solutions on the postharvest quality of crops grown in hydroponic systems. Thus, more studies should focus on the effect of animal manure solutions on the postharvest quality of crops grown in hydroponic systems. Also, further studies should investigate the effect of mixing two or more animal manure solutions on hydroponically grown horticultural crops.

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Chapter 3

Optimising nutrient content in animal manure extracts for hydroponic crop production: Comparative analysis and extraction methods

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Abstract

Using organic manure as a sustainable nutrient source for hydroponic crop production necessitates understanding of its nutrient content, aligning with crop requirements, and refining extraction methods for optimal nutrient availability. This study aimed to compare the nutrient concentrations of fresh manure and vermicompost from cow, goat and chicken sources and to optimise nutrient extraction methods. The layout of the experiment was a completely randomized design with two factors, vermicompost at three levels (chicken, cow and goat) and extraction method (aerobic and anaerobic). The vermicomposting process was done over nine months, after which nutrients and moisture content were analysed in the fresh and vermicompost samples. Nutrient optimisation was achieved through passive (anaerobic) and active (aerated) extraction methods. After composting, cow manure showed the highest content of all the nutrients, followed by goat manure (N, P, Ca, Mg, Zn, Cu and Mn) and chicken manure (P, Ca, Mg, Zn, Cu and Mn). There was a significant decrease in moisture content in all sources over the composting period, fresh chicken and cow manure had high moisture content compared to the composted manures. The significant differences between aerated and non-aerated extraction methods were found in chicken-based compost extract (N, P, K, Ca, Mg, Zn, Mn, Cu and EC), cow-based compost extract (P, Mg, Cu and Zn) and goat-based compost extract (P, K, Ca and Mg). The pH of all animal-based compost extracts remained unaffected by the extraction method. Therefore, the active extraction method enhanced nutrient availability in the animal-based compost extracts. These findings highlight the efficacy of the aerated extraction method in enhancing nutrient availability from animal-based compost extracts, paving the way for more sustainable and efficient hydroponic crop production systems.

Keywords: Aerated compost tea, aerobic extraction, anaerobic extraction, non-aerated compost tea, vermicomposting.

3.1 Introduction

Food production is liable for a big portion of global greenhouse gas (GHG) emissions, comprising 35 to 37% of the total (Xu et al., 2021). Analysis suggests that animal-based food production, including livestock feed, contributes to 57% of these emissions, while plant-based food production contributes 29%, leaving the remaining 14% attributed to other food uses. Within the animal sector, cattle-related foods (including dairy and beef) contribute 61% of the total GHG emissions, with 8% coming from chicken-related foods (meat and eggs), and 6% from other small ruminants. The rest of the remaining emissions stem from pig meat (9%), buffalo milk and meat (8%) and other poultry types and inedible products. This indicates that both the livestock and crop industry have serious environmental hazards. Both industries must be managed sustainably to mitigate their environmental impacts and ensure long-term ecological health.

Livestock manure, as a by-product of livestock production (Zhang, 2012), holds significant value as a resource for plant nutrients, organic matter, and beneficial microorganisms (Kumar et al., 2013). By incorporating animal manure into agricultural practices, farmers can adopt cyclic agriculture principles, where waste products are recycled back into the system as valuable resources. Animal manure is a source of macro (N, P and K), micro (Mn, Zn, Cu, Cl, Fe, Mo and B), and secondary (Ca and Mg) plant nutrients that are essential for plant growth and development. It is commonly applied to improve nutrient availability and crop production thus reducing the need for commercial/synthetic fertilizer (Ogejo, 2010). This approach will reduce the reliance on synthetic fertilizers, promoting nutrient cycling within agricultural ecosystems, offsetting greenhouse gas emissions and moving towards net-zero agricultural systems.

One of the major challenges in agriculture is unfavourable environmental conditions such as extreme temperatures, relative humidity, and increasing spread of pests and diseases (Singh et al., 2015). South African farmers are facing the big challenge of producing enough quality food to feed the whole country (Maboko et al., 2011). Crop production under protected hydroponic systems has gained momentum over the years because of its ability to produce crops, fruits and flowers all year round without being limited by season (Charoenpakdee, 2014). However, the use of high concentrations of inorganic fertilizers in hydroponic systems may lead to the accumulation of nitrogen compounds in vegetables thus risking human health (Phibunwatthanawong and Riddech, 2019a). Additionally, the cost of these inorganic fertilizers is constantly increasing due to inflation and not all farmers in most developing countries can afford them (Mowa et al., 2017). In the context of extracting nutrients from animal manure for hydroponic crop production, the utilization of animal waste material presents a valuable opportunity to create a closed-loop nutrient cycle, aligning with principles of circular agriculture and sustainable food production. However, formulating hydroponic nutrient solutions using fresh manure may be harmful to crops because untreated manure may carry harmful disease-causing agents such as E.coli and Salmonella (Johannessen et al., 2005).

Vermicomposting has emerged as an innovative biotechnology for decomposing organic waste into value-added products (rich soil amendments) using earthworms and microorganisms (Jjagwe et al., 2019; Olle, 2019; Pilli and Sridhar, 2019). Furthermore, vermicompost reduces the use of water for irrigation and pest attacks, while enhancing seed germination, seedling growth and development (Olle, 2019; Rahman, 2021). Moreover, it improves high water-holding capacity, aeration, drainage and porosity of the soil. Previous research has reported that there is a slow release of plant nutrients over time in compost (Rowell and Hadad, 2004) which hinders the use of animal manure at a commercial level. However, limited research has been conducted to evaluate the nutrient concentrations of fresh and composted animal manures to extract hydroponic nutrient solutions. This study aims to: i) Compare the nutrient concentrations of fresh manure and vermicompost from cow, goat and chicken manure, ii) Optimise nutrient extraction using passive and active extraction methods.

3.2 Materials and methods

3.2.1 Site location

The research took place at the Controlled Environment Research Unit (CERU) within the University of KwaZulu-Natal, Pietermaritzburg (29°40'05.7"S; 30°24'20.9"E), spanning from November 2022 to September 2023. The experiments were carried out in a 4.5 cm × 6 cm glasshouse, maintaining an average relative humidity of 32.8% and a temperature of 33.7°C.

3.2.2 Manure collection and preparation

Dry cow (CW) and goat (GT) manure samples, approximately 3 months old, were collected from Cedara Agricultural College Dairy Farm located in Hilton, Pietermaritzburg, KwaZulu-Natal Province (29°32'02.04"S; 30°16'23.88"E). One-month-old chicken (CHIC) manure samples were obtained from the chicken house of the Discipline of Animal and Poultry Science at Ukulinga Research Farm, of the University of KwaZulu-Natal, Pietermaritzburg (29º40’05.7”S 30º24’20.9”E).

A 350 kg sample of each manure type was composted with 3 boxes of worms (*Eisenia fatida*) purchased from Wizard Worms situated in Greytown, KwaZulu-Natal. Composting was done in a woven sack bag with a capacity of 1 ton, ensuring a moisture level moisture of about 40 - 60% by regular watering. The compost was routinely monitored and turned regularly after 4 days throughout the composting period. Samples for each type of manure were collected before composting and again 10 months later. The samples were subsequently transported to the Cedara Agricultural Analytical Laboratory for a full mineral analysis.

3.2.2.1 Conversion of solid animal manure into liquid

The anaerobic passive (anaerobic) extraction method which was used to convert solid manure into a liquid solution is by Gross et al. (2008) with a slight modification. This method involved adding manure or compost to water 1:10 ratio (waste: water, w/v) (Ksheem, 2014). Briefly, 5 g of compost was mixed with 50 mL of distilled water and replicated 3 times. The samples were then shaken for 30 minutes in a glass beaker using a magnetic stirrer. After shaking, the samples were then stored in a cold room set at 4 °C for further analysis. After a week, extraction was done using a funnel and glass wool to filter the liquid. After extracting, the liquid extract was put into a freezer set at -24 °C for further analysis.

The active (aerobic) extraction method by Ingham (2005) was used with a slight modification by (Saba et al., 2023). During the extraction process, the compost was weighed into a woven sack bag made with hessian material (Ksheem, 2014). Thereafter, a bag containing the compost was immersed in water with sugar molasses for 48 hours to obtain a nutrient solution and the mixture required aeration throughout the extraction period (Merrill and McKeon, 1998; Scheuerell and Mahaffee, 2002; Weltzien, 1991), the sugar molasses served as a food source for the microbes (Phibunwatthanawong and Riddech, 2019a).

Briefly, a 1:10 compost-to-water ratio recommended by Weltzien (1990) was used; where 50 g of compost was weighed, put into a hessian cloth and tied with an elastic band. Then, 500 mL of distilled water was measured in a 1000 mL plastic volumetric flask. Thereafter, regent 9500 double outlet air pumps were plugged in and inserted in water for aeration for about 15 minutes and 5 g of sugar molasses was added before the extraction cloth was inserted. The process was done for all three compost mixtures. The pumps had 4 W power, 230 V/50HZ and 240 L/h output. The teas were left in the laboratory (room temperature). After 48 hours of aerobic extraction, 50 ml per tea from each flask was extracted into a 50 ml plastic specimen jar and placed in a freezer. The liquid extracts were put into a freezer set at -24 °C and then taken to Cedara Agricultural Analytical Laboratory for a full mineral analysis.

3.2.3 Experimental design

The layout of this study had two main factors namely, vermicompost at three levels (CHIC, CW and GT) and extraction methods at two levels (passive/ anaerobic and active/ anaerobic). The experiment had 8 treatment combinations, each replicated 3 times resulting in 18 experimental units. The design followed a factorial setup with two factors (3 × 2 × 3) and was arranged in a randomized way.

3.2.4 Statistical analysis

The analysis of variance (ANOVA) was carried out using GenStat Version 23rd Edition (VSN International, Hemel Hempstead, UK). Mean values recorded were separated by LSD (Least Significant Difference) at a 5% level of significance.

3.3 Results and discussion

3.3.1 Nutrient concentration (N, P, K, Ca, Mg, Cu, Mn and Zn) and moisture content of composted vs non-composted animal manure

The results in Table 1 showed significant differences ($p < 0.05$) in nutrient concentrations of composted and non-composted manures. The interaction between the source of manure and the state of the manure (composted/ non-composted) had a significant effect on the total N ($p = 0.013$) and K ($p < 0.001$) content, it however had no significant effect ($p = 0.084$) on P. The N content showed significance in the following order goat > cow > chicken for composted manures. There were slight but insignificant differences ($p = 0.262$) between compost and non-composted manure in N concentration. There was an increase in the P concentrations in all types of manure over the composting period. However, only the chicken manure had a significant increase (22000 mg/kg) in the P concentration compared to the goat and cow manure (10300 mg/kg and 6800 mg/kg). The K concentration significantly decreased for chicken (23500 mg/kg – 19000 mg/kg) and goat (25000 mg/kg - 8300mg/kg) manure over the composting period, the increase in the K concentration of cow manure was not significant (6300 mg/kg - 7500 mg/kg).

The interaction between the source of manure and the state of the manure (composted/non-composted) had a highly significant ($p < 0.001$) effect on the Ca and not significant ($p = 0.657$)

effect on Mg concentration. The Ca concentration in all manure sources increased over the composting period but the increase was significantly different for only chicken manure (57000 mg/kg – 112000 mg/kg). The concentration of Mg significantly increased for both chicken (14970 mg/kg – 18430 mg/kg) and goat (8100 mg/kg – 11000 mg/kg) manures respectively, the increase in the concentration of cow manure was not significantly different (3300 mg/kg – 5100 mg/kg).

The interaction between the source of manure and the state of the manure used showed highly significant differences ($p < 0.001$) in the concentration of copper, and significant differences in Manganese ($p = 0.002$) and Zinc ($p = 0.029$). The Cu, Mn and Zn content increased over the composting period. All the sources of manure recorded a significant increase in the Cu content with CHIC having the highest (121.60 mg/kg) Cu concentration compared to CW (35.07 mg/kg) and GT (35.90 mg/kg). The difference in the Mn content was only significant for goat and cow manure respectively, the difference in chicken manure was not significant (486.7 mg/kg – 511.3 mg/kg). On the other hand, the difference in the Zn concentration was only significant (698.6 mg/kg – 851.6 mg/kg) for chicken manure.

The interaction between the source of manure and the state of the manure used (composted/ non-composted) showed highly significant differences ($p < 0.001$) in the moisture content (Fig. 1). There was a significant decrease in moisture content over the composting time for cow (69.5% - 56.1%) and chicken (71.4% - 54.7%) manure, and a significant increase for goat manure (25.8% - 46.8%).

This study characterises the nutrient concentrations of composted (with earthworms) and non-composted (fresh) manure from different animal sources such as cow, chicken and goat and evaluates the optimization of nutrients using two different extraction methods (anaerobic and aerobic). A study by Gichaba et al. (2020) in the chemical analysis of goat manure-based vermicompost reported that the goat manure-based vermicompost has very high nitrogen, very high available P and exchangeable K compared to non-composted goat manure. The above results are in agreement with these findings for P and N but not for K. The decrease in K in all types of animal manure throughout the composting period may be attributed to the imbalance in moisture content recorded during composting which may be the results of the method used to measure moisture content. During the vermicomposting period, the squeezing method by Cooperband (2000) was used to measure the moisture content of the compost. This method can be unreliable since it depends on the amount of pressure applied by an individual when squeezing the compost. Studies found that *Eisenia fetida* worms thrive at 40 - 60% moisture (Borges et al., 2017; Keng et al., 2023), if the moisture content is too low inside the compost it lowers the microbial activities in worms thus lowering the decomposition process. On the other hand, when the moisture content is too high it may result in anaerobic conditions (Cooperband, 2000) which can cause potassium volatilization or leaching of nutrients. The moisture content is dependent on the type of manure. This is because different types of manures have different water-holding capacities. After composting, cow manure had the highest moisture content followed by chicken. This may be because both cow and chicken manure have high water-holding capacity compared to goat manure. The goat manure particles are more separated compared to cow and chicken manure.

Furthermore, there was a slight increase observed in macronutrients of cow manure, the concentration of N increased by 7.14%, P by 10.29% and K by 16% over the composting period. These findings are comparable to the study by Jjagwe et al. (2019) where the observed N, P and K showed an increase from week zero to week 12. The authors further concluded that vermicomposting of cattle manure showed a high potential of returning nutrients compared to other methods such as composting, stockpiling and aerobic digestion. Vermicompost tend to have more nutrients than traditional compost (Olle, 2019).

The results for goat and cow manure are however in contrast to a study by Irshad et al. (2013) who observed a high N concentration in fresh manure, a significant increase in exchangeable P in composted manure and a decrease in K after composting buffalo, poultry, camel, goat and cattle manures. The study by Irshad et al. (2013) supports the current results for the N, P and K trend of chicken manure, where the N and K concentration for non-composted was higher than that of composted manure and the P content increased over the composting period. The decrease in N over the composting period may be due to the ammonium volatilization. Fresh chicken manure generally has a high amount of N and a low carbon nitrogen (C/N) ratio (Nahm, 2003) which creates unfavourable conditions for worms to survive. Hence, some studies advise for pre-composting before introducing worms into a chicken manure pile (Chanu et al., 2018).

One of the important chemical characteristics of animal manure-derived vermicompost is that it has more mineral elements such as nitrates, soluble potassium, exchangeable phosphorous, calcium and magnesium compared to commercial growth media (Kinigopoulou et al., 2023). This is due to the presence of both macro and micronutrients in the worm casting which provides all nutrients in a form that is easily absorbed by the plants (Pilli and Sridhar, 2019).

Therefore, these studies support the finding of the current study where a significant increase in the Ca and Mg concentrations was observed for goat, cow and chicken composted manures.

The current study also found that there was an increase in all the micronutrients over the vermicomposting period. During the process of vermicomposting animal manure, the worms break down the solid biomass through digestion and are released through a worm casting (Rahman, 2021). This then increases the surface area available for the stimulation of microbial activities (Gichaba et al., 2020; Rahman, 2021). This may lead to the release of micronutrients for plant uptake. The findings of the current study are in contrast with the results of (Kinigopoulou et al., 2023) who after vermicomposting cattle manure reported the same levels of micronutrients (Mg, Fe, Mn, Zn, Cu and B).

Table 3.1: Nutrient concentration of different types of animal manure when composted and non-composted, and when using aerated and non-aerated extraction methods.

