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Determining the Effects of Selected Organic Fertilizer on Growth and Yields of Tomato (*Lycopersicon esculentum*: Var. Rio Grande Tomatoes) in Mundri West County, Western Equatoria State, South Sudan

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Abstract

Worldwide, the demand for agro-organic foods that are healthy, nutritious, and environmentally friendly is increasing dramatically across all nations among consumers. Tomatoes being one of the dietary requirements in almost every meal is not exceptional and its availability in the market all year round is very important to farmers as well as consumers because it is highly demanded as a vegetable par excellence; which is either eaten raw in salads, cooked or processed into liquid ingredients. This study investigates the impact of chicken, goat, and cow manure treatments on tomato plant growth response to height, leaf length, and width, as well as fruit yield. The experimental field trials were conducted over two planting seasons in Mundri West County. It followed a Complete Randomized Design (CRD) approach, consisting of four blocks. Each block contained three treatments replicated four times and a control group. The data of measured parameters from all 16 plots were subjected to one-way Analysis of Variance (ANOVA) using the Gen Stat 14th Edition software. The findings indicate significant differences ($P < 0.05$) among all the different organic manure applications on tomato plant growth parameters compared to the control group. Chicken manure resulted in the tallest tomato plants (30.1 and 37.9 cm), longest leaves (9.9 and 10.4 cm), and widest leaves (2.1 and 2.5 cm) in both seasons respectively. The study showed plots treated with chicken manure had a highly significant impact ($P < 0.05$) on the prevalence of aphids (1.0) and white flies (1.4) with the lowest value compared to those with cow and goat manure applied. Addi-

tionally, chicken manure led to the highest yields (39.30 and 49.49 tons/ha) in both seasons. Based on these findings, it can be concluded that using chicken manure effectively improves the performance of Rio Grande Tomatoes, and thus, farmers are encouraged to utilize chicken manure to maximize their tomato yields.

Keywords

Tomato Yield, Organic Fertilizers/Manures, Tomato Pests, Mundri West, South Sudan

1. Introduction

1.1. Background to the Study

Tomato (*Lycopersicon esculentum*) is an herbaceous vegetable plant that is now one of the most widely grown and eaten fruits worldwide. Tomato is one of the most important vegetables grown worldwide for its edible fruits and nutritional value. They are nutritious and contain vitamins A, B, and C, iron, and phosphorus [1]. It is an excellent source of vitamins, minerals, and antioxidants which help control cancer, and health diseases as well as improve the general health of man [2]. They also contain antioxidants like carotenes, ascorbic acid, and phenolic compounds which help to prevent some diseases [3]. As it is a relatively short-duration crop and gives a high yield, it is economically attractive and the area under cultivation is increasing daily. Moreover, tomatoes contribute to a healthy, well-balanced diet and are rich in minerals, essential amino acids, sugars, and dietary fibers. Tomato fruits are consumed fresh in salads or cooked in sauces, soup, and meat or fish dishes [4] [5]. They can also be processed into purees, juices, and ketchup. Canned and dried tomatoes are economically important processed products.

The estimated world production of tomatoes is about 89.8 million Mg from an area of about 3,170,000 ha; the leading producers are in China (with 25.3% of the total production), USA, Mexico, and Egypt [6] [7]. Tomato production is widely distributed in Asia, Europe, North, and South America, and in North Africa. Demand for tomato products has, in recent years, risen on the international market. Tomato production has a long tradition among farmers in Africa. Farmers like growing tomatoes because the crop grows fast, covers large areas with little investment, has a high demand in the market, and has a reasonably good yield and a good return [8] [9]. However, the average yield of tomatoes in Africa has remained low, with 19.1 $Mg \cdot ha^{-1}$ in Africa, as compared to 23 $Mg \cdot ha^{-1}$ in Asia, and 27.2 $Mg \cdot ha^{-1}$ averaged over the world [10].

Tomato can be cultivated at optimal altitudes of up to 2000 m above sea level and it can also be cultivated in areas that receive over 600 mm of rainfall annually. It should be well distributed throughout the growing season. Tomato

performs well in warm climatic conditions with an optimal day and night temperature range of 20˚C - 25˚C and 15˚C - 17˚C, respectively. Tomato requires well-drained sandy loam, or clay loam soils with an optimal soil pH range of 6.0 - 7.5. Globally, Asia and Africa account for about 79% of the overall tomato productivity area with about 65% of the world yields [10]. The rise of food production is the major challenge to meet the food requirements of the growing population in agriculture and it will remain essential in the future due to the pressure of inhabitants. Many factors influence the crop quality in food production and one of the main factors is the fertilization system [11]. Soil fertility is one of the major problems limiting crop production. The growth and yield of vegetable crops are mainly dependent on the quality and form of fertilizers used. So, to increase soil fertility and yield, inorganic fertilizers are often used.

In this regard, synthetic fertilizers are the best ways of crop production, but continuous application of chemical fertilizers increases organic matter depletion, and alteration in soil textures, and damages the chemical and physical properties of soil [12]. Moreover, these fertilizers are expensive and sometimes they are not readily available in the market. Considering these facts, society is increasingly concerned about environmental hazards, especially with respect to health hazards created by the indiscriminate use of agrochemicals. In addition, inorganic fertilizers could increase the cost of crop production, thus, many countries are considering organic agriculture as the well-established and certified form of cropping systems among all the alternative cropping patterns. Furthermore, consumers often look upon the taste of organic products and they should be healthier than the conventional ones. Apart from the release of nutrients, the application of organic fertilizers improves the structure and stability of the soil and enhances the yield and quality of crop plants such as tomatoes.

It has been demonstrated that using microorganisms to degrade organic nitrogen in organic sources such as manure results in nitrates and ammonium production which in turn are used for plant production [13]. Organic fertilizers are farmyard manure (FYM), sheep manure (SM), poultry manure (PM), goat manure (GM), chicken manure (CM), and composts among others have been used for crop production for centuries. The use of these forms of fertilizers certainly pre-date chemical (mineral) fertilizers, which is of the more recent development in comparison with organic fertilizers [13]. Organic fertilizers are more environmentally friendly since they are from natural and organic sources. Contrarily, observations show that continuous use of mineral fertilizers creates potential pollution effects on the environment [14].

In South Sudan, the annual production of tomatoes is six million tonnes lower as a number of factors such as agronomic constrained its productivity, among which, a shortage of inputs such as fertilizers (manure and inorganic fertilizers) are key constraints to tomato production [15]. However, the use of any type of fertilizer depends on several factors such as soil type, nature of the crop, and socio-economic conditions of the area. The use of organic fertilizers is highly en-

couraged in areas with high livestock populations where inorganic fertilizers are less available and costly and cannot be afforded by smallholder and traditional vegetable producers as emphasized by [16]. Soil fertility in smallholder farms is almost entirely dependent on locally available resources; cattle manure, cereal and legume Stover, and woodland litter are commonly used as sources of organic fertilizers, but they are rarely applied in sufficient quantities to impact crop yields. The use of high-quality organic fertilizers is rarely practiced, although, through research and extension activities, some farmers now include legume green manures or legume-based fallows in their crop sequences [17]. Despite the fact that organic manure such as cow, goat, and poultry manure (dung and urine), is available and accessible in Mundri West County, its usage as organic fertilizer is being ignored. Therefore, this study is to evaluate the effects of selected organic fertilizers (Cow, Chicken, and Goat) manure on the growth and yield of the Rio Grande tomato variety.

The soils of South Sudan are heterogeneous and require different management practices and fertilizer applications. Most soils of South Sudan are moderately fertile but in the absence of soil amendments and appropriate cultural practices, the soil is reported to be losing the nutritional balance required for efficient and sustainable crop production. The most common deficient soil nutrients are phosphorus, calcium, and potassium. Many areas of South Sudan and Mundri West County in particular (arable land even virgin lands), are low in the availability of phosphorus as well as organic matter. Nutrient imbalances have translated into low crop yields even from newly cultivated fields. Low agricultural production results in low income, poor nutrition, low consumption, poor education, poor health, vulnerability to risks, and lack of empowerment and employment [18]. For this reason, farmers are facing a lot of challenges in regard to the improper usage and application of available organic fertilizers for the production of tomatoes especially in agropastoral communities of Mundri County where cow, goat, and chicken wastes are readily available. Despite the presence of these natural manures, their use in the production of tomatoes is low leading to low production and yields. Among those challenges is farmers' limited knowledge of organic fertilizer use and application. Moreover, synthetic fertilizers have adverse effects such as pollution which leave high levels of residues in the produce [19]. The application of sustainable and long-lasting fertilizer is the most important factor that affects the yield and quality of tomatoes [20]. Yield variation in tomatoes may also occur due to pest and disease infestation, use of unimproved cultivars, and variation in cultural practices [21] [22] [23]. Low crop yield has been experienced due to these challenges. Although some work has been done in line with organic manure application in tomato growing, there still remains a gap in the quantity and right type of fertilizers to be applied to tomato fields to improve production and yields, yet their potential is not being properly utilized and the farmers are not sure of what type of manure they can apply to the cultivated soils and vegetables. This could have been attributed

partly to insufficient knowledge, limited training and awareness, and a general lack of exposure to different kinds of organic fertilizers. Therefore, the study investigated the substantial on-farm trials and contribution of the selected organic fertilizers as essential nutrient components in the production of tomatoes in Mundri West County. The study hypothesized the following specific objectives: to determine the effect of selected organic manure (chicken, goat, and cow) on the growth of the Rio Grande tomato variety; examine the effect of selected organic manure on the prevalence of pests of tomato variety, and to assess the effect of selected organic fertilizers on the yield of tomato variety. The Research further measures the following two hypotheses:

1) The application of selected organic manure has no effect on the growth of the Rio Grande tomato variety.

2) Application of selected organic manure has effects on the prevalence of pests of the Rio Grande tomato variety.

1.2. Conceptual Framework

Globally, the production of tomatoes (vegetables) has been increasing over the years, partly in response to population growth and also because of the increasing living standards in most Countries and above all, due to active encouragement to consume fruits and vegetables by government and private health agencies [24]. Tomato is one of the most commonly grown fresh market vegetables despite being highly perishable. Tomato subjected to different levels of media and types of organic fertilizer application can behave differently in terms of growth rate, yield, and qualities. So, evaluating the effects of the use of cow, chicken, and goat manure as independent variables with treatment on tomatoes by studying the growth and yield parameters is paramount. This independent variable in an experiment is manipulated, and it is assumed to have a direct effect on the dependent variable (plant height, leaf length, leaf width, etc.) (**Figure 1**), for example, the quantities of manure (organic fertilizer) to be applied in certain crop fields including tomato plant [25]. The application of organic manure affects the growth and yield of tomatoes for instance, growth parameters such as plant height, leaf length, and leaf width among others are affected [26].