TYPE	**NON-COMP**	**COMP**	**MEANS**
N (mg/kg)			
CHIC	25000 cd	22000 d	**23500 c**
CW	26000 bcd	28000 bc	**27000 b**
GT	29000 ab	32000 a	**30500 a**
P_m = <0.001	*LSD_m = 1783*	*$S.E.D._m$ = 819*	
P_{m*t} = 0.013	*LSD_{m*t} = 2522*	*$S.E.D._{m*t}$ = 1158*	
CV% = 5.3			
P (mg/kg)			
CHIC	18000 b	22500 a	**20250 a**
CW	6100 d	6800 d	**6450 c**
GT	8300 cd	10300 c	**9300 b**
P_m = <0.001	*LSD_m = 1553*	*$S.E.D._m$ = 504*	
P_{m*t} = 0.084	*LSD_{m*t} = 2196*	*$S.E.D._{m*t}$ = 1008*	
CV% = 10.5			
K (mg/kg)			
CHIC	23500 a	19000 b	**21250 a**
CW	6300 c	7500 c	**6900 c**
GT	25000 a	8300 c	**16650 b**
P_m = <0.001	*LSD_m = 2099*	*$S.E.D._m$ = 963*	

P_{m*t} = <0.001	LSD_{m*t} = 2968	$S.E.D._{m*t}$ = 1362	
Cv% = 11.3			
Ca (mg/kg)			
CHIC	57000 b	112000 a	**84500 a**
CW	8200 e	13300 de	**10750 c**
GT	16400 cd	21930 c	**19165 b**
P_m = <0.001	LSD_m = 3611	$S.E.D._m$ = 1658	
P_{m*t} = <0.001	LSD_{m*t} = 5107	$S.E.D._{m*t}$ = 2344	
Cv% = 7.6			
Mg (mg/kg)			
CHIC	14970 b	18430 a	**16700 a**
CW	3250 e	5100 de	**4175 c**
GT	8100 d	11370 c	**9735 b**
P_m = <0.001	LSD_m = 1236	$S.E.D._m$ = 567	
P_{m*t} = 0.657	LSD_{m*t} = 1749	$S.E.D._{m*t}$ = 803	
CV% = 9.4			
Cu mg/kg			
CHIC	101.0 b	121.6 a	**111.3 a**
CW	26.5 d	35.1 c	**30.9 b**
GT	29.0 d	35.9 c	**32.5 b**
P_m = <0.001	LSD_m = 2.46	$S.E.D._m$ = 1.23	
P_{m*t} = <0.001	LSD_{m*t} = 3.48	$S.E.D._{m*t}$ = 1.60	
CV% = 3.4			
Mn mg/kg			
CHIC	486.7 b	511.3b	**499.0 b**
CW	455.0 c	494.0 b	**474.5 c**
GT	493.0 b	574.3 a	**533.7 a**
P_m = <0.001	$\mathrm{LSD_m}$ = 13.87	$\mathrm{S.E.D._m}$ = 6.36	
P_{m*t} = 0.002	LSD_{m*t} = 19.61	$\mathrm{S.E.D._{m*t}}$ = 9.00	
CV% = 2.2			
Zn mg/kg			
CHIC	698.6 b	851.6 a	**775.1 a**
CW	148.8 e	188.4 de	**168.6 c**

GT	243.3 cd	327.2c	**285.3 b**
$P_m = <0.001$	$LSD_m = 40.01$	$S.E.D._m = 18.37$	
$P_{m*t} = 0.029$	$LSD_{m*t} = 56.59$	$S.E.D._{m*t} = 25.97$	
$Cv\% = 7.8$			

*Values in the same column sharing the same letter are not statistically different at LSD (p=0.005). Values are the means ± SE (n = 3). Note: **m**=type of manure, **m*t**= type of manure* treatment. **CHIC**: chicken, **CW**: cow, **GT**: goat, **Non-Comp**: non-composted manure, **Comp**: composted manure

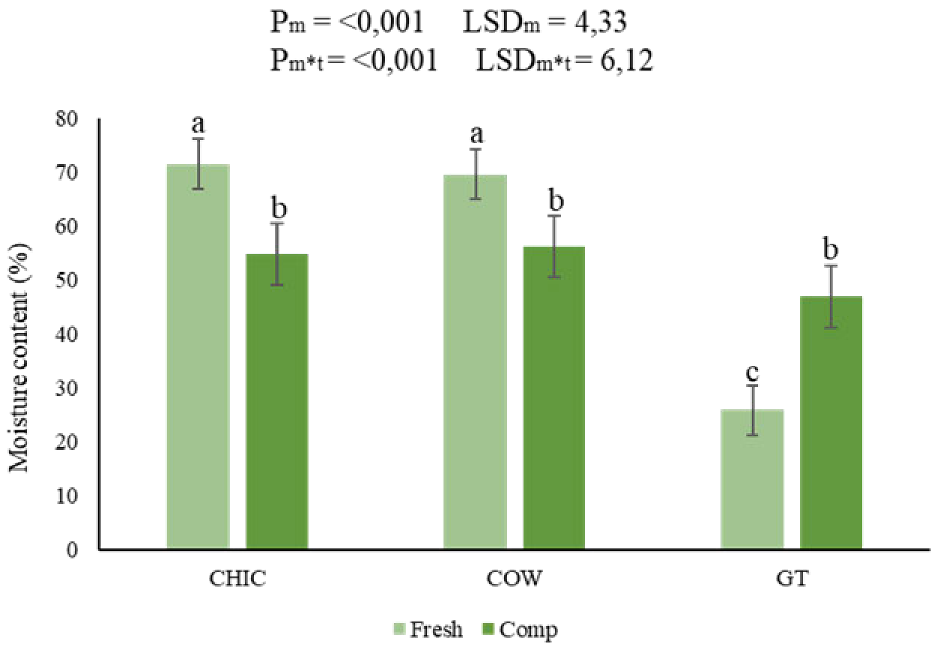

Figure 3.1: Moisture content of fresh and composted manure for chicken (CHIC), cow and goat (GT) manures. Values are the means ± SE (n = 3).

3.3.2 Nutrient concentration (N, P, K, Ca, Mg, Cu, Mn and Zn), pH and EC of aerated and non-aerated compost tea

The results in Table 2 showed significant differences ($p < 0.05$) in nutrient concentrations of different manure tea types extracted using passive and active extraction methods. The interaction between the source of animal manure and the type of extraction method used had a significant ($p = 0.002$) effect on N content, and high significance ($p < 0.001$) on P and K. The aerated chicken manure extract was significantly higher (4700 mg/L) in N concentration than goat (2900 mg/L) and cow (3400 mg/L) manure extract. There were significant differences in the P concentrations for all manure sources in both aerated and non-aerated manure extracts. Chicken aerated manure extract recorded the highest concentration of P (99.1 mg/L) while cow non-aerated manure recorded the lowest concentration of P at (0.4 mg/L). Both chicken and goat manure extract recorded significantly lower concentrations of K for non-aerated manure extract (659.6 mg/L and 1173.3 mg/L) compared to aerated manure extract (751.2 mg/L and 1426.1 mg/L).

The interaction between the source of animal manure and extraction method had a highly significant ($p < 0.001$) effect on the Ca and Mg concentrations. There were significant differences in Mg and Ca concentrations between aerated and non-aerated manure extracts in all sources of animal manures. Aerated chicken manure had the highest concentration of Mg (85.8 mg/L) compared to the other sources. Aerated (54.3 mg/L) and non-aerated (53.5 mg/L) cow manure extract had a significantly higher Ca concentration compared to other sources but the difference between them was not significant.

The interaction between the source of animal manure and the extraction method had a highly significant effect ($p < 0.001$) on the concentration of Cu, Mn and Zn (Table 2). The concentration of Cu was significantly lower in the non-aerated manure extract of all the sources compared to the aerated manure extract. The lowest Mn concentrations were recorded in non-aerated chicken manure extracts (0.02 mg/L), the Mn concentration was the same for both aerated and non-aerated cow manure extracts (0.77 mg/L). Aerated chicken manure had a significantly higher concentration of Zn (0.45 mg/L) among all the sources followed by aerated cow manure extract (0.13 mg/L).

The interaction between the source of animal manure and the extraction method had a highly significant ($p < 0.001$) effect on the EC and significance ($p = 0.028$) on the pH level (Fig. 2&3). The pH of non-aerated chicken manure extract (7.8) was lower than the aerated chicken manure (7.9), while aerated cow (6.3) and goat (8.4) manure extract were higher than the non-aerated manure extract (5.9 and 8.0), but the difference was not significant. All the manure sources recorded a lower EC content in non-aerated manure extract compared to aerated compost tea. There were significant differences in EC amongst different treatments but no significant difference between the two extraction methods. However, for chicken-based compost tea, aerated manure extract had a significantly higher EC (2.7 mS/cm) compared to non-aerated manure extract (2.2 mS/cm).

Factors such as the C/N ratio and the N concentration of the original compost normally affect the final nutrient concentration of the compost tea. The high N content and low C/N ratio in chicken waste (Nahm, 2003) may be the cause of a significantly high N concentration in aerated compost tea. The high nutrient concentrations of macro and micronutrients in aerated compared to non-aerated compost tea are attributed to the presence of oxygen in aerated compost tea.

When oxygen is introduced into the compost tea during brewing, it bubbles the water forming aggressive movements which separate a range of microbes (Minor, 2017). Moreover, when the microbes are free, they start to feed and produce. The presence of enough food and a conducive temperature (38 °C - 43 °C) increases the metabolism which influences high microbe count in a space of 12 - 36 hours (Scheuerell, 2004). However, when there is a decrease in oxygen can result in the loss of nutrients (Ingham, 2005). On the other hand, non-aerated compost tea is produced under anaerobic conditions (absence of oxygen) which have a longer brewing time and limits the reproduction of microorganisms (Shaban et al., 2015).

As much as aerated cow manure compost tea had high concentrations of K and Ca compared to non-aerated cow compost tea, the difference was insignificant. This means extraction method did not cause variation in the concentration, which may be due to varying solubilities in calcium and potassium compounds. Similar insignificant differences were found in the Zn and Mn content of both aerated and non-aerated goat manure. This may be because the suspension of the compost in water for a specific period is intended to extract nutrients whether the oxygen is present or not (Scheuerell, 2004).

The aerated compost tea had a high pH compared to non-aerated compost tea in all the sources of manure, but the difference was insignificant. The pH values of both aerated and non-aerated cow compost extract were within the range of optimal pH of the hydroponic nutrient solution (5.5 - 6.5) (Kechasov et al., 2021) for chicken and goat manure compost tea. However, the pH was between 7,78 - 8,43 which may reduce the availability of micronutrients in plants. The high pH may be due to high microbial activities in organic fertilizers (Williams and Nelson, 2014). According to Charoenpakdee (2014), EC measures the strength of a hydroponic nutrient solution. The EC of the current study showed significance in the following order, goat > chicken > cow-based compost tea, despite the type of extraction method used, this may be because of the diet of the individual animal. The EC of all sources of the nutrient solutions was less than 3.5 mS*cm^{-1} which is the recommended standard (Mowa et al., 2018).

Table 3.2: Nutrient concentration of different types of animal manure extracts when using aerated and non-aerated extraction methods.

TYPE	**Aera**	**Non-Aera**	**MEANS**
N (mg/l)			
CHIC	4700 a	3400 b	**4050 a**

CW	3400 b	2300 bc	**2850 b**
GT	2900 bc	2000 c	**2450 b**
$P_m = <0.001$	$LSD_m = 574$	$S.E.D._m = 264$	
$P_{m*e} = 0.002$	$LSD_{m*e} = 800.00$	$S.E.D._{m*e} = 373$	
CV% = 14.7			
P (mg/l)			
CHIC	99.1 a	64.9 b	**82.0 a**
CW	10.5 e	0.40 f	**5.5 c**
GT	36.0 c	30.3 d	**33.2 b**
$P_m = <0.001$	$LSD_m = 1.95$	$S.E.D._m = 0.90$	
$P_{m*e} = <0.001$	$LSD_{m*e} = 2.76$	$S.E.D._{m*e} = 1.27$	
CV% = 3.9			
K (mg/l)			
CHIC	751.2 c	659.6 d	**705.4 b**
CW	205.7 e	192.7 e	**199.2 c**
GT	1426.1 a	1173.3 b	**1299.7 a**
$P_m = <0.001$	$LSD_m = 15.84$	$S.E.D._m = 7.27$	
$P_{m*e} = <0.001$	$LSD_{m*e} = 22.40$	$S.E.D._{m*e} = 10.288$	
CV% = 1.7			
Ca (mg/l)			
CHIC	30.8 b	20.0 d	**25.4 b**
CW	54.3 a	53.5 a	**53.9 a**
GT	25.0 c	13.2 e	**19.1 c**
$P_m = <0.001$	$LSD_m = 1.55$	$S.E.D._m = 0.71$	

$P_{m*e} = <0.001$	$LSD_{m*e} = 2.19$	$S.E.D._{m*e} = 1.00$	
$CV\% = 3.8$			
Mg (mg/l)			
CHIC	85.8 a	45.9 bc	**65.9 a**
CW	47.9 b	42.1 c	**45.0 b**
GT	44.9 bc	30.9 d	**37.9 c**
$P_m = <0.001$	$LSD_m = 1.78$	$S.E.D._m = 0.82$	
$P_{m*e} = <0.001$	$LSD_{m*e} = 2.52$	$S.E.D._{m*e} = 2.52$	
$CV\% = 2.9$			
Cu mg/l			
CHIC	0.17 a	0.06 b	**0.12a**
CW	0.04 c	0.02 d	**0.03 c**
GT	0.04 c	0.03 cd	**0.04 b**
$P_m = <0.001$	$LSD_m = 0.01$	$S.E.D._m = 0.01$	
$P_{m*e} = <0.001$	$LSD_{m*e} = 0.012$	$S.E.D._{m*e} = 0.01$	
$CV\% = 12.3$			
Mn mg/l			
CHIC	0.20 b	0.02 d	**0.11 b**
CW	0.77 a	0.77 a	**0.77 a**
GT	0.08 c	0.05 cd	**0.07 c**
$P_m = <0.001$	$LSD_m = 0.03$	$S.E.D._m = 0.01$	
$P_{m*e} = <0.001$	$LSD_{m*e} = 0.04$	$S.E..D_{m*e} = 0.02$	
$CV\% = 6.4$			

Zn mg/l			
CHIC	0.45 a	0.04 c	**0.25 a**
CW	0.13 b	0.05 c	**0.09 b**
GT	0.05 c	0.03 c	**0.04 c**
$P_m = <0.01$	LSD$_m$ = 0.01	S.E.D.$_m$ = 0.004	
$P_{m*e} = <0.01$	$LSD_{m*e} = 0.02$	S.E.D.$_{m*e}$ = 0.006	
CV% = 6.8			

*Values in the same column sharing the same letter are not statistically different at LSD (p=0.005). Values are the means ± SE (n = 3). Note: **m** =type of manure, **m*e** = type of manure* extraction method. **Non-Aera**: non-aerated compost tea and **Aera**: aerated compost tea.

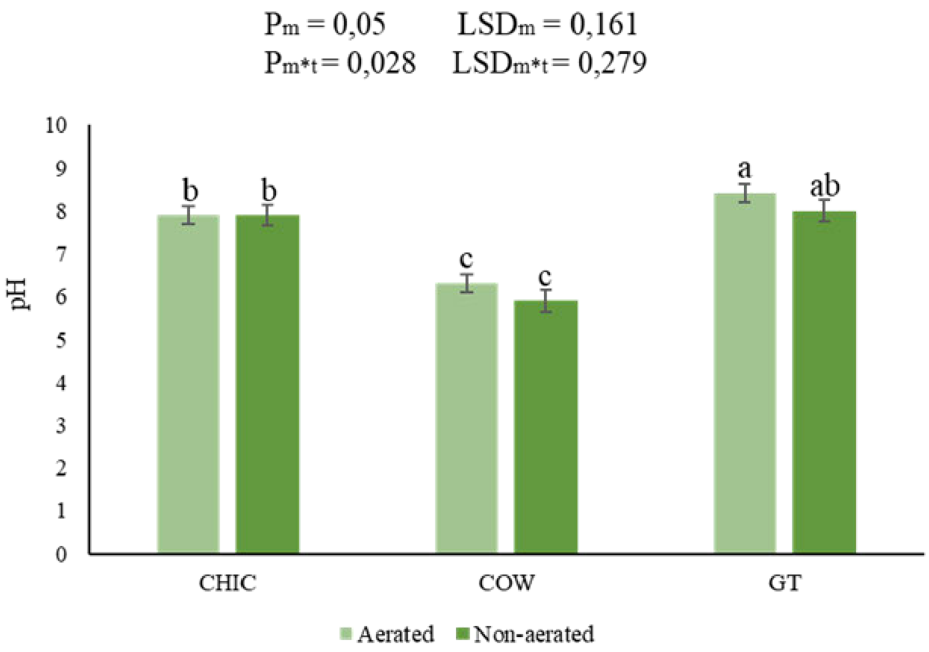

Figure 3.2: Potential of hydrogen (pH) of aerated and non-aerated compost extract formulated from chicken (CHIC), cow and goat (GT) manures. Values are the means ± SE (n = 3).