2. Literature Review

2.1. Overview of Tomato Production

Tomato (*Lycopersicon esculentum mill.*) is one of the most important vegetables worldwide with a relatively short crop duration, gives a high yield, and is economically attractive and the area under cultivation is increasing daily [5]. The estimated world production of tomatoes is about 89.8 million Mg from an area of about 3,170,000 ha; the leading producers are China (with 25.3% of the total production), USA, Mexico, and Egypt [27]. Tomatoes contribute to a healthy, well-balanced diet and are rich in minerals, vitamins, essential amino acids, sugars, and dietary fibers while it contains much higher vitamin B and C, iron,

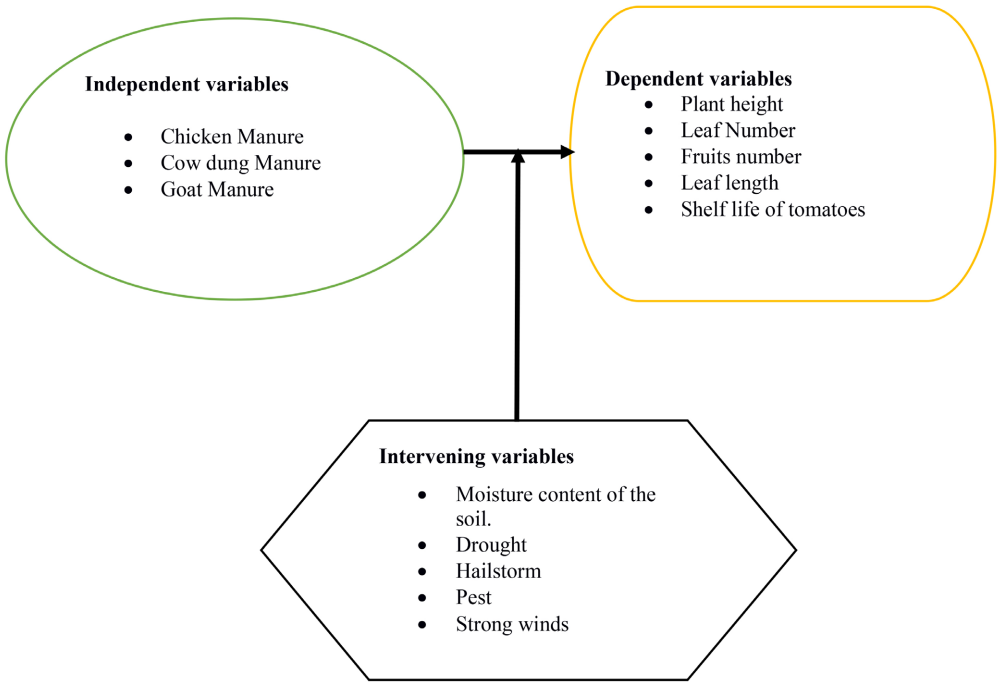

Figure 1. Conceptual framework of variables of selected organic manures and tomato growth and yield parameters and their influencing factors (Source: Author, 2023).

lycopene, and phosphorus [1] [2]. Tomato fruits are consumed fresh in salads or cooked in sauces, soup, and meat or fish dishes. They can be processed into purées, juices, and ketchup. Canned and dried tomatoes are economically important processed products [5].

2.2. Origin, Cultivation, and Benefits of Tomato (*Solanum lycopersicum*)

Tomato belongs to a family called Solanaceae which contains many important food crops, including potato and aubergine (eggplant) [28]. According to [28], the center of origin of the word tomato is considered to be the Andean zone, whereas it is considered that the tomato was domesticated in Mexico and that the name of tomato was derived from tomatil natiso tongue of Mexico. Tomato is regarded as fruit in some quarters and as a vegetable in others, but whichever way, tomato is a nutritious ingredient in preparations of food. In addition, [29] reported that tomato fruit is an essential component of the human diet for the supply of vitamins, minerals, and certain types of hormone precursors in addition to protein and energy. Tomato not only contributes to the share of agriculture in the national economy but possesses a great potential and comparative advantage to compete in the liberated economy. [30] indicates that the total production of tomatoes in Ethiopia has shown a marked increase since it is the most profitable crop providing higher income to small-scale farmers than other vegetable crops. Tomato can be grown as a subsistence crop for domestic use, where few plants yield fruit for the whole family, and as a commercial cash crop

by vegetable growers [31]. Tomato seed yield is directly proportional to tomato fruit yield. In South Sudan, its production is still very low compared with countries like China, Japan, the United States, and other sub-Saharan African countries. According to [32], tomato yield per hectare in South Sudan is 4.9 tonnes per hectare ($t{\cdot}ha^{-1}$), 25 $t{\cdot}ha^{-1}$ in China, and 52.8 $t{\cdot}ha^{-1}$ in Japan and the United States. In addition, the world's total tomato output was 77.5 million tonnes from 2.9 million hectares in 2022. Presently, tomato is one of the most widely grown vegetable food crops globally including not only in South Sudan but other parts of Africa and the whole world at large, second to potatoes production [32] [33]. It is among the key crops in the horticultural industry in many developing countries. Despite the fact that the South Sudan tomato satisfies the internal demand and has strong export demand, there is a seasonal scarcity. However, traditionally tomato fruit has been marketed as fresh-picked and is a best-selling fresh market vegetable crop [6].