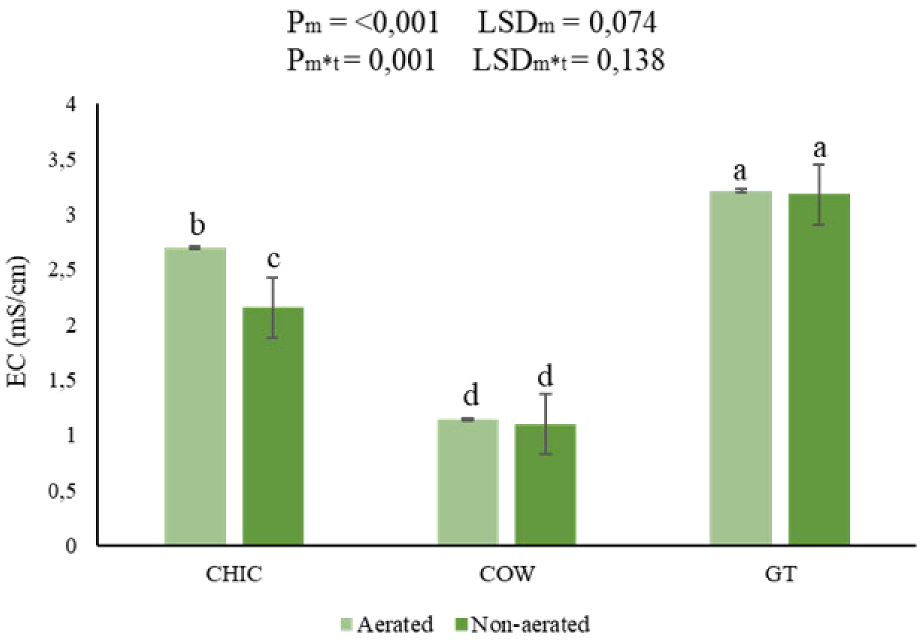

Figure 3.3: Electrical conductivity (EC) of aerated and non-aerated compost extract formulated from chicken (CHIC), cow and goat (GT) manures. Values are the means ± SE (n = 3).

3.4 Conclusion

This study compared nutrient concentrations of fresh and composted animal manure. The results found that there was an increase in the nutrient content of chicken, cow and goat manure over the composting period. There was an increase in all the nutrients in cow manure, goat manure (N, P, Ca, Mg, Zn, Cu and Mn) and chicken manure (P, Ca, Mg, Zn, Cu and Mn), vermicomposting also affected moisture content of all animal manure sources. This means that vermicomposting enhances the nutrient availability in animal manure. Furthermore, the nutrient extraction was optimized using passive extraction (non-aerated) and active extraction (aerated) methods. The results showed an increase in nutrients in aerated extraction compared to non-aerated extraction. The increase was observed in chicken-based compost tea (N, P, K, Ca, Mg, Zn, Mn, Cu and EC), cow-based compost tea (P, Mg, Cu and Zn) and goat-based compost tea (P, K, Ca and Mg). Therefore, it can be concluded that the presence of oxygen during nutrient extractions optimizes the concentration of nutrients in chicken, cow, and goat-based compost tea. Due to the low nutrient concentrations in non-aerated compost extracts compared to the aerated manure extract, a study where warm water (21 – 29°C) will be used to extract nutrients using passive extraction method, with an aim of extracting nutrients which are comparable to aerated compost extracts is recommended.

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Chapter 4

The effects of different animal manure extracts on growth, leaf gas exchange and chlorophyll fluorescence of tomatoes grown in soilless culture

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Abstract

The global livestock industry is rapidly growing due to the necessity to fulfil the demand of the increasing population. In the process, tons of animal waste are produced causing significant environmental hazards if disposed of irresponsibly. This study assessed the effect of animal manure extracts in the soilless hydroponic system on growth, leaf gas exchange and chlorophyll fluorescence of tomatoes (*cv.* CLX 532). This experiment was set up as a completely randomized design with four treatments, which included three types of animal manure-derived hydroponic nutrient extracts namely cow manure extract: CME, chicken manure extract: CHME, goat manure extract: GME and a commercial fertilizer as a control. The treatments were replicated three times with three plants per replicate. The results demonstrated variation amongst different fertilizer treatments in height, stem diameter, stomatal conductance (*gs*), intercellular CO_2 rate (*Ci)*, intrinsic water use efficiency (*WUEi)*, maximum fluorescence (*Fm'*), maximum quantum efficiency of photosystem II (*Fv/Fm'*), non-photochemical quenching (*qN*), and electron transport rate (*ETR*). The plant height was higher in GME (123.01 - 150.09 cm) and CHME (21.10 - 132.70 cm), stem diameter was larger in CHME (0.49 - 10.09 cm) and GME (0.55 - 7.33 cm) and the means of the number of fruits were higher on GME (5.796), CHME (5.65) and commercial fertilizer (5.17). The findings further showed that the application of GME and CHME enhanced *Ci, WUEi, Fm'* and *qN*. Meanwhile, CME significantly improved *gs, Fv/Fm'* and *ETR* of the tomato fruits. Thus, the conclusion is that animal manure extract may be used as a feasible source of nutrients in the production of tomatoes especially CHME and GME since the effect of these two types is comparable to commercial fertilizers.

Keywords: Chlorophyll fluorescence, growth, fertigation, hydroponic system, nutrient solution, photosynthesis

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4.1 Introduction

Tomato (*Solanum lycopersicum* L.) is the second most significant vegetable crop globally after potato and it is cultivated worldwide with the exception of Antarctica (Panno et al., 2021; Sotelo-Cardona et al., 2021). It is classified as a vegetable in the culinary art, however, according to the scientific classification tomato is a fruit as it grows from the ovary of the flower (Ganesan et al., 2012). Between 2013 and 2022 there was over 10% percent increase in tomato production worldwide with Asia being the lead producer (FAOSTAT, 2023; Malherbe and Marais, 2015). The production reached 186 million tons in 2020 which is two times more than in 2000 (FAO, 2022). Tomatoes are known to provide important nutritional components of a human diet due to their richness in vitamins A and C and lycopene (Anza et al., 2006; Rana et al., 2014).

South Africa is the major producer of tomatoes in Sub-Saharan Africa and is the most dominant in the Southern African Development Community (SADC) (Malherbe and Marais, 2015), producing about 421 000 tons in 2019 (Bozo et al., 2019). Over the years, the method of producing tomatoes in South Africa has changed from traditional field cultivation to modern protected cultivation. For decades, South Africa largely relied on field cultivation to produce tomatoes. However, due to production constraints such as climate change, limited land for cultivation and infertile soils (Maboko et al., 2011; Rana et al., 2014; Sotelo-Cardona et al., 2021), more farmers are adopting modern cultivation methods.

The use of protected cultivation is a more practical and cost-efficient solution with many benefits. Several studies have demonstrated that protected cultivation improves growth, yield (Maboko et al., 2010) and quality (Maboko et al., 2011) as it allows the farmers to control and optimize the internal environment (Maboko et al., 2017; Sotelo-Cardona et al., 2021). Moreover, the ability to manipulate conditions under protected cultivation creates a less hospitable environment for pests and weeds, which lessens the need for pesticides and herbicides (Pavani et al., 2020). The drip irrigation technique is the widely preferred hydroponic method by both small-scale and commercial farmers (Sheikh, 2006). It is commonly used to grow tomatoes, cucumbers and peppers. In this method, nutrient solutions are pumped from the reservoir through a pump and transmitted directly to plant roots through drip emitters (Sharma et al., 2018; Sheikh, 2006). The rate at which the solution is released depends on the settings on a timer, the schedule normally ranges around 5 - 10 minutes per hour depending on the stage of development of the plant (Sheikh, 2006).

One of the biggest challenges faced by the agricultural sector is the excessive use of chemical fertilizers. It has been reported that the world's chemical usage is about 1.9 x 10 ^{11} Mt and China ranks first accounting for 25% of world usage (Wan et al., 2021). This global problem stems from the need to meet the demands of the world's growing population. However, the overuse of these fertilizers is also detrimental to the environment. The leaching of these chemicals is linked to water contamination (Aderinoye-Abdulwahab and Salami, 2017). They further promote weed growth and come at a high cost for small-holder farmers (Aderinoye-Abdulwahab and Salami, 2017; Tikász, 2019).

To meet the growing food demand and reduce production costs, farmers need to consider using alternative sources of nutrients such as animal manure. Several studies have proven that the application of compost improves the chemical, physical and biological fertility of the soil (Budiyanto and Achmad, 2022; Eleduma et al., 2020; Usman, 2015). Furthermore, it increases the soil water-holding capacity, provides readily available plant nutrients (N, P, K, Ca and Mg) for plants to absorb and acts as a buffering agent against undesirable fluctuations of the soil pH (Adhikary, 2012; Arancon et al., 2005; Colín Navarro et al., 2019; Katakula et al., 2021; Koç et al., 2021; Mohammed and Sookoo, 2016; Usman, 2015).

As part of the waste management strategies, several studies have been conducted to evaluate the effect of organic fertilizers on the yield and growth of different crops. The results showed that solid organic fertilizers enhance crop growth and yield, due to the presence of nutrient availability and microbial activities (Borges et al., 2017; Gichaba et al., 2020; Kinigopoulou et al., 2023; Mehdizadeh et al., 2013; Siavoshi et al., 2011; Thomas et al., 2019). Furthermore, a study by Adekiya and Agbede (2017) reported an increase in ash, carbohydrate, protein and mucilage N, P, K, Ca and Mg content of okra fruits with the application of both organic and synthetic fertilizer. This is because, animal manure has macronutrients, essential micronutrients, as well as growth-promoting agents for example indole-3-acetic acid and gibberellic acid (Mohammed and Sookoo, 2016). Similar findings were reported on the effect of compost tea on plant growth and yield, studies reported an increase in nutrient uptake, plant height, plant diameter and weight (fresh and dry) (Fahrurrozi et al., 2019; Ibrahim et al., 2019; Muktamar et al., 2017; Ranasinghe et al., 2021). Additionally, the application of compost tea elevates quality parameters such as mineral nutrients, total carotenoids (Pant et al., 2011), TSS content (Ali et al., 2014) and total phenolics (Javanmardi and Ghorbani, 2012). However, limited research has been conducted to compare growth and photosynthesis in vermicompost tea and commercial fertilizers in hydroponics. Therefore, this study assessed the potential of animal manure extracts as an alternative nutrient source to the currently used inorganic fertilizers under hydroponics. The effect of animal manure extracts on growth, leaf gas exchange and chlorophyll fluorescence in tomatoes was also assessed.

4.2 Materials and methods

4.2.1 Site selection

This study was conducted at the Controlled Environment Research Unit (CERU) within the University of KwaZulu-Natal, Pietermaritzburg (29º40’05.7”S 30º24’20.9”E), spanning from September 2023 to December 2023. The experiment was conducted in a 4.8 m × 6 m glasshouse, maintaining an average relative humidity of 32.8% and temperature of 33.7 °C as presented in Figure 4.1.

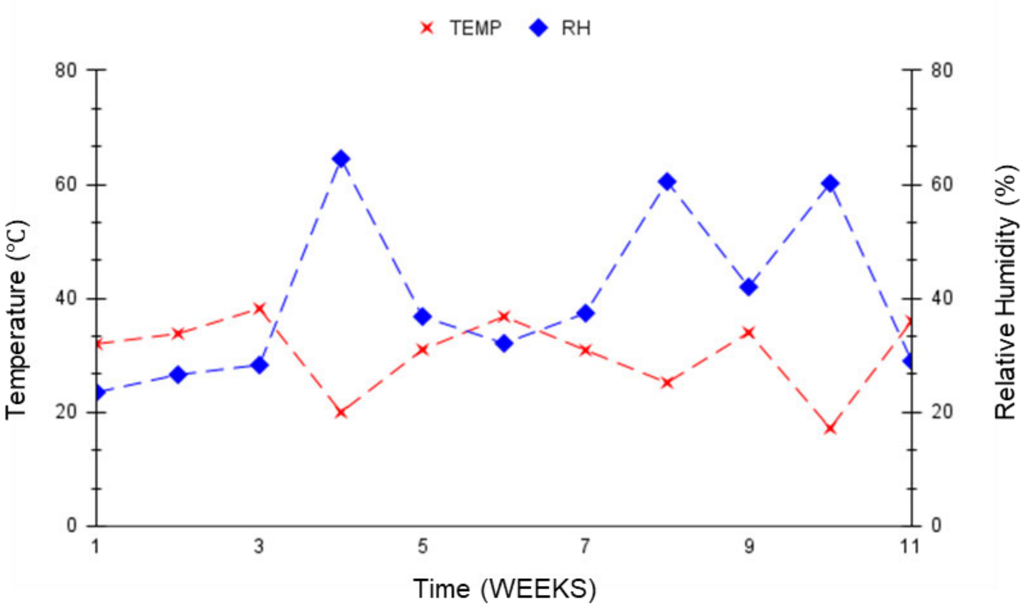

Figure 4.1: The temperature and relative humidity recorded using a data logger (Major Tech, Elandsfontein, Johannesburg, South Africa) during the study period.

4.2.2 Plant material

About four weeks-old tomato seedlings of the hybrid variety CLX 532 were procured from Sunshine Seedling Services, a Pietermaritzburg-based vegetable nursery. This cultivar is indeterminate and is amongst the most cultivated in South Africa under a greenhouse.

4.2.3 Manure collection and preparation

Dry cow and goat manure samples, approximately 3 months old, were collected from Cedara Agricultural College Dairy Farm located in Hilton, Pietermaritzburg, KwaZulu-Natal Province (29°32'02.04"S; 30°16'23.88"E). One-month-old chicken manure samples were obtained from the chicken house of the Discipline of Animal and Poultry Science in Ukulinga Research Farm of the University of KwaZulu-Natal, Pietermaritzburg (29º40’05.7”S 30º24’20.9”E).

A 350 kg sample of each manure type were composted with 3 boxes of worms (*Eisenia fatida*) purchased from Wizard Worms situated in Greytown, KwaZulu-Natal. Composting was done in a woven sack bag with a capacity of 1 ton, ensuring a moisture level of about 40 - 60% by watering regularly. The compost was routinely monitored and turned regularly after 4 days throughout the composting period (9 months).

4.2.4 Preparation of manure-derived hydroponic nutrient solution

The “active” aerobic extraction method by Tikasz et al. (2019) was used with a slight modification by (Saba et al., 2023) (Fig. 4.2). Briefly, 26 kg of each type of manure was weighed and put into an empty woven sack made from hessian material. Water was measured into a 260 L water tank, and a 6-outlet air compressor ACO - 400 was plugged in and inserted in water for aeration for 30 minutes before the bag full of compost was inserted. This process was repeated for all 3 types of compost, the tea was left in the glass house for 48 hours before transferring it to the 260 L JOJO tanks. This process was repeated every 7 days until the harvest date.

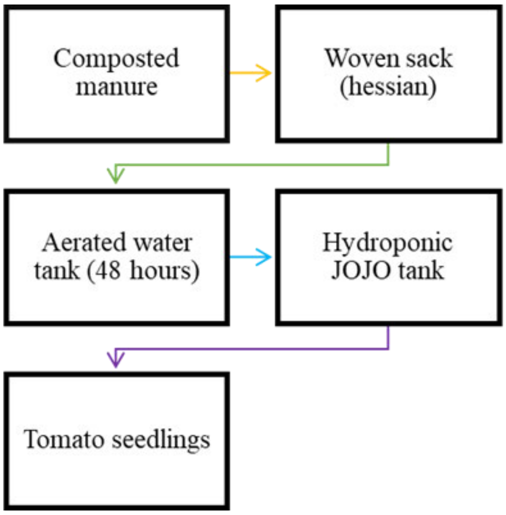

Figure 4.2: Diagrammatic representation of the preparation of the nutrient solutions using an active extraction method.

4.2.5 Hydroponic design

This experiment was conducted in a glasshouse to provide uniform conditions throughout the growth phases. About four weeks old tomato CLX 532 seedlings were transplanted into a 10 L black planting bag containing sawdust and inserted into planting slots of each channel. The AME with the following concentrations; GME- N (2900 mg/l), P (36.0 mg/l), K (1426.1 mg/kg), Ca (25.0 mg/l), Mg (44.9 mg/l), Cu (0.04 mg/l), Mn (0.08 mg/l), Zn (0.05 mg/l); CHME - N (4700 mg/l), P (99.1 mg/l), K (751.2 mg/l), Ca (30.8 mg/kg), Mg (85.8 mg/l), Cu (0.17 mg/l), Mn (0.20 mg/l), Zn (0.45 mg/l); CME- N (3400 mg/l), P (10.5 mg/l), K (205.7 mg/l), Ca (54.3 mg/l), Mg (47.9 mg/l), Cu (0.04 mg/l), Mn (0.77 mg/l), Zn (0.13 mg/l) were pumped from 260 L tanks into the planting pots, a water-soluble inorganic fertilizer mix was pumped separately from a 1000 L tank (Figure 4.2). The inorganic fertilizer was mixed according to the ratio used by Mngoma et al. (2022), 540 g Omnical, 100 g Multi-K and 600 g Nutriplex from transplanting to third flower, from third flower it was increased to 600 g Omnical, 400 g Multi-K and 800 g Nutriplex. The nutrient solution was refilled every 7 days for animal extract and 3 weeks for commercial fertilizer. Growth was monitored until the plants were ready to be harvested. The tomato plants were harvested after 12 weeks.