2.3. The Importance of Using Organic Fertilizers in Tomato Production

In most tomato production, organic fertilizers of animal and plant origin are environmentally and economically friendly fertilizers [34]. Organic fertilizers can contain both macro and micronutrients. The macronutrients in organic fertilizers such as NPK play important roles. Nitrogen promotes leaf growth and forms proteins and chlorophyll. Phosphorous contributes to root, flower, and fruit development. Potassium contributes to stem and root growth and the synthesis of proteins [35]. The use of organic fertilizers provides soil with essential nutrients and absorbs nutrients against leaching. Also, improve soil texture, increases the ion exchange capacity of the soil, increases soil microbial populations and activity, improves the soil's moisture-holding capacity, and enhanced soil fertility [36] [37]. Organic fertilizers promote the population of beneficial microorganisms and generally improve soil health [35]. Organic fertilizers increase crop production similar to inorganic fertilizers [38] because they contain both micro and macronutrients in addition to some plant-promoting factors and beneficial microorganisms [39]. Organic manure has organic matter which aids in improving all soil properties, such as water holding capacity, soil aggregation, aggregation stability, soil fertility, and cation exchange capacity. Organic fertilizers are essential in decreasing soil pH and useful in improving the availability of major and minor nutrients [40]. Organic fertilizers are not only the source of organic matter and nutrients but also boost microbial population, physical, biological, and chemical properties of the soil [41] [42]. Organic fertilizers including chicken manure, goat and cow dung manure are soil conditioners, which provide nutrients and organic matter within the soil also ameliorate the firmness, and structure of soil and can improve the physical, chemical, and biological properties of degraded or low-fertility soil and also be the source of Nitrogen, Phosphorous, and Potassium for plants [42].

Poultry Manure is relatively resistant to microbial degradation. However, it is essential for establishing and maintaining the optimum soil physical condition for plant growth. It is a good source of N for sustainable crop production, but its availability remains an important issue due to its bulky nature, while inorganic fertilizer is no longer affordable to poor farmers due to its high cost [43]. It is a good source of major and minor mineral elements that are capable of enhancing soil fertility which could be sustained with the addition of poultry manure. Poultry manure is widely recognized as a soil conditioner for raising soil pH and exchangeable base levels. Therefore, a combination of organic materials and mineral fertilizers is important for the management of these soils for the high yield of crops such as tomato plants and other vegetables [37] [43].

Goat manure has high nitrogen content as compared to cow, buffaloes, and horse manure. In addition, this nitrogen enhances the growth of plants and crops by nitrogen fixation, hence it increases the yield of crops by at least 20%. Garden bed use of goat manure can generate the ideal growing conditions for young plants. The dry pellets that are natural are both easy to collect and apply; however, they are also less messy than many other types of manure. There are infinite uses for goat manure [44]. Goat droppings can be used in almost all types of gardens, with that of flowering plants, herbs, vegetables, and fruit trees. It can also be composted and applied as mulch. Many fruit gardeners have noticed that after using goat manure, falling off their fruits before maturity due to natural calamities like wind, heavy rainfall, storm, and others have decreased by nearly 50% in all the areas where it has been applied. In general, goat manure is used as a fertilizer in most common areas [44]. For instance, goat manure fertilizer can provide substantive assistance to gardeners, producing healthier plants and crop yields. They do not only produce neater pelletized droppings, but their manure doesn't typically attract insects or burn plants as does manure from cows, buffaloes, or horses. Goat manure is essentially odorless and is helpful for the soil to sustain its pH. Furthermore, this manure comprises sufficient amounts of the nutrients that plants need to grow optimally, particularly when the goats have bed installs. As urine accumulates in their droppings, the manure holds more nitrogen, thus increasing its fertilizing potency [44].

Cow manure is also a type of organic manure that is not as rich in nitrogen as many other types such as poultry and goat manure. Cow manure that is composted is an excellent organic fertilizer as it contains high N, P, K, and other essential nutrients [45]. Cattle manure is fundamentally made up of grass and grain that is digested. Cow dung is rich in organic materials and high in nutrients. According to [42] [46], it comprises nitrogen of approximately 3 percent, 2 percent phosphorus, and 1 percent potassium (3-2-1 NPK). Composting cow manure has numerous benefits. Further to eradicating dangerous ammonia gas and pathogens, as well as weed seeds, cow manure that is composted improves large amounts of organic matter in the soil. Composted cow manure also comprises useful bacteria, which transform nutrients into easily accessible forms so

they can be released slowly without tender plant roots burning. Composting cow manure also produces about a third less greenhouse gases, making it environmentally friendly [46].

2.4. Impacts of Organic Fertilizers (Chicken, Goat, and Cow) Application on Tomato Yield and Prevalence of Selected Pests of the Rio Grande Tomato Variety

Chicken, goat, and cow manure have been used as suppliers of plant nutrients both macro and micronutrients essential for plant growth for decades [47]. The use of organic manure provides soil with essential nutrients and absorbs nutrients against leaching. It also improves soil texture, increases the ion exchange capacity of the soil, increases soil microbial populations and activity, improves the moisture-holding capacity of the soil, and enhances soil fertility [36]. Poultry manure application increases the growth and yield of black nightshade [48] [49]. This is witnessed as the application of chicken manure increases growth parameters such as plant height, leaf length, and leaf width among others [50] [51]. According to a study conducted by [52] and [53], the production indicators showed the tomatoes' agronomic parameters and the effect of chicken manure, cow manure, and goat manure on the yield of tomatoes. The increase in growth parameters by compound fertilizer could be attributed to the presence of NPK compounds in synthetic fertilizer [54]. The composition of manure plays an important role in optimal growth and increases the yield of tomatoes [55] [56]. The increment of yield by organic manure is due to the release of sufficient potassium into the soil for the growth of plants. One of the attributes of organic manure is its ability to hold adequate amounts of water needed for the growth of plants [57].

According to [58], the application of manure supplies the required nutrients, improves soil structure, water holding capacity, porosity, bulk density, and moisture retention, increases microbial population, and maintains crop quality. In spite of the large quantities of plant nutrients contained in synthetic fertilizers, compared to organic nutrients, the presence of growth-promoting agents in organic fertilizers makes them important in enhancing soil fertility and productivity. Therefore, high and sustained crop yield can be obtained with judicious and balanced NPK fertilization combined with organic matter amendment [47] [59]. Depending on the type of organic fertilizer applied, the increase in yield was 112% from compost, 90% from chicken plus cattle manure, 70% from chicken manure, and 50% from cattle manure compared to the untreated control. It is well known that the use of chicken and cow manure produced more fresh leaves in leafy vegetables. The use of organic manures such as compost, vermin compost, and others on the growth and yield of crops was also studied and resulted in increased productivity [60]. The positive effect of poultry manure on these growth attributes could also be due to the contribution made by the manure to the fertility status of the soils, as the soils were low in organic carbon content [47] [48] [61]. The manure when decomposed increased both

macro and micronutrients as well as enhanced physicochemical properties of the soil. The application of chicken manure increases the plant height, leaf length, and leaf width of cherry tomatoes [62]. Application of a mixture of organic manure lowers the prevalence and leaf damage of pests such as aphids in okra which improves soil's biological properties as well as its nutrition, and crop quality which are made into secondary metabolic compounds that promote vegetative growth and enhance insect and disease-resistance [47] [57]. Organic farming is paramount in reducing pest outbreaks due to the use of organic fertilizers [26] [63] as such reduction in aphids due to the application of organic manure was reported [64]. As a general result using organic fertilizers, especially in composted form had a positive effect on soil health and fertility, which consequently reduced pest infestation [65]. The positive effect of organic fertilizers added to soil may be attributed to stimulating the activity of bacteria which promotes the released availability of N, P, and the other nutrients in the soil and enhances nutrient absorption by tomato roots [66] [67].

2.5. Tomato Demand and Production

Consumer demand for tomatoes all year long has increased by 30% in the past 30 years and hence there is increased demand for tomato seed. Fresh consumption per capita in the US was 12.1 lb [68] [69]. To meet the growing demand for tomato seeds, the application of effective techniques such as plant spacing, and fertilization must be in place. Farmers get lower yields mainly due to inappropriate agronomic practices and the use of unimproved variety.

Improper spacing is among the notable reasons for the low productivity of tomato seeds [70]. The commonest practice by the resource-poor farmers in many parts of the tropics, especially in Africa is the growing of two or more crops on the same piece of land simultaneously or in a relay such that the period of overlapping of the crop is enough to include the vegetative phase. As a result, these farmers grow their crops at wide and random spacing because of the system of cropping [70]. However, as management practices improve and their crop sales, specific plant populations would be used. In tomato production, there is a huge deficit between what is supplied in the market and what is demanded, for example, while US tomato production has increased to meet demand, imported tomatoes still exceed domestic production. For instance, in 2018, the US imported 308,949 tons of tomatoes worth USD 365.5 million and only produced 175,949 tons [71] [72]. This low production has been caused by biotic and abiotic as well as cultural management practices. According to [73], the average yield depends upon certain production factors, among them appropriate and balanced nutrition plays an important role. Fertilizer application is one of the most important factors for obtaining an economical yield of tomatoes. Nitrogen plays an important role in plant growth and development; tomatoes especially need phosphorous after transplanting. However, according to [74], the knowledge of crop response to population density provides a basis for assessing the effect of

intraspecific competition. During seedling production, it is necessary to supply adequate organic; however, nutritional needs differ among crops. Although some work has been done by [75] on the effect of different spacing and urea application rates on fruit nutrient composition, growth, and yield of tomatoes, the exact nutrition needs for the production of quality tomato seed yield remain undefined. Hence this study investigates the effect of selected organic manure on the growth and yield of tomatoes.

2.6. Constraints to Tomato Production in South Sudan

South Sudan in the then Sudan has a strong horticultural industry spanning over several years of experience in the production of fruits and vegetables for the domestic and export market [76]. Tomato being a horticultural vegetable/fruit has contributed to the growth of the horticultural industry. During the last two decades, horticulture has emerged as a major export industry and together with oil is the top three foreign exchange earner for South Sudan [22]. Horticulture occupies 14% of the horticulture surface cultivated and contributes to 23% of the value of the sector's production. However, the sub-sector is faced with a number of challenges both biotic and abiotic factors [22] [32]. For example, among the horticultural crops, tomato faces a number of challenges including pests such as whiteflies and aphids, and various tomato diseases [33]. However, its potential yield is between 15 to 17 tonnes per acre and about 30 tonnes per hectare. The yield gap is attributed to a number of yield-reducing factors which affect plant growth. Apart from insect pests, there are diseases that significantly contribute to the yield gap [77] [78]. Other factors that could result in low seed yield in tomatoes include unimproved cultivars, poor plant stand, lack of use of fertilizers, variation in cultural practices, and other improved agricultural inputs in the management of the crops among others. Adequate fertilizer and proper spacing are required for proper growth and increased yield of both the fruits and seeds of tomatoes [75]. However, most African soil shows nutrient deficient problems after only a short period of cultivation because of the nature as well as prevailing environmental conditions. [79] reported that the two management practices that greatly influence tomato fruit yield are spacing and fertilizer application. The fertilizer does this through its ability to replenish the soil with nutrients that are lacking in the soil. However, according to [80], plant spacing greatly influences growth, yield, and quality parameters both in the fresh market and in processing tomatoes. This is because the correct spacing is crucial to ensure adequate and uniform distribution of light. This is also in conformity with [81] who indicated that plant spacing is the most important factor that affects the yield quality of fruit.