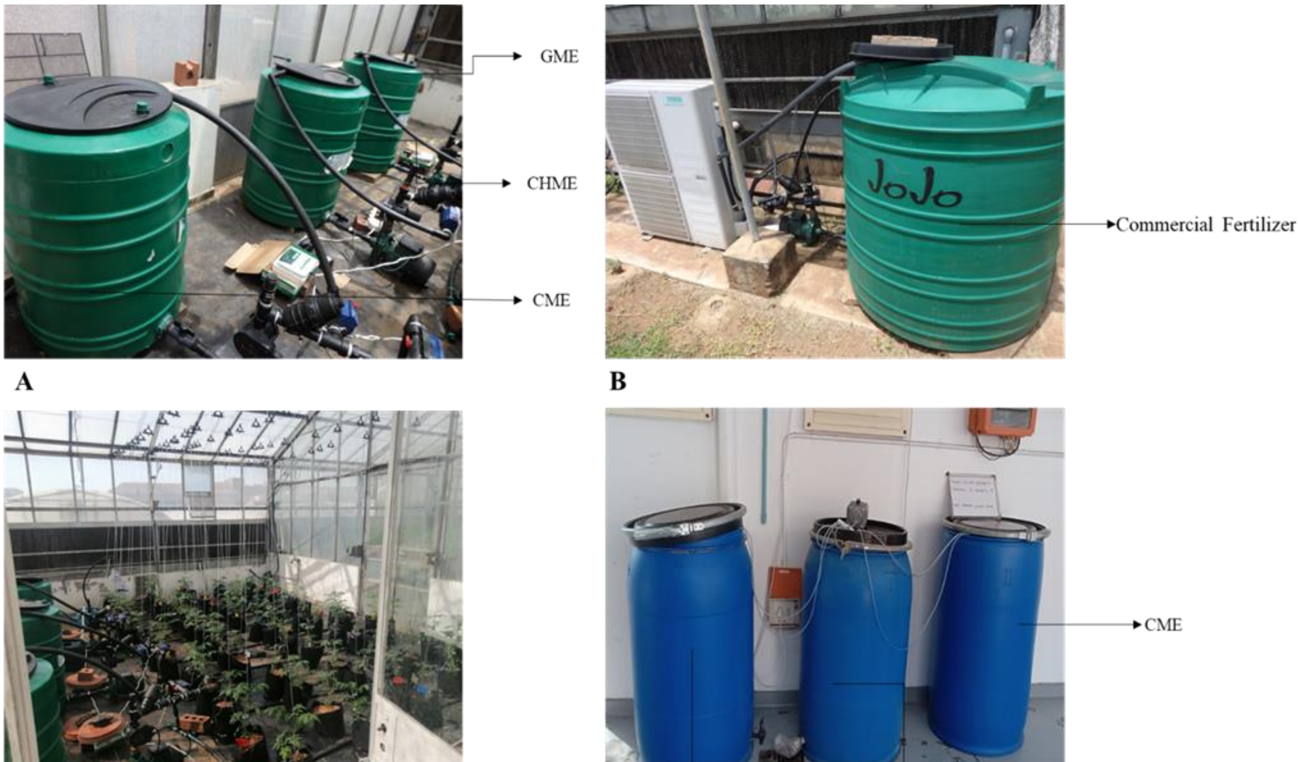

Figure 4.3: The extraction tank for animal manure extract (**A**), fertigation tank (**B**), the hydroponic setup for the study (**C**) and extraction of manure extract (compost tea) from the solid manure using aerobic extraction method (**D**).

4.2.6 Experimental design

The layout of the experiment was completely randomized design with three replicates per treatment. Each treatment was replicated three times and each replicate had three plants in individual growing bags resulting in 36 experimental units (4 × 3 × 3). Tomato seedlings were treated with three manure extracts as nutrient sources, namely, goat, chicken and cattle with a commercial hydroponic fertilizer mix as a control treatment. Solutions were topped up every 7 days with newly prepared solutions.

4.2.7 Data collection

4.2.7.1 Growth parameters

Plant height was quantified using a 10 m tape measure and recorded in cm, stem girth was measured using an electronic digital calliper in mm. The number of flower trusses and number of fruits were counted per plant. The chlorophyll content was recorded using a chlorophyll meter (SPAD - 502, Minolta Corp., Ramsey, NJ, USA).

4.2.7.2 Photosynthesis and chlorophyll fluorescence

Leaf gas exchange and chlorophyll fluorescence measurements were conducted using a Portable Photosynthesis System LI-6400 XT (Licor Bioscience, Inc. Lincoln, Nebraska, USA) equipped with an infrared gas analyser attached to a leaf chamber fluorimeter (LCF) (6400 - 40B, 2 cm^2 leaf area, Licor Bioscience, Inc. Lincoln, Nebraska, USA). The artificial saturated photosynthetic active radiation (PAR) was set at 1000 $\mu mol\ m^{-2}\ s^{-1}$ and reference CO_2 was maintained at 400 µmol mol-1. Initial measurements were recorded in two-week intervals starting from week two after transplanting, the device was used between 9h00 and 11h00 while it was still sunny. Sampling involved one leaf of each plant representing a replicate. Parameters of photosynthetic gas exchange parameters including, photosynthetic rate (*A*), stomatal conductance (*gs*), transpiration rate (*T*), intercellular CO_2 concentration (*Ci*) and ratio of intercellular and atmospheric CO_2 (*Ci/Ca*) concentration were recorded.

Figure 4.4: The effect of different sources of animal manure extract applied through fertigation on growth, yield, and performance of hydroponically grown tomatoes. One week after transplanting (**A**), three weeks after transplanting (**B**), five weeks after transplanting (**C**), seven weeks after transplanting (**D**), nine weeks after transplanting (**E**), eleven weeks after transplanting (**F**).

4.2.8 Statistical analysis

The analysis of variance (ANOVA) was carried out using GenStat Version 23rd Edition (VSN International, Hemel Hempstead, UK). Mean values recorded were separated by LSD (Least Significant Difference) at a 5% level of significance.

4.3 Results and discussion

4.3.1 Plant height, stem diameter and fruit number

The interaction between fertilizer treatments and growing time (weeks) had a significant ($p = 0.002$) effect on plant height (Fig. 4.5A). There was a visible increase in plant height over time, but the difference was not significant ($p > 0.05$) for the first 9 weeks after transplanting. However, at week 11 the height of tomato plants fertigated with cow manure extract (CME) was significantly lower than all other treatments at 114 cm. Goat manure extract (GME) had the highest tomato plant height at week 11. The plant height of tomatoes fertigated with GME (123.01 - 150.09 cm) and CHME (21.10 - 132.70 cm) was significantly higher than the height of tomatoes fertigated with commercial fertilizer (CF) (20.54 -141.27cm) and CME. Similar results were recorded by (Ali et al., 2014) who reported that foliar application of leachate from vermicompost or mustard oil cake had the tallest plant height than the control treatment. Furthermore, according to Mowa et al. (2017), the height of the tomato plants growing under the manure nutrient solution and conventional hydroponic solution increased over time compared to negative control. This may be due to vermicomposting of the animal manure before extracting the nutrient solution used in the hydroponic system. When the earthworms are introduced to solid waste, they convert it into a humus/organic-rich manure by decomposing the manure while enhancing the nutrient mineralization rate and stimulating microbial activities (Usman, 2015). This may result in a vermicompost that has nitrate, phosphate, exchangeable calcium and soluble potassium which can enhance plant growth and crop yield (Gichaba et al., 2020).

The treatments showed a highly significant effect ($p < 0.001$) on the stem diameter but the interaction between the treatments and the growing period (weeks) had no significant effect ($p = 0.184$) on the stem diameter (Fig. 4.5B). Between weeks 5 and 7 there was an increase in the stem diameter, but it was not significantly different for plants fertigated with commercial fertilizer and CHME. The stem diameter of plants fertigated with CHME (0.49 - 10.09 cm) and GME (0.55 - 7.33 cm) were significantly ($p < 0.05$) larger compared to the plants fertigated with commercial fertilizer (0.45 - 10.03 cm) and CME (0.35 - 9.52 cm). Similar results were reported by (Mowa et al., 2017) where the largest stem diameter was recorded under goat manure nutrient solution and conventional nutrient solution more than under tap water. Nitrogen is important for growth parameters such as plant height and stem diameter as it promotes vegetative growth (Javanmardi and Ghorbani, 2012; Mowa et al., 2017), it can therefore be argued that there is enough nitrogen in a compost tea in the form of nitrate in both CHME and GME.

Figure 4.5C represents the average number of fruits per plant over the growing time in response to different AMEs. The results showed that there was a significant interaction ($p < 0.021$) between the treatments and the growing period. On week 7 after transplanting, there was a significant increase in the number of fruits for all treatments. The means of GME (5.796), CHME (5.65) and commercial fertilizer (5.17) were significantly higher compared to CME (4.83). This could be attributed to the fact that vermicompost has an elevated amount of NPK content and plant hormones such as auxins, gibberellins, humic acid and cytokinin that promote plant growth and seed germination by controlling epical bud, stimulating cell elongation and cell division (Rahman, 2021; Tikasz et al., 2019). The results are similar to the findings by Ali et al. (2014) who reported the highest number of fruits under foliar application of leachate from vermicompost followed by leachate from mustard oil cake, while the control treatment had the lowest fruit number. However, they were in contrast with the findings by Kechasov et al. (2021) who found that the plants in high-mineral treatment had a higher number of fruits compared to the plants treated by an organic waste-based and low-mineral treatment. Both the interaction between the treatment and the growing time (weeks) after transplanting and treatments had no significant ($p > 0.05$) effect on the chlorophyll content (Fig. 4.5D). This means that there was no variation in the chlorophyll content for all treatments.

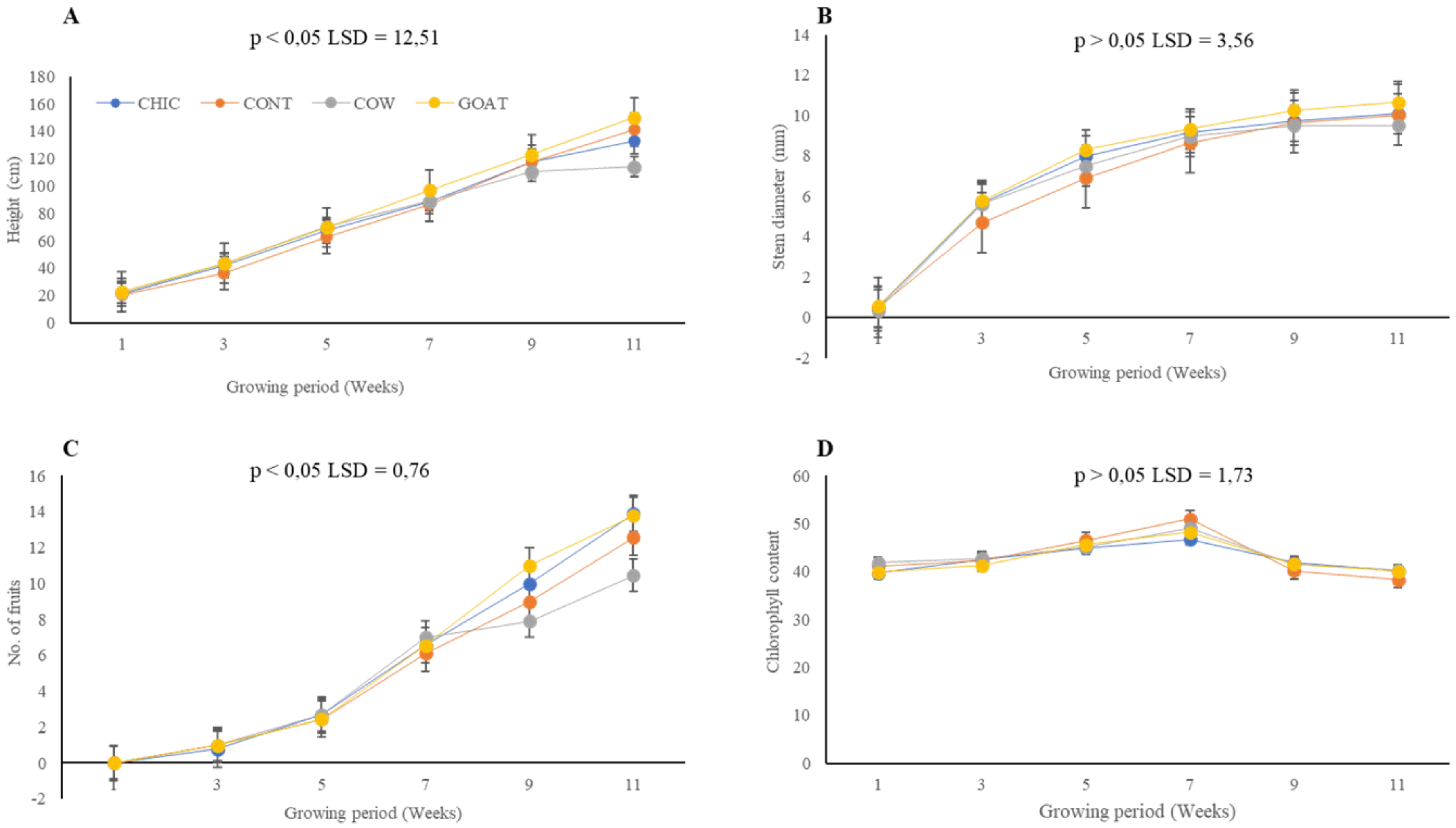

Figure 4.5: The effect of different sources of animal manure extract (chicken, cow and goat) against commercial fertilizer (control) on Plant height (**A**), Stem Diameter (**B**), Chlorophyll content (**C**) and Number of fruits (**D**) of hydroponically grown tomatoes (CLX 532). Values are the means ± SE (n = 10).

4.3.2 Leaf gas exchange parameters

The results in Figure 4.6 showed that the interaction amongst the treatments and the growing period had no significant effect on significant effect on all leaf gas exchange parameters. The treatments had a significant effect on the stomatal conductance (*gs*) (Fig. 4.6B). The commercial fertilizer had a significantly lower effect on the *gs* than all three sources of AME. Similar findings were observed by Efthimiadou et al. (2009) where the highest value of stomatal conductance was found in tomato plants treated with double-rate cow manure and where all the values of cow, and poultry manure were higher than the control. The *gs* decreased uniformly in the first six weeks for almost all the treatments excluding CME in week 4. Ye et al. (2020) reported that the application of organic fertilizer increased the *gs* stomatal conductance and *A* photosynthetic rate of pear jujube (*Ziziphus jujuba* Mill.), which is contrary to the results of the current study. These differences may be because there is a positive correlation between *A* and *gs* (Baroli et al., 2008) which means when the photosynthetic rate increases in response to environmental conditions, the stomatal pores widely open to take in more CO_2. However, the lack of variation in the photosynthetic rate in response to the treatments in the current study may justify the decrease in *gs*. The commercial fertilizer had a significantly ($p < 0.05$) high effect on the intrinsic water use efficiency (*WUEi*) followed by GME and CHME, respectively (Fig. 4.6H). These results are in contrast with Chatzistathis et al. (2023) who observed lower values of intrinsic water use efficiency in sheep manure (SM) and evergreen broadleaf litter (EBLS) compared to SM+EBLM and control. In the current study (Fig. 4.1) it was observed that the increase in temperature was somehow linked to the decrease in *gs* (Fig 4.5B) and an increase in *WUEi* (Fig. 4.6G) simultaneously. This may be because, when temperatures are high, the stomata pores close to reduce water loss through transpiration (Shezi et al., 2019), therefore, the plant utilizes internally stored water during photolysis, hence, the increase in *WUEi* with the decrease in *gs*.

The treatments had a significant effect on the intercellular CO_2 (*Ci*) (Fig. 4.6D), with the commercial fertilizer showing the greatest effect (638.00 μmol mol^{-1}). However, CHME and GME had a comparable effect to the commercial fertilizer. These findings were contrary to findings by (Chatzistathis et al., 2023) who reported that the intercellular CO_2 was significantly higher in SM+EBLS (combination of sheep manure and evergreen broadleaf litter) and EBLS (evergreen broadleaf litter) compared to sheep and control. However, Cristiano et al. (2018) reported similar results, where the application of animal manure-derived bio-stimulant through the roots drenching significantly increased the intercellular CO_2 by +11%. According to Shezi et al. (2019) when the stomatal conductance (*gs)* increases, a high percentage of stomatal pores open allowing CO_2 to enter and the opposite is true. This implies that both *gs* and *Ci* are directly proportional to each other. However, in the current study, the *gs* and *Ci* were inversely proportional, a decrease in *gs* increased *Ci* (Fig. 4.6A & D). This may be due to non-porosity factors that decrease the utilization of CO_2 when the stomatal pores are closed, thus the accumulation of CO_2 (Ye et al., 2020).