3. Materials and Methods

3.1. Description of the Study Site

The experiment was carried out in Mundri West County of Western Equatoria

State, Republic of South Sudan. It is located between longitude 30˚15'0"E and latitude 5˚24'0"N along Juba Rumbek highway. It borders Mvolo County to the north, Mundri East County to the east, and Maridi County to the west. Mundri has a tropical savanna climate prevailing with both wet and dry season patterns, experiencing warmth every month. The climate of the area varies from time to time, the wet season is overcast, the dry season is partly cloudy, and it is hot and oppressive year-round. The temperature typically varies from 74˚F to 92˚F and is rarely below 71˚F or above 96˚F. The average annual temperature for Mundri is 37˚C and about 571 mm of rainfall [82], with the highest average temperature ever recorded in Mundri being 37˚C in February and the lowest being 29˚C in July [21]. The County is categorized as part of the equatorial maize and cassava livelihoods zone [82], and as part of South Sudan's lush greenbelt zone, almost 60% of the population is estimated to practice agriculture as their main economic activity.

3.2. Land Preparation of Experimental Plots and Transplanting

This experiment was carried out in a period of 90 days after sowing seeds for transplants in October-February 2022 because tomatoes take three months to grow to maturity. The land was ploughed to the fine tilth by repeated harrowing and leveling using human labor force. Then, the layout was made, and the plots were prepared.

The various manures (chicken, goat, and cow) were collected and independently applied in the prepared plots without being mixed. The manure is left for at least two weeks to decompose and is thoroughly dried before being applied to the tomato plots so that it is used as a source of nitrogen, phosphorus, and potassium. The composting procedure was to build piles comprising organic animal wastes (dung and urine) separately, and mixing in soils and peats. All piles were monitored for turning every week until all substrates were completely degraded to yield mature compost. All the animal manure in question including chicken manure was applied to their respective treatment plots immediately after 7 days of transplanting the tomato plant seedlings.

The seedlings were transplanted on 15th January 2022 to plots measuring 3 m × 2 m at a spacing of 90 cm × 60 cm to achieve the required plant population and growth [79]. All agronomic practices (Weeding was done in the 3rd week after transplanting, watering was done on a daily basis during evening hours depending on the level of moisture content of the soil, staking was done at the flowering stage, diseases and pests were controlled by organic chemical which were sprayed at an interval of 7 - 14 days and it was done during evening hours) during the growing season as recommended by [83]. Recommended fungicides (Ridomil and MZ63%-3.5 kg·ha^{-1}) to control leaf diseases and cypermethrin (100 g·ha^{-1}) to control insect pests, were sprayed at a seven-day interval from transplanting to 20 days before the first harvest [79] [83].

3.3. Experimental Research Design, Treatments, and Field Layout

The experiment was carried out using a complete randomized design, (CRD), comprising four treatments with four replicates giving a total of sixteen, (16) plots (Table 1). This was experimented on the Rio Grande tomato variety, with a spacing of 90 × 60 cm within and between the rows. Each plot measured 3.0 × 2.0 m and the whole field measured 13.5 × 7 m, walkways of 0.5 m were left in between each plot. The below indicated treatment specifications:

T1 = Control (CTRL)

T2 = Cow manure (CM)

T3 = Goat manure (GM)

T4 = Chicken manure (CKM)

In the experiment, seeds were sown and raised on the nursery bed for a month and later transplanted to the field that had been prepared one week before transplanting. Transplanting was done late in the evening and then the seedlings were covered in the morning to prevent the direct effect of sunlight since the experiment was carried out during the dry season at the transplanting time. Each plot consisted of twelve (12) seedlings which made a total of one hundred ninety-two (192) seedlings in the whole planted field.

3.4. Data Collection and Sample Size

The data was collected from four (4) randomly selected seedlings from each plot. During data collection, only tomato plants that are in the middle of the plot were sampled. Data was taken on plant height, number of leaves per plant, number of branches per plant, number of fruits per cluster per plant, and seed yield per fruit weight. Data on plant height, number of leaves, number of fruit, and plant lifespan was collected from sixty-four plants by random sampling system. The plant height was measured from the soil level of the plant to the apical bud of the plant using a meter rule [84]. The number of Leaves was counted after seven days of transplanting [85] [86]. The number of fruits was counted and recorded from the time the fruits started to ripen [85]. Lastly, the lifespan of the plant under study was determined. Data on yield was obtained from each plot by tomato fruit which has reached physiological maturity [87].

Using the technique, as described by [88], four plants in the middle of the block were selected for data collection which was done immediately after seven days of transplanting and it ran for 9 consecutive weeks. Firstly, data was collected

Table 1. The field layout of the experimental treatments.

T1 R1	**T2 R2**	**T1 R1**	**T4 R3**
T1 R1	T2 R2	T1 R1	T4 R3
T3 R3	T1 R1	T2 R2	T3 R4
T2 R4	T3 R3	T3 R3	T2 R2
T4 R4	T3 R3	T4 R2	T1 R1

to show the effect of chicken, goat, and cow manure on the growth traits of the Rio Grande tomato. Secondly, data was collected to show the effect of selected organic manure on plants, the number of leaves, the number of fruits, and the lifespan collected. Finally, data on the effect of selected manure on the yield of the Rio Grande tomato variety was assessed after tomatoes had reached physiological maturity after the 9 weeks.