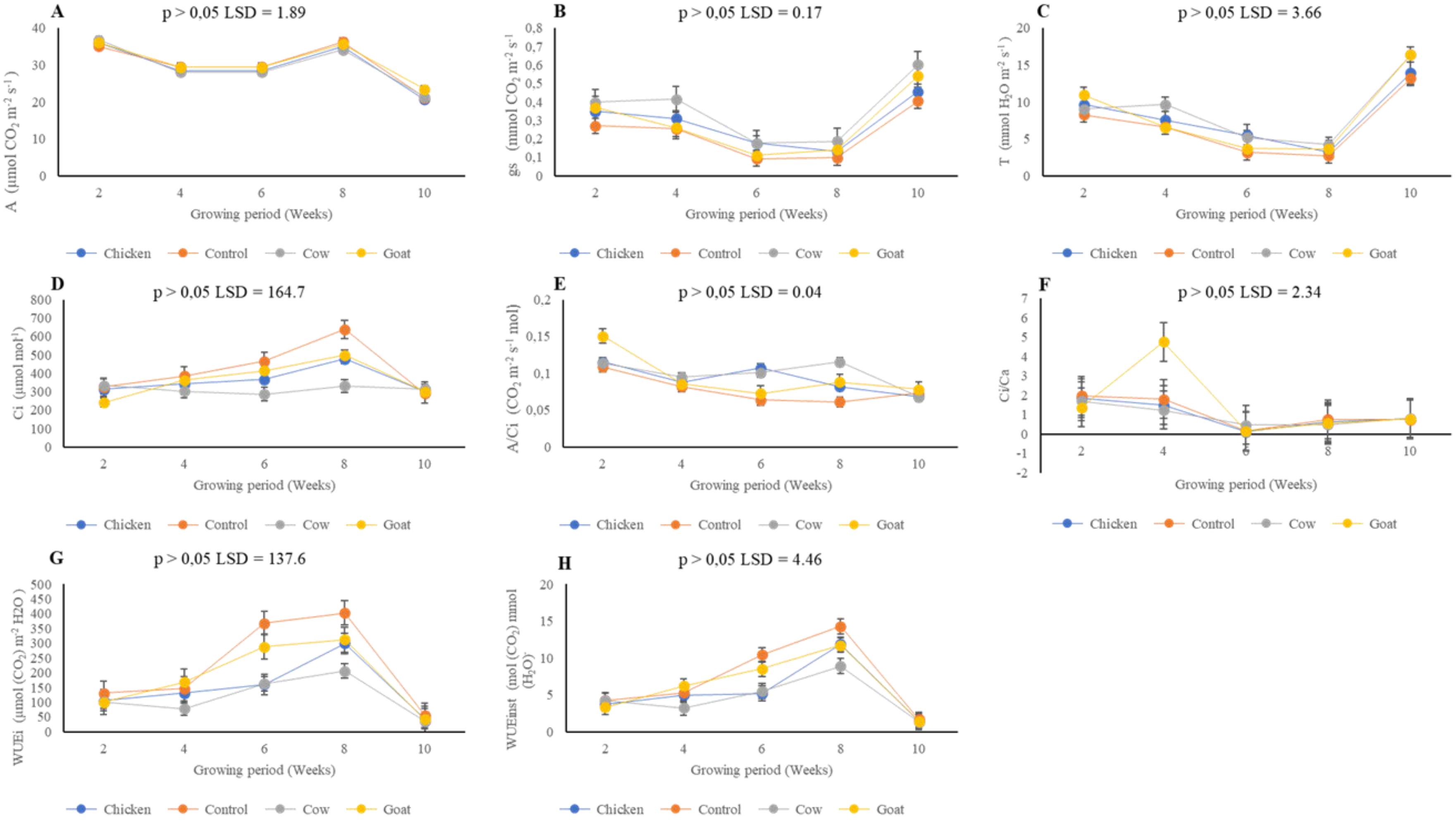

Figure 4.6: The effect of different sources of animal manure extracts (chicken, cow and goat) compared to commercial fertilizer (control) on leaf gas exchange parameters of hydroponically grown tomatoes (CLX 532) recorded weekly. Photosynthesis rate (**A**), stomatal conductance (**B**), transpiration rate (**C**), intercellular CO2 rate (**D**), photosynthesis rate/ intercellular CO2 rate (**E**), the ratio of intercellular and atmospheric CO2 concentration (**F**), intrinsic water-use efficiency (**G**), instantaneous water-use efficiency (**H**). Values are the means ± SE (n = 10).

4.3.3 Chlorophyll fluorescence parameters in response to different sources of animal manure extract

The maximum fluorescence (*Fm'*) was significantly affected by the interaction between the treatments and the growing period (Fig. 4.7B). Both commercial fertilizer and CHME had significantly higher means of *Fm'* (2197.22 and 2155.48 µmol m^{-2} s^{-1}) than CME (2071.42 µmol m^{-2} s^{-1}). The highest values recorded for *Fm'* were in week 6 after transplanting for all treatments, however, the difference amongst all treatments was insignificant. In week 2 after transplanting, the effect of CME was significantly lower compared to other treatments. The interaction between the treatments and the growing period showed a significant effect on the maximum quantum efficiency of photosystem II photochemistry (*Fv/Fm'*) (Fig. 4.7C). The application of CME caused a significant increase in *Fv/Fm'* compared to other treatments. These findings are similar to the results of Cristiano et al. (2018) who observed a significant increase in *Fv/Fm'* due to the dosage (0.1g L^{-1}) of manure-derived bio-stimulant through root application. Mngoma et al. (2022) observed an increase in both *Fm'* and *Fv/Fm'* of tomatoes and linked the increase to the protective mechanism of the photosystem from photo inhibitory damage. However, the current results reported an increase in *Fv/Fm'* when the *Fm'* decreased, this may imply a reduction in the efficiency of photosynthetic processes. The differences in the results may be attributed to the different conditions in which the studies were conducted such as temperature and relative humidity. Factors such as light intensity and quality, temperature and relative humidity affect the chlorophyll fluorescence of the plant (Maxwell and Johnson, 2000; Özer, 2017).

The results in Figure 4.6F showed that the interaction between the treatments and the growing period had a significant effect on non-photochemical quenching (*qN*) (Fig. 4.7F). Similar to *Fm'*, non-photochemical quenching (*qN*) was observed to be higher where commercial fertilizer and CHME were applied. The value of *qN* increased between weeks 4 and 6. The increase in *qN* in plants fertigated with CHME may be due to the high pH in chicken compost (Dikinya and Mufwanzala, 2010; Mahendra et al., 2020) compared to goat and cow compost. It should be noted that both goat and cow compost are neutral while chicken compost is more alkaline. This may enormously affect the nutrient availability for plant uptake, causing nutrient deficiency or excess (Fageria and Zimmermann, 1998) thus affecting the ability of the plants to control *qN*. The interaction between the treatments and the growing period had a highly significant ($p < 0.001$) effect on the electron transport rate (*ETR*) (Fig. 4.7G). At week 2 after transplanting, the *ETR* was significantly higher in CME fertigated plants. There was no variation in *qP* in all the treatments (Fig. 4.7E). However, CME had a slightly higher value *qP* in week 2 compared to all the other treatments, this may have influenced the *ETR* since there is a strong correlation between *qP* and *ETR* (Shezi et al., 2019). This may imply that there was a high movement of electrons due to an important mechanism for photo-inhibition protection (Mandizvo et al., 2022; Mashilo et al., 2017).

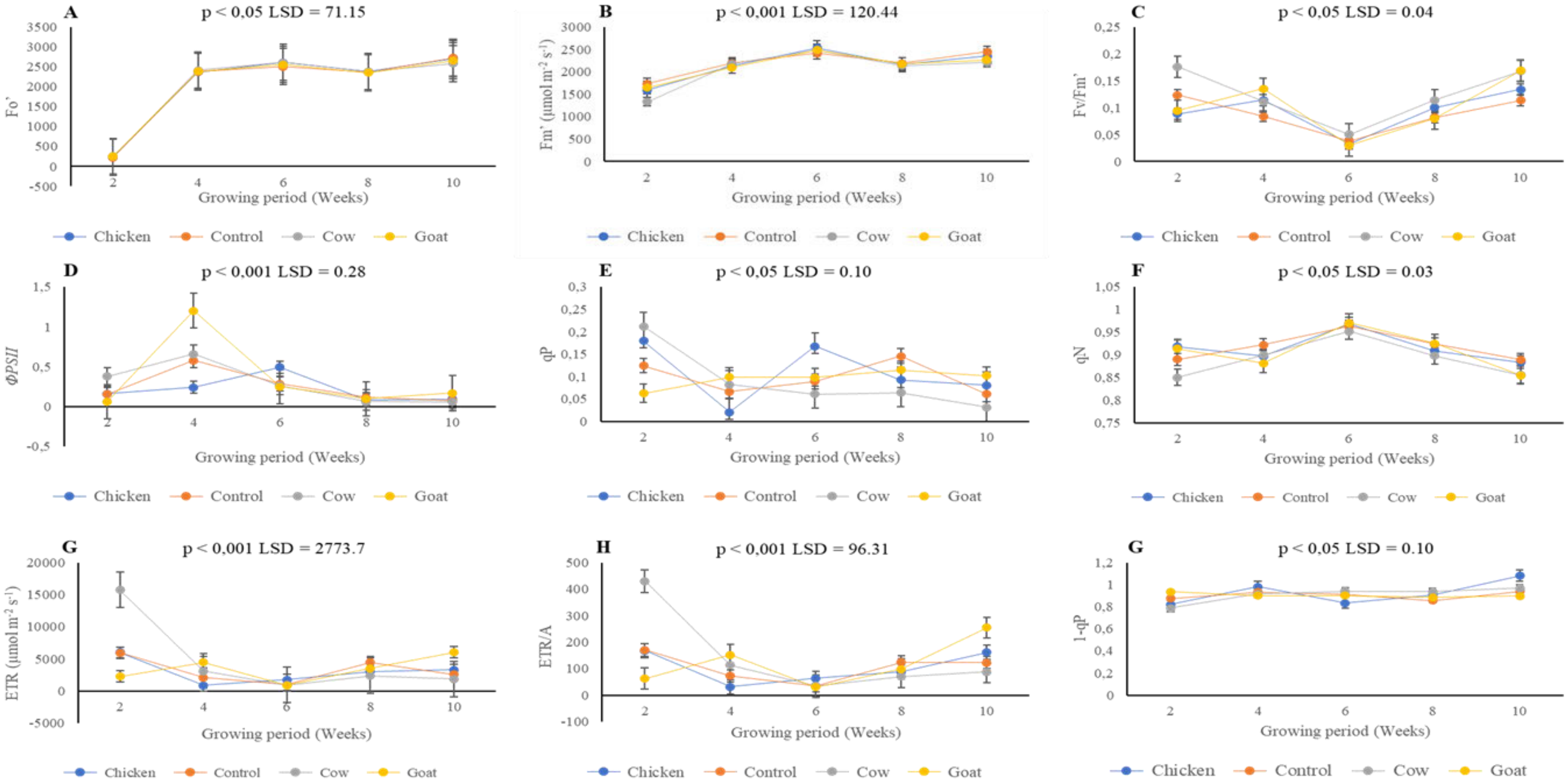

Figure 4.7: The effect of different sources of animal manure extracts (chicken, cow and goat) compared to commercial fertilizer (control) on chlorophyll fluorescence parameters of hydroponically grown tomatoes (CLX 532). Minimum fluorescence (**A**), maximum fluorescence (**B**), maximum quantum efficiency of photosystem II (**C**), effective quantum efficiency of PSII photochemistry (**D**), photochemical quenching (**E**), non-photochemical quenching (**F**), electron transport rate (**G**), relative measure of electron transport to oxygen molecules (**H**), proportion of open reaction centres (**I**). Values are the means ± SE (n = 10).

4.4 Conclusion

This study evaluated the effect of the integrated use of animal manure extract and drip soilless system on growth, leaf gas exchange and chlorophyll fluorescence in tomatoes. Variability amongst different treatments was observed, goat manure extract followed by chicken manure extract affected growth parameters (height, stem diameter and the number of fruits), *Ci, WUEi*, *Fm'* and *qN* more than commercial fertilizer and cow manure extract. This may be mainly because of the high nitrogen concentration in both goat manure extract and chicken manure extract. While cow manure extract affected *gs*, *Fv/Fm'* and *ETR* more compared to other treatments. Therefore, animal manure extracts especially goat manure extract and chicken manure extract can be used as an alternative source of nutrients in tomato production as they produce results which are comparable to commercial fertilizers. Further studies may evaluate the effect of animal manure mixed with commercial fertilizer at a specific ratio as a nutrient source in vertical soilless culture.

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Chapter 5

The effect of compost extracts on yield, physico-chemical and nutritional quality of tomatoes *(Solanum lycopersicum)* grown in soilless cultivation

Abstract

In response to the environmental challenges facing the agricultural sector, growers are moving towards innovative and sustainable cultivation methods such as the hydroponic production system. This study evaluated the effect of different sources of manure on the yield, physico-chemical and nutritional quality of tomatoes (*cv.* CLX 532) grown in a hydroponic system. The experiment was set up as a completely randomized design with four treatments, which included three types of animal manure-derived hydroponic nutrient extracts namely chicken (CHME), cow (CME), goat (GME) and a commercial fertilizer as a control. Tomato fruits from each treatment were harvested and analyzed for macro and micronutrients, physicochemical attributes such as total soluble solids (TSS), titratable acidity (TA), total soluble solid to titratable acidity ratio (TSS/TA), BrimA, colour index and firmness. The total phenolics and ascorbic acid content were also assessed. The results showed significant differences in yield, physico-chemical and nutritional quality among different treatments. The number of fruits was higher in CHME (7.33) than in commercial fertilizer (5.83), CME (5.17) and GME (4.83). The shoot mass (fresh and dry) was higher in commercial fertilizer (458.3 and 103.3g), GME (453.3 and 93.3 g) and CHME (421.7 and 90.0 g) compared to CME (286.7 and 83.3 g). TSS was higher in CHME (6.47 °Brix) compared to other treatments. While TA was higher in both commercial fertilizer and CHME (0.62% and 0.61%) than in GME and CME (0.44% and 0.39%). Both TSS/TA and BrimA were lower in commercial fertilizer (7.59) and (2.83) than in animal manure extracts (AME). CHME had a higher colour index (30.32) while GME had higher firmness (316.9 N) than other treatments. Lastly, GME had the highest phenolic concentration. Fruit fertigated with commercial fertilizer had more macronutrient content while fruits fertigated with animal manure-based nutrient solutions had more micronutrients. Therefore, animal manure extract can be used as a nutrient source in the production of tomatoes as it produces fruit quality which is comparable to commercial fertilizers.

Keywords: Animal manure extract, fertigation, nutritional, physico-chemical, tomatoes, quality

5.1 Introduction

Over 180 million tons of tomatoes are produced worldwide per year, which is 165% more than in the last two decades (Wyngaard and Kissinger, 2022). Tomatoes are globally popular as they can be consumed raw or processed (Frusciante et al., 2007; Marsic et al., 2011). They are an important component of the healthy diet because of their high-functioning compounds such as lycopene and ß-carotenes which are significant for the human diet (Al-Dairi et al., 2021). Several studies have identified tomatoes to be a good source of antioxidants such as carotenoids, vitamin C, phenolics and flavonoids (Cruz-Carrión et al., 2022; Marsic et al., 2011). The high concentration of these antioxidants can help prevent chronic non-communicable illnesses such as cancer, cardiovascular and neurodegenerative diseases (Ali et al., 2020; Tilahun et al., 2017).

The major factors affecting the yield and quality of tomatoes include drought, extreme temperatures, lack of fertile soil and shortage of clean water for irrigation (Abdelaal et al., 2022; Hornick, 1992).With the growing population, there is a need to produce more food in a short period, as a result, growers currently use fertilizers to boost their production. Using organic fertilizers is not a new phenomenon, it has been practiced for over 12,000 years (Loss et al., 2019), it involves applying livestock manure, green manure, crop residues, compost and household waste. On the other hand, the use of synthetic fertilizer only started during the Industrial Revolution and these fertilizers are either mined from mineral deposits or produced industrially through chemical processes (Gupta and Hussain, 2014). As much as these two types of fertilizers are applied to supply plants with essential nutrients needed to enhance growth and yield, they do not differ significantly in terms of nutritional quality (Naeem et al., 2006). The benefits of synthetic fertilizers over organic fertilizers include the high levels of readily available nutrients, there is no need to decompose before application, rapid and significantly increased plant growth and yield (Sharma and Chetani, 2017). Alternatively, organic fertilizers improve the water and nutrient holding capacity on a medium, supply nitrogen in usable form, do not contribute to pollution and are available at little to no cost (Gupta and Hussain, 2014; Sharma and Chetani, 2017; Wang et al., 2018). However, the nutrients in organic fertilizers are released slowly over time which may cause insufficient nutrients in plants at early stages of growth, and produces lower yield than synthetic fertilizers (Heeb et al., 2006).

Overuse of chemical fertilizers is one of the challenges in crop cultivation as they lead to long-term and short-term consequences that may harm both humans and the environment (Pilla et al., 2023). This then becomes the biggest challenge for farmers as they are expected to produce enough nutritious food while ensuring environmental, social and economic sustainability (Ramírez-Gottfried et al., 2023). Several studies have investigated the effect of organic farming on the yield of different crops and the results vary. Most studies reported an increase in the yield (number of harvested fruits/ grains per plant and total biomass) of organically grown crops (Abdel-Haleem et al., 2022; Gao et al., 2023; González-Hernández et al., 2022; Reganold et al., 2010), this is because the application of organic fertilizers formulated more solute in the soil therefore increasing yield (Norhayati et al., 2019). However, Amarante et al. (2008) reported that the organic orchard produced fewer Royal Gala apples, smaller weights and less yield of Fuji apples compared to commercial fertilizer. The author further speculated that it was due to the limited macronutrients in the organic orchard soil. Further research has evaluated the quality of organically produced crops, the findings discovered less mass loss (Reganold et al., 2010), high firmness (Amodio et al., 2007), improved titratable acidity (Norhayati et al., 2019) and high total soluble solids (Abdel-Haleem et al., 2022; Mowa et al., 2018; Norhayati et al., 2019) of organically grown plants compared to conventional. Additionally, crops cultivated in organic farms had high antioxidant activities (ascorbic acid, total phenolics and carotenoids) (Amodio et al., 2007; Faller and Fialho, 2010; Gao et al., 2023; Giménez et al., 2020; Khalil and Hassan, 2015). Despite the extensive body of research on the effect of organic farming on yield and quality, there are still limited studies on the impact of organic fertilizers on quality in soilless cultivation. Therefore, this study investigated the effect of chicken, cow and goat manure extracts as nutrient source on yield, physicochemical quality and nutritional quality of tomatoes grown in the hydroponic system.

5.2 Materials and methods

5.2.1 Plant Materials and environmental conditions

Four weeks old tomato (*Solanum lycopersicum*) seedlings of the indeterminate hybrid variety CLX 532 were procured from Sunshine Seedling Services, a vegetable nursery based in Pietermaritzburg. This research was conducted at the Controlled Environment Research Unit (CERU) within the University of KwaZulu-Natal, Pietermaritzburg (29º40’05.7”S; 30º24’20.9”E), spanning from September 2023 to December 2023. The tomato plants were grown in a 4.8 m × 6 m glasshouse, maintaining an average relative humidity of 32.8% and temperature of 33.7 °C. After harvesting, the fruits were taken to the university's postharvest laboratory with conditions maintained at 25 °C and 45% relative humidity.

5.2.2 *Experimental design and crop establishment*

The layout of the experiment was completely randomized with four treatments and four replicates per treatment. The four treatments consisted of three animal manure extract (AME) with the following nutrient concentrations; goat manure extract (GME)- N (2900 mg/l), P (36.0 mg/l), K (1426.1 mg/kg), Ca (25.0 mg/l), Mg (44.9 mg/l), Cu (0.04 mg/l), Mn (0.08 mg/l), Zn (0.05 mg/l); chicken manure extract (CHME) - N (4700 mg/l), P (99.1 mg/l), K (751.2 mg/l), Ca (30.8 mg/kg), Mg (85.8 mg/l), Cu (0.17 mg/l), Mn (0.20 mg/l), Zn (0.45 mg/l); cow manure extract (CME) - N (3400 mg/l), P (10.5 mg/l), K (205.7 mg/l), Ca (54.3 mg/l), Mg (47.9 mg/l), Cu (0.04 mg/l), Mn (0.77 mg/l), Zn (0.13 mg/l); and a commercial fertilizer. The tomatoes were planted for 12 weeks and harvested on week 13. A few healthy tomato fruits were randomly selected at harvest to further analyze the quality parameters. The harvested tomato fruits were washed with distilled water, cut into pieces, freeze-dried in a VirTis benchtop Pro freeze-dryer (SP Scientific Inc, Stone Ridge, NY, USA) and crushed into fine powder with an aromatic coffee grinder (Mellerware, China). The powder samples were used for nutritional analysis and some were sent to Cedara Agricultural Analytical Laboratory for mineral analysis, the rest of the tomato harvested tomato fruits were used for physiological quality analysis.

Commercial Fertilizer CHME CME GME

Figure 5.1: The effect of different sources of animal manure extracts applied through fertigation on the fruit quality of tomatoes grown in the hydroponic system. **CHME**; chicken manure extract, **CME**; cow manure extract, **GME**; goat manure extracts.

5.2.3 *Chemicals and reagents*

The chemicals used in this experiment included NaOH, Phenolphthalein, metaphosphoric acid, 2,6- Dichlorophenolindophenol, Folin-Ciocalteu reagent, 2,2-Diphenyl-1-picrylhydrazyl antioxidant, ferulic acid, sodium carbonate, methanol and hydrochloric acid were all of analytical grade, procured from Monitoring and Control Laboratories (Durban, South Africa), Prestige Laboratory Supplies CC (Durban, South Africa) and Sigma Aldrich (Johannesburg, South Africa).

5.2.4 Data recorded and plant materials used

5.2.4.1 Number of fruits, fruit size and plant biomass

All yield and physicochemical quality parameters were measured during the harvest date. The harvest took place at week 13 after transplanting. Fruits with mature green to red colour were harvested and counted. After harvesting, fruit mass was determined using a weighing balance (WTB200, RADWAG. Poland) in grams. Fruits from the plants in which measurements were taken were put in a tomato packaging box. The mass of the roots, stem and leaves was recorded before and after being oven dried at 60 °C for 48 hours.

5.2.4.2 Colour

The colour was measured on the harvest day using a Konica Minolta Chroma meter CR - 300, INC, Japan (López Camelo and Gómez, 2004). Fruit colour measurements included lightness (L^*), green to red (a^*), blue to yellow (b^*) and chroma (C) the results were combined as the tomato Colour Index (Hobson et al., 1983) using Equation 1.

$$\text{Colour index} = 2000a \div \text{LC} \qquad (1)$$

5.2.4.3 Firmness

Fruit firmness was measured on the same day using a hand-held firmness tester (Bareiss, Germany). Three readings were recorded at the equatorial region of the fruit on a scale of 100 (hard and unripe) to 0 (soft and overripe).

5.2.4.4 Total soluble solids (TSS)

Total soluble solid percentage (TSS) was determined using a method by (Ncama et al., 2017) with a little modification. Concisely, tomato fruits were blended using a Warring blender and filtered into a 50 mL beaker using a nylon filter. The digital refractometer (RFM340 +, Bellingham + Stanley Ltd, Tunbridge Wells, UK) was calibrated by cleaning a prism with distilled water, wiping it with a clean paper towel and measuring a zero sample. Subsequently, the tomato juice of each fruit serving as a replicate was then measured by pipetting 2 - 3 drops of tomato juice into the refractometer prism to determine TSS. The TSS was expressed in °Brix.

5.2.4.5 *Titratable acid (TA)*

The process of measuring *TA* involved using a Mettler Toledo compact titrator G20S (Greifensee, Switzerland). In short, the samples were prepared by pipetting 8 mL of juice into a 100 mL beaker. The, 42 mL distilled water was added to the juice in the beaker using a separate clean pipette tip and titrated with 0.1M NaOH to a pH value of 8.1 using a Mettler Toledo. The acid was calculated as a percentage of citric acid using a factor of 0.0064, Equation 2.

$$\text{Percentage acid} = \frac{Titre(mL\ NAOH)Xacidfactor X100}{8(mL\ Juice)} \qquad (2)$$

The solid acid ratio and BrimA were calculated using Equations 3 and 4, respectively.

$$\text{Solid acid ratio } = \text{TSS/TA} \qquad (3)$$

$$BrimA = TSS - k\ (TA) \qquad (4)$$

The term BrimA (Brix minus acid) is defined as the index employed to assess the equilibrium between Brix and acidity (Magwaza and Opara, 2015), equation 4 was formulated by (Jordan et al., 2001). Where *k* is a constant that reflects the tongue's higher sensitivity to *TA* (titratable acidity) in comparison to *TSS*. The *k* allows *TSS* amounts that surpass *TA* to make the same numerical changes to *BrimA*. The equation was adjusted according to the recommendation by Obenland et al. (2009) who changed the value of k from 5 to 3 or 4 to omit the negative values of *BrimA* of oranges.

5.2.4.6 *Ascorbic acid (Vitamin C) concentration*

Ascorbic acid was determined using the method by (Boonkasem et al., 2015) with little modification. Exactly 0.1 g of freeze-dried samples was extracted using 5 mL of 3% metaphosphoric acid and vigorously shaken. The mixtures were centrifuged at 12 098 G for 10 minutes. The supernatant was collected and 1 mL was mixed for 15s with 5 mL 0.05 mM DCPIP. Samples and absorbance were read at 515 nm against blank immediately before 15 sec using the spectrophotometer (UV-1800, Shimadzu Corporation, Japan). The ascorbic acid was calculated using a concentration between 0 - 20 ug/mL of ascorbic acid ($R^2 = 0.987$).

5.2.4.7 *Total phenolic concentration (TPC)*

A method by (Ah-Hen et al., 2012) with a slight modification was used to determine the total phenolic concentration. The TPC was determined by the Folin-Ciocalteu photo-colorimetric method. Freeze-dried tomato powder (0.2 g) was measured into centrifuge tubes, and 4 ml of

80% ethanol combined with 1% HCL was added. The mixture was then homogenised by shaking it in an orbital shaker at 200 rpm for 2 hours at 25 °C. The mixture was centrifuged for 10 minutes at 700 rpm. The supernatant (100 µL) was combined with 750 µL of the Folin-Ciocalteu reagent and left in the dark for 10 minutes. Thereafter, 750 µL sodium carbonate solution was added to the mixture and was left to stand for 90 minutes at 22 °C. Finally, the absorbance was measured at 765 nm using a UV - 3600 spectrophotometer (Shimadzu, Kyoto, Japan) and compared to a standard curve concentration between 0 - 40 µg /100 µL ferulic acid to calculate the actual concentration of the sample extract ($R^2 = 0.994$).

5.2.5 Statistical analysis

The analysis of variance (ANOVA) was carried out using GenStat Version 23rd Edition (VSN International, Hemel Hempstead, UK). Mean values recorded were separated by LSD (Least Significant Difference) at 5% level of significance.

5.3 Results and discussion

5.3.1 Average fruit mass and number of tomatoes

The treatments had a significant effect ($p = 0.043$) on the number of fruit but had no significant effect ($p = 0.072$) on the fruit mass (Fig. 5.2A and B). The CHME followed by commercial fertilizer produced a significantly high fruit number (7.33 and 5.83) compared to CME and GME (5.17 and 4.83). The current results are similar to the results by Mowa et al. (2017) who reported that plants fertigated with chemical fertilizer produced more fruit than plants fertigated with goat manure solution and tap water. On the other hand, the application of CME produced bigger fruit (153.6 g) in weight on average followed by GME (139.6 g) and commercial fertilizer (138.9 g) (Fig. 5.2B). CHME produced the smallest fruit (129.6 g) on average but the difference in fruit weight amongst treatments was not significantly different. These results are similar to the findings by Mowa et al. (2018) where the fresh weight of fruits produced using goat manure-derived hydroponic nutrient solution was comparable to those produced using chemical fertilizers. Kechasov et al. (2021) also discovered that the plants treated with organic waste-based fertilizer produced fruit with the highest fresh weight compared to the plants treated with high and low-mineral treatment. Organic manures are generally rich in macro- and micronutrients (El-Khalily et al., 2023), however, chicken manure contains these nutrients in abundance compared to goat and cow manure. This may be the primary cause of the high number of fruit in plants fertigated with CHME, its application increases the nutrient availability, water retention and nutrient uptake by plants (Amalia et al., 2020; Mayele and Abu, 2023), thus increasing the reproductive growth. Furthermore, it is likely that the high fruit mass in plants fertigated with CME and GME is due to the low vegetative growth observed in the two treatments. Both CME and GME produced fewer fruits compared to CHME and commercial fertilizer, therefore, there was less competition for photoassimilates amongst the fruits produced by CME and GME thus producing bigger fruits. When a plant prioritizes vegetative growth, it delays fruit development and ripening (Sainju et al., 2003). The bigger fruit sizes over commercial fertilizers may also be due to the slow release of nutrients in organic manure, which promotes uniform growth and fruit development throughout the growing period (Hasnain et al., 2020).

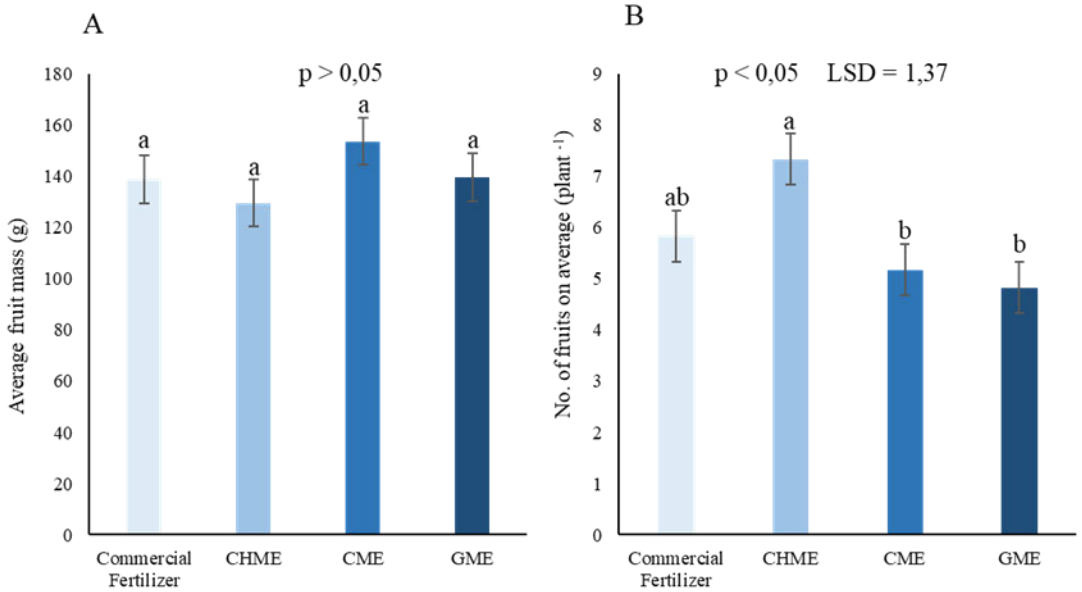

Figure 5.2: The average fruit mass (**A**) and number of tomato (CLX 532) fruits (**B**) grown in soilless cultivation, in response to different sources of animal compost extracts and commercial fertilizer. Where **CHME**- chicken manure extract, **CME**- cow manure extract, **GME**- goat manure extract. Values are the means ± SE (n = 4).

5.3.2 Fresh mass and biomass

The results in figure 5.3 represent the fresh and dry weight of the shoots and roots of tomatoes fertigated with different sources of animal manure extracts. The treatments had a significant effect on the fresh and dry weight of the shoot (p = 0.023 and p = 0.032), fresh root weight (p = 0.005) but had no significant effect on the dry root weight (p = 0.083) (Fig. 5.3A-D). The CME had a significantly smaller shoot mass (dry and fresh) compared to all other treatments at 286.7g and 83.3g. Commercial fertilizer had the largest shoot mass (fresh and dry) (458.3g and 103.3g), followed by GME (453.3g and 93.3g) and CHME (421.7 and 90.0g). These findings are similar to the results by Williams and Nelson (2014) who reported lower shoot fresh and dry mass of butterhead lettuce (*Lactuca sativa* L. ‘Rex’) under organic fertilizer compared to inorganic fertilizer. This is however contrary to Kechasov et al. (2021) who found that tomato (*cv*. Dometica) plants treated with organic waste-based fertilizer had a bigger fresh weight compared to high-mineral or low-mineral treatment. These differences may result from the type of organic fertilizer, the rate and the time of application. It may also be attributed to the fact that different type of fertilizers may affect plant yield in various ways due to their distinct compositions. When the nutrients are available in high quantities, plants utilise them more extensively according to their demand thus affecting plant biomass (Mowa, 2018; Zaller, 2007). Furthermore, plants fertigated with GME had significantly higher fresh root mass (401.7 g) followed by CME (340 g) compared to other treatments. These results are similar to the findings by Mowa (2018), who reported high biomass weight in tomatoes fertigated by organic fertilizer compared to inorganic fertilizers. These similarities may be attributed by the source of manure used and the method of application. The author also used goat manure to formulate the hydroponic nutrient solution which was applied through fertigation. These results may suggest that the plants were able to absorb the available nutrients including nitrate in the growing medium, to the extent that made available.