3.5. Determination of Plant Height, the Number of Leaves, Branches, Seed Yield Per Fruit, Fruits Per Cluster, and Shelf Life

The plant height was measured from the ground level to the highest tip (apical bud) for the four sampled and tagged tomato plants. This was done using a meter ruler at intervals of 7 days up to harvest/maturity and recorded in centimeters. The number of leaves was counted at an interval of 7 days for the period of 5 consecutive weeks from the day of transplanting and the average of each treatment was computed. The number of primary and auxiliary branches was counted at physiological maturity. When all plants had ceased growth, branches of four sampled and tagged tomato plants from each plot were then subjected to counting. A number of fruits per cluster were done by counting them at the maturity stage and the average of each treatment was computed. Four fruits were randomly collected from each batch harvested (1st, 2nd, and 3rd) crushed and seeds were extracted. The seeds were counted manually and the average number of seeds per fruit was expressed as the number of seed yield per fruit. To determine the shelf life of the fruits, the researcher counted and recorded the number of days the fruits took from the day of harvesting to the days it was presumed to be unsafe for use.

3.6. Field Management Practices: Weeding and Irrigation

The weeding activities were conducted four times for the entire experimental period mainly to reduce crop competition with weeds. The experiment required close attention to feeding the plants in the block through irrigation where watering was done continuously every evening after transplanting the tomato seedlings for one week.

3.7. Statistical Analysis

The experiment measurement data were recorded in Excel spreadsheets, data cleaned, coded, and were subjected to analysis of variance (ANOVA) using GenStat statistical package (Genstat 15th Edition) and means were compared using Fisher's protected Least Significant Difference (LSD) at $P \leq 0.05$ [89] [90]. These were then displayed in tabular or graphical form.

4. Results and Discussion

The application of chicken manure, goat manure, and cow manure had a signif-

icant ($P < 0.05$) influence on the growth of the Rio Grande tomato variety. The results of the study revealed that the application of chicken manure had the utmost positive influence on growth traits of the Rio Grande tomato variety such as plant height, leaf length, and leaf width compared to goat manure and cow dung manure for both seasons. Analysis of variance indicated that the application of chicken manure ($P < 0.05$) influenced the prevalence of aphids and whiteflies in the Rio Grande tomato variety. Finally, the application of chicken manure had a significant ($P < 0.05$) increase in yield of the Rio Grande tomato variety compared to plots with its counterparts.

4.1. Effects of Selected Organic Manure on Tomato Plant Height

Generally, the application of chicken, goat, and cow manure significantly ($P < 0.05$) increased plant height (Table 2). In the third week after the application of fertilizers, plots that were treated with chicken manure had the highest mean plant height of 14.5 and 16.6 cm in both seasons one and two respectively. In the fifth week of data collection, plots that had chicken manure showed the highest mean plant height of 30.1 and 37.9 cm in both seasons one and two respectively (Table 2). The result indicated that goat manure followed chicken manure in influencing plant height. On the other hand, plots applied with cow manure significantly ($P < 0.05$) produced the lowest plant height. In week three after the application of fertilizers, plots that were treated with cow manure had the lowest mean plant height of 8.7 and 12.6 cm in both season one and two respectively (Table 2). This is similar to 21.9 cm and 25.4 cm in both seasons respectively, in the fifth-week application compared to chicken and goat manure applications (Table 2). Generally, plots with cow manure produced the lowest plant mean height in all the weeks but were higher than the control plots compared to plots with goat manure and chicken manure. These results demonstrate that plots, where chicken manure was applied, had adequate and significant amounts of soil nutrients required to boost growth resulting in better plant heights. The ideal addition of chicken manure promotes the degradation of plant

Table 2. Mean plant heights (in cm) computed after transplanting in the two seasons.

Treatments	Season 1			Season 2		
	Week 3	Week 4	Week 5	Week 3	Week 4	Week 5
Control	6.0	9.6	15.9	6.6	12.9	19.3
CM	8.7	12.9	21.9	12.6	18.8	25.4
CKM	14.5	21.8	30.1	16.6	26.3	37.9
GM	13.4	20.0	28.9	14.9	24.1	34.1
Fpr.	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV%	3.3	4.0	4.6	1.6	1.3	2.8
l.s.d	1.055	1.514	1.355	0.745	1.501	1.543

dry organic matter (lignocellulosic) and effectively leads to the improvement of soils and peats (humic acid) for tomato growth and increased fruit yield as compared to other manure types (goat, cow, etc). When applied appropriately, chicken manure can become key in accelerating the degradation process and promoting the formation of humus and thus can provide a basis for the industrial production of tomatoes in the short run. It subsequently promotes rapid vegetative growth and enhances insect pest and disease resistance to tomato infestation by lowering leaf damage and the prevalence of pests such as aphids and whiteflies [47] [65].

These results corroborate the findings of [37] that the combined application of Poultry manure, results in an increase in plant height, number of leaves per plant, and number of fruits per plant [91] opined that organic manure, especially Poultry manure could increase plant height of crops when compared with other sources of manures. The results of the study are in line with those of [92], that chicken manure caused a significant improvement in plant growth parameters**.** This can only be linked to nutrient availability in chicken manure. [93] also reported that poultry manure-treated plants gained maximum plant height as compared to inorganic fertilizers [94]. [95] further reported that poultry manure influenced plant growth thus obtaining taller plants in chicken manure-treated plots. Also, other results show that the application of organic manure had a positive effect on the plant height [65].