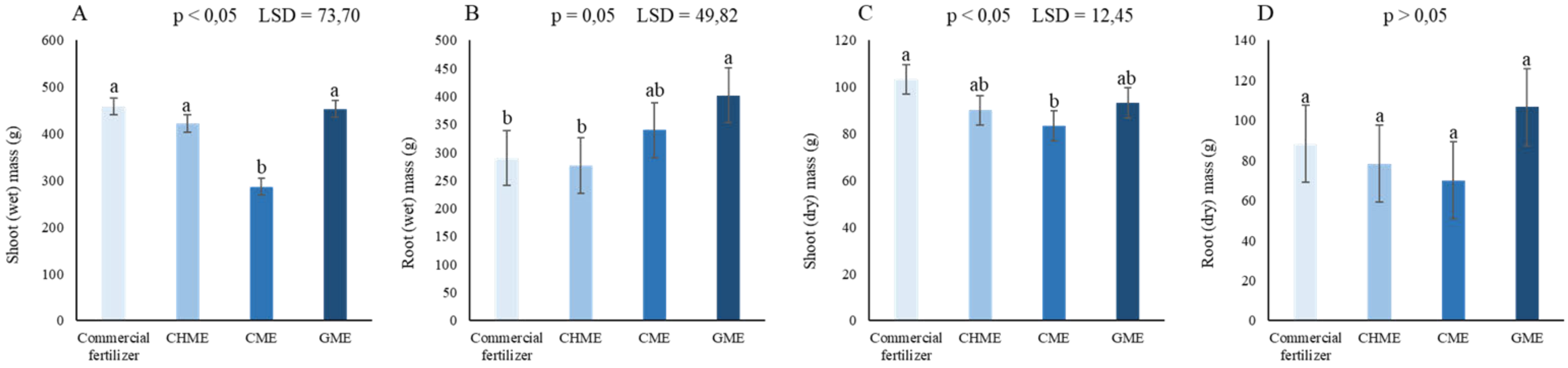

Figure 5.3: The effect of different sources of animal compost extract and commercial fertilizer on the fresh mass and biomass of tomato fruits (CLX 532), grown in soilless cultivation for 12 weeks. Where **CHME**- chicken manure extract, **CME**- cow manure extract, **GME**- goat manure extract. Values are the means ± SE (n = 4).

5.3.3 Nutritional content

The treatments had a highly significant effect ($p < 0.001$) on P, Ca, a significant effect on K ($p = 0.033$) and Mg ($p = 0.05$) but had no significant effect on N ($p = 0.296$) (Table 5.1). The order of significance in P content was as follows; commercial fertilizer > CHME > GME > CME, while K content was significantly higher in fruits fertigated with commercial fertilizer at 4.41 mg/kg followed by CHME (3.63 mg/kg) and CME (3.47 mg/kg). A similar trend was observed where commercial fertilizers had a significantly higher Ca content (1162 mg/kg) followed by CME (705 mg/kg). The significantly high P, K and Ca in commercial fertilizers were likely because chemical fertilizers are specifically formulated to provide certain nutrients which promote growth and fruit nutritional quality (Amalia et al., 2020). This means that during the production of chemical fertilizers, the nutrient concentrations are balanced to serve a specific role at different stages of plant production. However, the concentrations of these nutrients are imbalanced in AME as indicated in section 5.2.2 of the current study, this imbalance of nutrients could result in inadequate levels of macronutrients accessible for plant uptake. Furthermore, it may also be because chemical fertilizers easily dissolve and release essential nutrients in a form easily absorbable by plants (Thepsilvisut et al., 2022).

Various nutrients fulfil different roles during the production of crops, phosphorus is responsible for root and plant structure development, cell division, photosynthesis and respiration, while potassium is essential for stomatal opening, cell elongation, synthesis of enzymes and sugar and fruit maturation (Nadeem et al., 2018; Saba, 2020). Moreover, calcium helps in the development and maintenance of fruit quality, stabilizes the cell membrane, enhances canopy growth and facilitates root and leaf elongation (Almeida et al., 2023; Nadeem et al., 2018). When these nutrients synergize, they contribute to fruit weight, yield and quality, therefore, regardless of the slow release of the nutrients over time, their impact is evident on the fruit mass, number of fruits (fig. 5.2) and firmness (fig. 5.4 F) produced by AME in comparison to commercial fertilizers.

The Mg content was found to be higher in fruits fertigated with CHME and CME, these findings agree with Kassem and Marzouk (2010) who reported high magnesium content in date palm (*Phoenix dactylifera* L.) grown using cow dung than mineral fertilizers. It could be argued that the high Mg content in tomato fruits fertigated with CHME and CME is because of the high Mg content in these nutrient solutions over GME. When the organic fertilizer is applied, the nutrients are not immediately available to plants (Naeem et al., 2006), they are released slowly over time and are made available for root absorption over an extended period thus the accumulation in tomato fruits. In the realm of crop production magnesium plays an important role in the synthesis of chlorophyll and photosynthesis and contributes to the stabilization of ribosomal particles which are essential for protein synthesis (Jaswal, 2021; Nadeem et al., 2018; Saba, 2020). It further supports phosphorus absorption, this is true for the current study, CHME had the highest concentration of Mg amongst other types of AME and tomato fruits fertigated with CHME exhibited higher levels of phosphorus.

The treatments had a significant effect ($p = 0.003$) on Cu, ($p = 0.004$) Fe and ($p < 0.001$) on Mn and Zn content. The Cu concentrations were higher in CHME (0.75 mg/kg) and GME (0.27 mg/kg), and a similar trend was observed in Fe concentrations where CHME and CME were significantly higher (8.5 mg/kg and 8.1 mg/kg) than commercial and GME fertilizer (6.68 mg/kg and 5.3 mg/kg). The Mn concentration was significantly higher in CME (18.4 mg/kg) than in other treatments, while Zn showed significance in the following order CHME > commercial > CME > GME. Overall, animal manure-derived hydroponic solutions produced fruits with high levels of micronutrients compared to commercial fertilizer. This is attributed to the organic fertilizer's ability to supply a range of nutrients (El-Khalily et al., 2023) which are then slowly released over time (Sainju et al., 2003). The organic matter then increases the absorbing ability of the root system for nutrient uptake (Hasnain et al., 2020). The application triggers over 100 enzymes, contributes to carbon dioxide emission, enhances the production of proteins, vitamins, sugars and starch and influences the lignin and phenolic concentrations (Bafoev et al., 2022; Malakouti, 2008; Toor et al., 2021). The lack of these nutrients may significantly affect yield and quality, despite the low concentrations of micronutrients supplied by AME, the yield of AME rivalled if not exceeded that of commercial fertilizer. Therefore, it can be speculated that the nutrients supplied by AME were utilized efficiently.

Table 5.1: The effect of animal compost extract and commercial fertilizer on the nutrient content of tomatoes (CLX 532) grown for 12 weeks in soilless cultivation. Where **CHME** (chicken manure extract), **CME** (cow manure extract) and **GME** (goat manure extract).

Nutrient solution source	Nutrient concentration (mg/kg)								
	N	**P**	**K**	**Ca**	**Mg**	**Cu**	**Fe**	**Mn**	**Zn**
Commercial fertilizer	19270 a	3861a	44100 a	1162 a	1180 b	0.18 c	6.68 ab	13.41 b	16.09 b
CHME	21020 a	3363 b	36300 ab	440 c	1349 a	0.75 a	8.49 a	11.82 b	18.73 a
CME	20430 a	1391 d	34700 ab	705 b	1338 a	0.27 bc	8.11 a	18.40 a	13.56 c
GME	21720 a	1616 c	33900 b	458 c	1154 b	0.64 ab	5.53 b	8.81 c	1098 d
P < 0.05	NS	**	*	**	*	*	*	**	**
LSD		*160*	*7000*	*115.5*	*162,1*	*0.27*	*1.38*	*1.37*	*1.49*
cv%	*7.2*	*3.2*	*9.9*	*8.9*	*6.9*	*31.5*	*10.2*	*5.5*	*5.3*

*Values in the same column sharing the same letter are not statistically different at LSD (p=0.005). Values are the means ± SE (n = 4). Note: ** - P < 0.001, * - P < 0.05 and NS - P > 0.05.

5.3.4 TSS, TA, TSS/TA, BrimA, colour index and firmness

The treatments had a highly significant effect ($p < 0.001$) on TSS, TA, TSS/TA and BrimA (Fig. 5.5A - F). TSS was significantly higher in CHME (6.47 °Brix) compared to other treatments. In the current study, a high colour index was also observed in plants fertigated with CHME which was an indication of ripeness (Fig. 5.5E). Similar results were observed by Buajaila et al. (2021) where high TSS was recorded in fruits treated with composted poultry manure + urea compared to fruits treated with commercial fertilizer. The similarities are possibly due to the nutrient composition in chicken manure. The high TSS in CHME may be due to the fact that the application of organic fertilizer increases *Ascomycota* which is a fungi responsible for facilitating root extension, nutrient availability and nutrient absorption by plant roots (Fan et al., 2023), thereafter increasing starch accumulation through photosynthesis (Buajaila et al., 2021). Furthermore, a similar trend was observed in TA where CHME and commercial fertilizer had a significantly higher effect (0.62 and 0.61) than GME and CME (0.44 and 0.39). These results are in contrast with the findings by Ye et al. (2020) who reported lower TA in 'jujube' pear treated with organic fertilizers compared to the chemical fertilizer. These differences can be attributed to several factors such as plant species, nutrient profile and environmental conditions, different plant species may have varying responses to the fertilizers whether organic or inorganic. Each species has specific nutrient requirements that can impact the regulation of organic acids thus influencing TA. Tomatoes generally have different nutrients requirements at different stages of growth, in the current study however, AME supplied the same amounts of nutrients throughout the growing period. Therefore, the increase in both TSS and TA in tomato fruits fertigated by CHME is likely due to the fact that certain nutrients were not provided according to the plant's requirements (section 5.2.2) which may have resulted in an intake of some nutrients more than others.

The CME, GME and CHME significantly affected TSS/TA (12.9, 11.4 and 10.6) (Fig. 5C). The results agree with the findings reported by Ye et al. (2020) where the solid acid ratio of decomposed sheep manure was higher than that of control. It can be speculated that since the nutrients that enhanced TSS/TA in both these studies are sourced from livestock waste which has been decomposed, the nutrient composition is similar to a certain degree hence the similar effect. BrimA showed significance in the following order CHME> CME> GME> commercial fertilizer (Fig. 5D). When the organic fertilizer is applied, it stabilizes as it decomposes (Colín Navarro et al., 2019). The stabilization decreases microbial activities while slowly releasing essential nutrients for plant uptake. The availability of a sustainable supply of nutrients may contribute to fruit quality thus increasing sugar-acid ratio, BrimA and colour index.

The treatments showed a significant effect on the colour index (p = 0.03) and firmness (0.014) of tomatoes (Fig. 5.5E and F). The colour index was significantly higher in plants fertigated with CHME and commercial fertilizer (30.2 and 28.9). Studies claim that high nitrogen and low Ca levels delay colour development (Amarante et al., 2008; Mditshwa et al., 2017) however, despite the high N and low Ca content on the CHME used in this study, the colour index increased. This may be attributed to the high microbial activities in organic waste-based compost tea (Williams and Nelson, 2014) which plays an important role in nutrient absorption by plants. This may impact the formation of pigments responsible for tomato colour development. However, these results may warrant further assessment of the impact of CHME on the enzymatic processes that regulate colour development in tomato fruits. The firmness was significantly higher in GME (316.9 N) followed by CHME (253.1 N). These results are in contrast with the findings by Kilic et al. (2021) who reported that different strawberry cultivars treated with commercial fertilizer and a combination of organic + commercial fertilizer were firmer than strawberries treated with organic fertilizers. Fruit firmness is mostly affected by high Ca content (Choi, 2020), in this study however, GME and CHME had more effect on tomato firmness despite the low Ca content. This may be attributed to the polysaccharide components in the animal diet. Similar results were reported by Choi (2020), who observed an increase in cherry tomato firmness treated with a starfish nutrient solution (SF) which had lower Ca content.

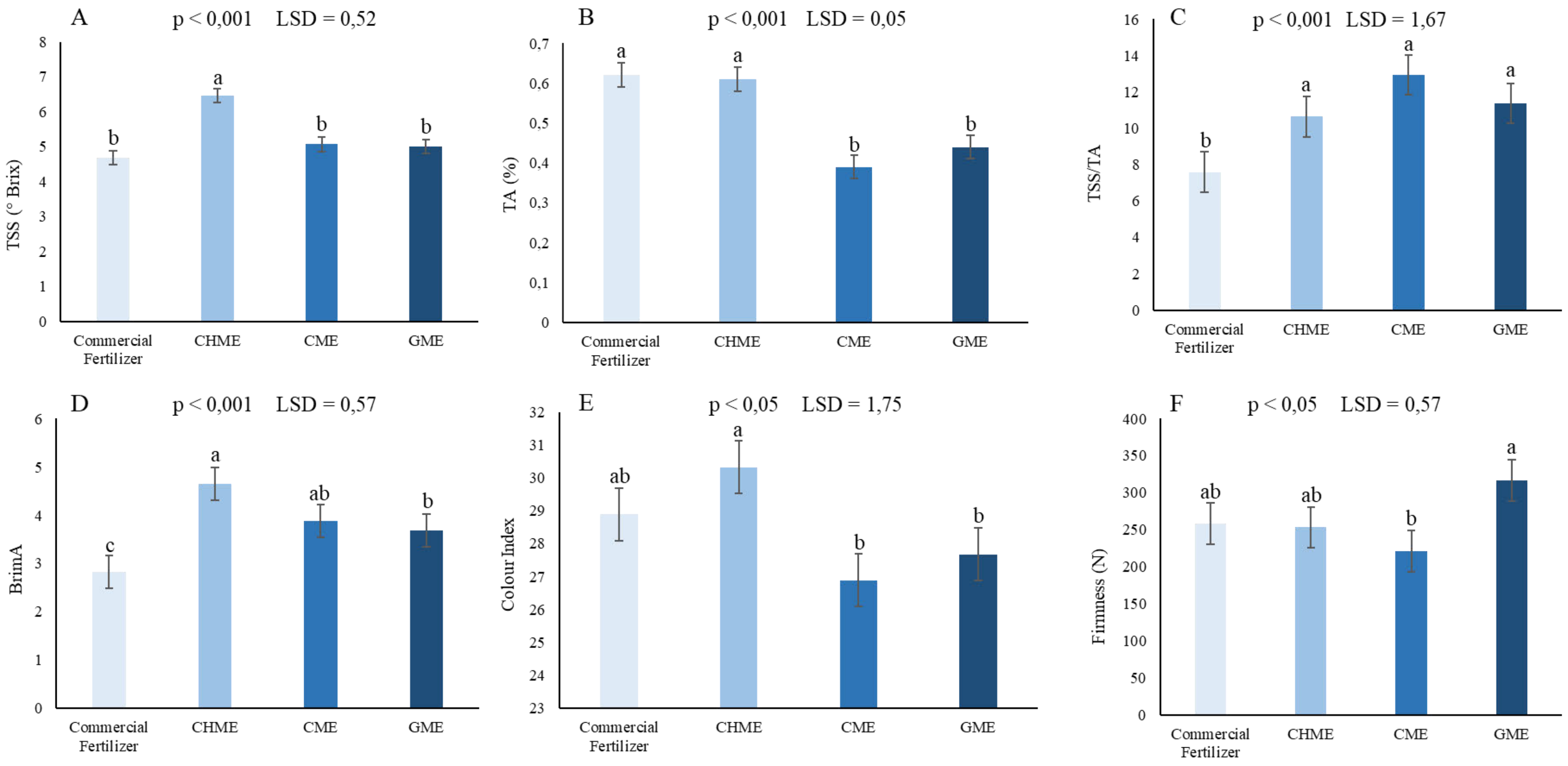

Figure 5.4: Effect of animal compost extracts and commercial fertilizer on total soluble solids (**A**), titratable acidity (**B**), solid acid ratio (**C**), BrimA (**D**), colour index (**E**) and firmness (**F**) of tomatoes (CLX 532) grown for 12 weeks in soilless cultivation. Where **CHME**- chicken manure extract, **CME**- cow manure extract, **GME**- goat manure extract. Values are the means ± SE (n = 4).

5.3.5 *Total phenolics and Ascorbic acid*

The treatments had a highly significant effect on the total phenolic and no significant effect (p = 0.20) on the ascorbic acid of tomatoes (Fig. 5.6A - C). GME had a significantly high effect (2.61 g/kg) on the concentration of the phenolic followed by CME (2.25g/kg) compared to CHME and commercial fertilizer (1.86 g/kg and 1.82g/kg). The results agree with the findings by Toor et al. (2006) who reported high total phenolics in tomatoes grown using organic fertilizers compared to mineral fertilizers. Furthermore, they are also similar to results by Amodio et al. (2007) who reported high phenolic content in organically kiwi fruits. The author speculated that the increase in total phenolics with the organic fertilizer was due to the pathogen pressure on the organically grown kiwi fruits, this pressure arose from the absence of pesticide application which caused biotic and abiotic stresses. The direct impact of organic fertilizers as a nutrient source in the production of total phenolics is still unclear (Rodríguez-Ortiz et al., 2022), however cultivation methods and environmental factors can impact the phenolic compounds. Nevertheless, the increase in total phenolics in the current study is not related to the environmental conditions or cultivation method used because the conditions were uniform in all treatments. However, it may be attributed to the nutrient composition of the nutrient sources used, there might have been a surplus or deficiency in GME and CME over CHME which may have caused plant nutrient stress. When plants encounter stress-inducing conditions they produce more phenolic compounds as a defence mechanism (Khalil and Hassan, 2015; Mowa et al., 2018).

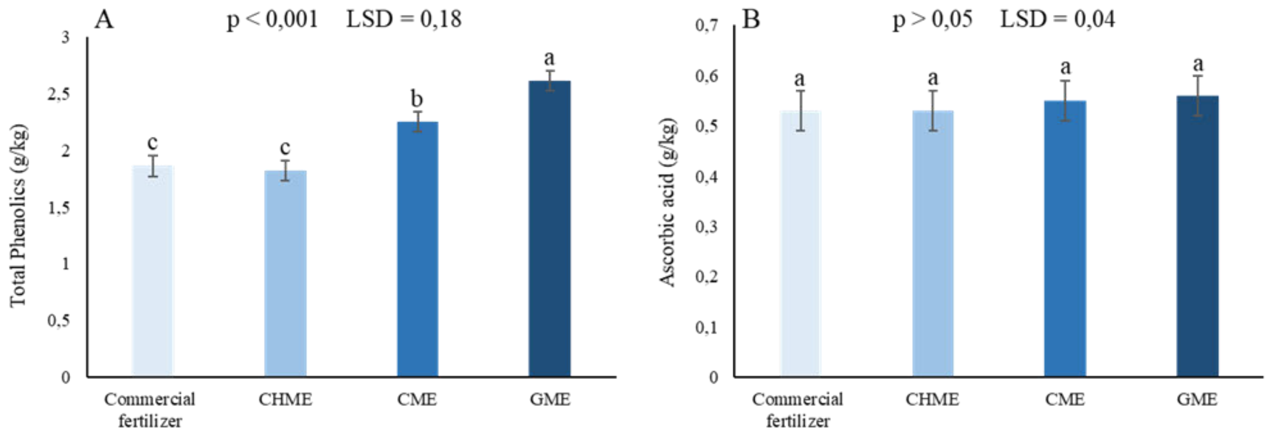

Figure 5.5: The effect of animal compost extract and commercial fertilizer on phenolics (**A**) and ascorbic acid (**B**) of tomato fruits (CLX 532) grown in soilless culture for 12 weeks. Where **CHME**- chicken manure extract, **CME**- cow manure extract and **GME**- goat manure extract. Values are the means ± SE (n = 4).

5.4 Conclusion

This study evaluated the effect of different sources of manure (chicken, cow and goat) on yield, physiochemical and nutritional quality of hydroponically cultivated tomatoes (CLX 532). The application of these treatments showed variation, chicken manure extract had increased the number of fruits, shoot mass, TSS, TA, TSS/TA, BrimA, colour index, and firmness. While the goat manure extract improved TSS/TA, BrimA, firmness and phenolics concentration, the cow manure extract increased shoot mass. Fruits fertigated with commercial fertilizer had more macronutrients than fruits fertigated with animal manure-derived hydroponic nutrient solution. On the other hand, tomato fruits fertigated with animal manure-derived hydroponic nutrient solution had more micronutrients than fruits fertigated with commercial fertilizer. Therefore, animal manure extracts especially goat manure and chicken manure extract can be used as an alternative source of nutrients as they produce quality comparable to commercial fertilizer. Future studies should investigate the effect of combinational use of chicken and goat manure. The effect of animal manure-based fertilizers on shelf-life of tomatoes should also be investigated.

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Chapter 6

General discussion, conclusion and recommendations

6.1 Introduction

Crop cultivation under a protected structure and in a soilless hydroponic system has gained popularity in commercial farming for over 40 years (Sheikh, 2006). This is because hydroponic systems allow for crop production all year round without limitations such as climate, soil infertility and shortage of arable land (Jan et al., 2020). It is part of sustainable agricultural practices and may help farmers produce enough food to feed the growing world population. However, some countries have environmental legislation which obligates farmers to use environmental friendly systems when producing their crops (Rodríguez-Ortega et al., 2019). In such instances, using hydroponic systems may not be feasible due to the excessive use of inorganic fertilizers. These inorganic fertilizers are nitrate-based and nitrate tends to accumulate in the leaves of vegetables, high levels of these nitrogen compounds in plants are harmful to humans, plant growth and the environment (Phibunwatthanawong and Riddech, 2019a; Williams and Nelson, 2014). Furthermore, inorganic fertilizers might be too pricey for some farmers (Mowa et al., 2017).

Simultaneously, the livestock industry is rapidly growing with the same objective of fulfilling the needs of the growing population. This comes with an increase in animal waste production which may cause land and water pollution if it is not properly disposed (Copeland et al., 2006). Animal waste can be used in plant production because they are rich in macro and micronutrients, vitamins and growth-promoting hormones (Mehdizadeh et al., 2013). Thus, repurposing the abundantly available organic waste for fertilizer is one of the sustainable approaches that can enhance plant production (Ramírez-Gottfried et al., 2023). Therefore, there is a need for the development of an integrated system for improving crop yield while minimising land pollution from animal waste. This study aimed to fill this research gap by generating hydroponic nutrient solutions from different sources of animal manures (chicken, cow and goat) to enhance the yield and quality of tomatoes through fertigation.

6.2 Key research findings

6.2.1 The use of animal manure for soilless crop production: A review

The objective of the literature review (chapter 2) was to outline and understand soilless culture, and the effect of animal manure on soilless crop production. It further highlighted the suitability of animal manure extracts and their impact on hydroponically grown vegetables. The review touched on the soilless crop production and different types of soilless culture namely water culture and substrate culture (Baudoin et al., 2013; Jan et al., 2020; Sharma et al., 2018). Studies have discovered that using the soilless systems is more beneficial than soil cultivation. The benefits include the absence of soilborne diseases and the elimination of weeds without using herbicides (Conversa et al., 2021). Furthermore, the application of nutrients is uniform which creates an ideal growing environment and increases yield and quality in areas with soil fertility problems (Baudoin et al., 2013; Putra and Yuliando, 2015). However, the installation and the materials used to build these systems is very expensive, they need a lot of inputs for construction and maintenance (Baudoin et al., 2013; Olympios and Choukr-Allah, 1999) and they need electricity to operate. The implementation of such systems then becomes a challenge in most African countries because about 70% of African small-scale farmers rely on crop production for their income (Onyeneke et al., 2023), they prefer spending less and gaining more. Limited research has been conducted to address the installation costs and maintenance costs of hydroponic systems. There is a pool of research to be conducted on developing cost-effective yet durable materials and technologies for constructing hydroponic systems. The possibility of developing solar/wind-operated systems should be explored.

The review further highlighted the importance and constraints of using organic fertilizers, either in a solid or liquid form. Several studies observed an increase in crop growth and development, root growth, nutrient uptake and yield with the application of organic fertilizers (Budiyanto and Achmad, 2022; Eleduma et al., 2020; Gichaba et al., 2020; Uwah and Eyo, 2014). Siavoshi et al. (2011) reported the application of organic fertilizers improved growth, productivity and yielded better rice grains than inorganic fertilizers. However, the spread of pathogens, the release of greenhouse gases and the possibility of water contamination by these fertilizers is still a primary issue (Ksheem, 2014; Kyakuwaire et al., 2019). Research has been done in an attempt to mitigate such concerns, these studies integrated organic fertilizers and soilless production methods of crop production (Andrian et al., 2019; Charoenpakdee, 2014; Magwaza et al., 2020; Mowa et al., 2017; Mowa et al., 2018; Phibunwatthanawong and

Riddech, 2019a). However, no study has been conducted on the effect of aerated compost extract on tomatoes (CLX 523) grown in a hydroponic system. Therefore, the current study was done to address this research gap.

6.2.2 Optimizing nutrient content in animal manure extracts for hydroponic crop production: comparative analysis and extraction methods

Chapter 3 evaluated the nutrient content of chicken, goat and cow as fresh manure and a vermicompost. The results reported a variation in the nutrient concentrations (N, P, K, Ca, Mg, Cu, Zn and Mn) throughout composting time. Nearly all nutrients increased in all sources of animal manure, this suggested that vermicomposting increased microbial activities due to the presence of worms in the manure (Kinigopoulou et al., 2023; Olle, 2019; Pilli and Sridhar, 2019; Rahman, 2021). Studies by Gichaba et al. (2020), Jjagwe et al. (2019) and Kinigopoulou et al. (2023) also found that vermicomposting enhances micro and macronutrient concentrations, this is mostly due to the breaking down of manure by worms into a worm casting. Cow and chicken manure had high moisture content due to their high ability to hold water.

This study further optimised nutrient extraction by using passive (anaerobic) and active (aerobic) extraction methods. The aerated compost extract had a higher nutrient concentration than non-aerated compost extract. This increase may be due to the presence of oxygen in the aerated compost extract, which creates a conducive environment for microbes (Minor, 2017). When food is available and the temperature is favourable, the metabolism increases thus increasing microbial activities. However, a decrease in oxygen levels can result in nutrient loss (Ingham, 2005; Scheuerell, 2004).

6.2.3 The effect of different animal manure extracts on growth, leaf gas exchange and chlorophyll fluorescence of tomatoes grown in soilless culture

Chapter 4 assessed the effect of animal manure extracts on growth, leaf gas exchange and chlorophyll fluorescence in tomatoes. Goat manure extract (GME) and chicken manure extract (CHME) caused more variation in plant height and stem diameter than the other treatments. The reported results may be due to vermicomposting before extracting the nutrient solution. During the process of decomposition by worms, the mineralization of nutrients and microbial activities is enhanced, which may result in compost that is rich in nitrate, phosphate, exchangeable calcium and soluble potassium (Gichaba et al., 2020; Usman, 2015). These nutrients are responsible for increasing plant growth and yield. These findings corroborate the results by Ali et al. (2014) and Mowa et al. (2017) who reported high plant height and stem diameter in crops fertigated with organic fertilizers. They are however, in contrast with the findings by Liu et al. (2011) who reported high stem diameter in crops fertigated by commercial fertilizers compared to organic fertilizers. There was an increase in the number of fruits in tomatoes fertigated with CHME, GME and commercial fertilizer. These results were found to be similar to the results by Ali et al. (2014) who observed an increase in the number of fruits under the foliar application of organic fertilizer. The increase in the number of fruits may be due to the high amount of NPK and plant hormones in the vermicompost which are responsible for plant growth and seed germination (Rahman, 2021; Tikasz et al., 2019).

For the first six weeks after transplanting, the AME significantly decreased the *gs* of the tomato plants. Simultaneously, there was an increase in the *WUEi,* this trend may be due to temperature since it is one of the factors that affect *gs*. It was observed in the current study that when temperature increased the *gs* decreased and the *WUEi* increased. According to Shezi et al. (2019), when the temperatures are high, the stomatal pores close to decrease water loss. Therefore, the plant utilizes internally stored water during photolysis, hence, the increase in *WUEi* with the decrease in *gs*. Commercial fertilizer, CHME and GME had a similar effect on *Ci*, when the stomatal pores open it allows for more carbon dioxide to enter and the opposite is true (Shezi et al., 2019). This suggests that the *gs* and *Ci* are directly proportional to each other, but in this case, they are inversely proportional. It is likely because of the non-porosity factors that reduce the utilization of CO_2 when the stomatal pores are closed, thus the accumulation of CO_2 (Ye et al., 2020).

Commercial fertilizer and CHME increased the *Fm,* while cow manure extract (CME) had a significantly lower effect on *Fm* but significantly increased *Fv/Fm.* The current findings agree with the results observed by Cristiano et al. (2018) who reported a significant increase in *Fv/Fm* due to dosage (0.1g L^{-1}) of manure-derived bio-stimulant through root application. This increase in *Fv/Fm* with a decrease in *Fm* may mean a reduction in the efficiency of photosynthetic processes. Furthermore, the commercial fertilizer and CHME also enhanced *qN*, chicken compost is more alkaline while cow and goat composts are more neutral. This means that the pH of chicken compost is high and may affect the availability of nutrients to be absorbed by plants which may lead to nutrient imbalance (Fageria and Zimmermann, 1998) thus affecting the ability of the plants to control *qN*. CME had a significant effect on *ETR* at week 2, as much as there was no variation in *qP* in all treatments. Due to the slightly high values of *qP* at week 2 under CME, it could be hypothesized that the increase in *ETR* in week 2 was due to the strong correlation between *ETR* and *qP* (Shezi et al., 2019). This may mean that there was a high movement of electrons due to an important mechanism for photo-inhibition protection (Mashilo et al., 2017).

6.2.4 The effect of different manure extracts on yield, physiochemical and nutritional quality of tomatoes (Solanum lycopersicum) grown in soilless cultivation

Chapter 5 investigated the effect of different sources of manure (chicken, cow and goat) on yield, physiochemical quality and nutritional quality of tomatoes grown in the hydroponic system. The AME caused variation in the number of fruits, shoot mass, root mass and micronutrient concentration. The CHME produced a high number of fruits, while CME had the lowest shoot mass. The current results were in contrast with the results by Mowa et al. (2017) who reported a higher number of fruits in plants fertigated by a chemical fertilizer than organic fertilizers. These findings may be due to the high nutrients available in animal compost extract which are supplied readily available for plant uptake (Amalia et al., 2020; El-Khalily et al., 2023; Mayele and Abu, 2023). The smallest shoot mass in CME is probably due to the virus which affected the plant fertigated with CME between weeks 9-11. Furthermore, fruits fertigated with commercial fertilizers exhibited high concentrations of macronutrients because inorganic fertilizers are highly soluble and the nutrients released are easily assimilated by plants (Thepsilvisut et al., 2022). On the other hand, plants fertigated with AME were high in micronutrients because organic fertilizers have a broad range of nutrients compared to inorganic fertilizers (Hasnain et al., 2020).

Plants fertigated with CHME had high TSS, TA, BrimA, colour index and firmness in tomato plants fertigated by CHME. While those fertigated with GME had high values of TSS/TA, BrimA and firmness. The high colour index in tomatoes fertigated with CHME is an indication of ripeness, therefore, the increase in the TSS may be because of the hydrolysation of starch into simple sugars during ripening (Buajaila et al., 2021). Similar findings were reported by Buajaila et al. (2021), where high TSS was observed in fruits treated with poultry manure + urea than in fruits treated with commercial fertilizer. The high TA in fruits fertigated by CHME is probably because of an imbalance of nutrients in the chicken compost which may lead to an uneven intake of nutrients by plants. All sources of AME had a significant effect on TSS/TA and BrimA. The stabilization of organic fertilizers during decomposition decreases the microbial activities while slowly releasing nutrients to be taken by plants (Colín Navarro et al., 2019). The availability of a sustainable supply of nutrients may contribute to fruit quality thus increasing sugar-acid ratio, BrimA and colour index. On the other hand, fruits fertigated with GME and CHME were firmer than fruits fertigated with commercial fertilizer and CME. These results are in contrast to the findings by Kilic et al. (2021) who found that strawberries treated with chemical fertilizer and chemical fertilizer + organic fertilizer were firmer than those treated with only organic fertilizer. Firmness is normally enhanced by high Ca content (Choi, 2020), despite low Ca content in GME and CHME, the tomato fruits were firmer. This is likely due to the polysaccharide components in the goat and chicken diet.

High total phenolic were recorded in plants fertigated by GME, this increase may be linked to vermicomposting which is known to alter the physical and chemical status of the compost. The change slowly decreases the C : N ratio (Olle, 2019) causing plant nutrient stress (González-Coria et al., 2022), in response to stress plants may trigger antioxidant activity (Mowa et al., 2018).

6.3 Conclusion

This study formulated and tested the hydroponic nutrient solutions from chicken, cow and goat compost on tomato plants in soilless cultivation. This study found that vermicomposting animal manure enhances the nutrient concentration of chicken, cow and goat manures. However, chicken manure had a high concentration of N and K before composting compared to post-composting. In such cases, pre-composting is recommended before introducing the worms to the compost. Furthermore, the study also found that the active extraction method extracts more nutrients compared to the passive extraction method. The pH of cow compost extract for both aerated and non-aerated was within the ideal pH range for the hydroponic nutrient solution. The EC of the aerated compost extract was slightly higher than non-aerated compost extract, however, they were all within the range of the optimum EC of the hydroponic nutrient solution. The animal compost extract had a positive effect on growth and photosynthesis parameters, specifically goat and chicken compost extract enhanced height, stem diameter, the number of fruits, *Ci, WUEi*, *Fm* and *qN* while cow compost extract increased *gs, Fv/Fm* and *ETR*. Animal compost extract further affected quality parameters, specifically chicken compost extracts enhanced the number of fruits, shoot mass, TSS, TA, TSS/TA, BrimA, colour index, firmness and phenolics concentration, goat compost extract increased TSS/TA, BrimA, firmness and phenolics concentration and cow compost extract improved shoot mass and antioxidant activity. All types of animal compost extracts had a similar effect on the micronutrient concentrations of tomato fruits. Based on these findings, animal compost extracts can be used as a substitute for commercial fertilizers, specifically goat and chicken compost extract as they influence growth, photosynthesis, and quality in a similar way as commercial fertilizers.

6.4 Recommendations for future research

- Further studies should focus on using warm water to extract hydroponic nutrient solution in a passive extraction method.
- Investigate the effect of the combined application of chicken + goat + cow manure extract on disease control during crop production.
- Evaluate the effect of animal manure mixed with commercial fertilizer at a specific ratio as a nutrient source in vertical soilless culture.
- Assess the shelf life of tomatoes fertigated with different sources of animal manure extracts.
- Farmers should consider using composted goat, chicken or cow manure as a base layer before planting as a soil amendment.
- Tomato farmers should consider incorporating chicken-based vermicompost by mixing it with the planting medium, this may help farmers to spend less money on chemical fertilizers.

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