4.2. Effect of Selected Organic Manure on Tomato Leaf Length

Analysis of variance indicated that the application of chicken manure, goat manure, and cow manure had a significant ($P < 0.05$) influence on leaf length in both seasons (**Figure 2**). In week three of data collection after the application of organic manures, plots with chicken manure performed significantly ($P < 0.05$) on leaf lengths of 7.8 and 8.1 cm in both seasons (one and two) respectively. In

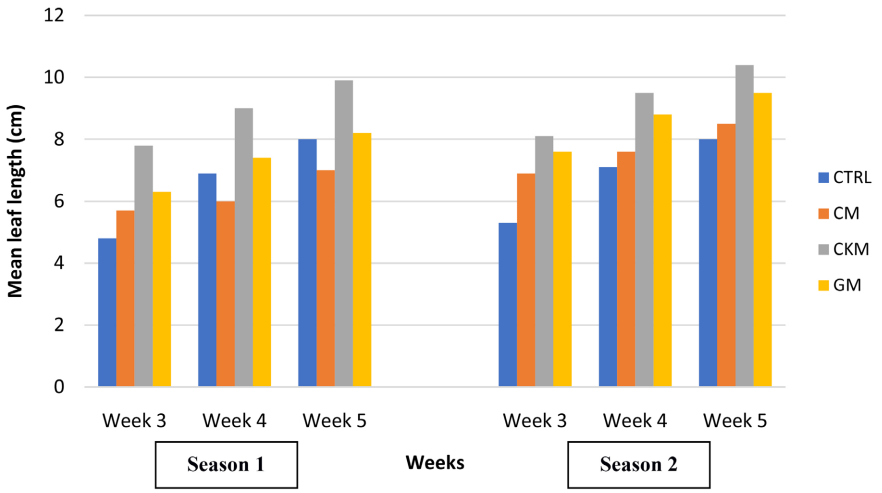

Figure 2. Mean leaf length of tomato plant seedlings measured in seasons one and season two.

week five, plots treated with chicken manure had the highest significant ($P < 0.05$) leaf lengths of 9.9 and 10.4 cm in season one and season two respectively (**Figure 2**). The results of the study revealed that plots with goat manure followed chicken manure in the growth of leaf lengths. On the other hand, plots with cow manure have the lowest significant ($P < 0.05$) leaf length of 6.0 and 6.9 cm in both seasons respectively. Similarly, in week five, cow manure had the lowest value of leaf lengths accounting for 7.0 and 8.5 cm in both seasons respectively (**Figure 2**).

The results, therefore, indicated that an integrated supply of plant nutrients through organic fertilizers played a significant role in sustaining soil fertility and crop productivity in terms of vegetative and reproductive growth. Several researchers have demonstrated the beneficial effect of organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P, and K fertilizers for a few years, without any micronutrient or organic fertilizer. Previous studies also reported that the use of organic fertilizers had a higher positive effect on microbial biomass and hence soil health [96]. Chicken manure produced the highest leaf length because it dissolves quicker hence the highest leaf length obtained [97]. The results are again in harmony with those of [98] who delineated that organic manure increases plant growth due to the availability of nutrients that increase the water-holding capacity of the soil resulting in enhanced growth. Goat and Cow manures also gave a relatively significant increase in leaf length due to available nutrients improving the growth and development of the plant.

4.3. Effect of Selected Organic (Animal) Manure on Tomato Leaf Widths

Analysis of variance revealed that the application of organic manure significantly ($P < 0.05$) increased the mean leaf width. In week three of data collection after the application of organic manure, plots treated with chicken manure produced significant leaf width of 3.3 and 2.9 cm in both seasons respectively, compared to goat and cow manure (**Table 3**). This has even increased significantly in week five to 5.7 and 5 cm in both seasons respectively (**Table 3**). On the other hand, the lowest mean leaf width was recorded for plots with cow manure at 2.1 and 2.5 cm in both seasons respectively but higher than that of control plots. A similar decrease in week five was shown in plots treated with cow manure with leaf widths of 3.9 and 4.4 cm in both seasons (**Table 3**). Chicken manure has the highest leaf width because it reduces soil acidity and also plays a big role in soil nutrient enrichment which conforms to a study done by [97]. Chicken manure also has an abundance of macro-nutrients such as NPK. The application of phosphorus and nitrogen fertilizer enhances root development, which improves the supply of other nutrients, and water to the growing parts of the plants, resulting in an increased photosynthetic area, and more dry matter accumulation [97].

Table 3. Mean leaf width within 3, 4, and 5 weeks after transplanting in both seasons 1 and 2.

Treatments	Season 1			Season 2		
	Week 3	Week 4	Week 5	Week 3	Week 4	Week 5
Control	1.8	2.3	3.7	1.9	2.1	3.8
CM	2.1	3.1	3.9	2.5	3.4	4.4
CKM	3 .3	4.8	5.7	2.9	4.0	5.0
GM	2.4	3.2	4.7	2.8	3.7	4.8
Fpr.	0.011	0.002	<0.001	<0.001	<0.001	<0.001
CV%	2.4	1.8	1.9	1.5	3.9	3.5
l.s.d	0.4889	0.5157	0.5142	0.3254	0.1555	0.2588

Poultry manure also increased leaf area more than the other treatments possibly because poultry manure was appropriate for increasing carbon content, water holding capacity, aggregation of soil, and decrease of bulk density, all of which interplay to increase leaf area and total chlorophyll content of cabbage plant. These results are unlikely in contrast with the findings of several researchers that organic manure increases vegetative growth and biomass production effectively [99]. Moreover, [100] found that incremental application of organic manure increased the growth, dry matter accumulation, yield, and quality of the plant, the results are in agreement with those of other researchers. Poultry manure increases the growth parameters of okra such as; plant height, stem girth, leaf length, and leaf width [101].

The significant increase in leaf width as a result of the application of poultry manure may be attributed to the beneficial role of manure in enhancing soil nitrogen, phosphorus, potassium, and other essential nutrients which in turn improve growth and development of the plants during the trials. The positive effect of poultry manure on these growth attributes could also be due to the contribution made by the manure to the fertility status of the soils, as the soils were low in organic carbon content. The manure when decomposed increased both macro and micronutrients as well as enhanced physicochemical properties of the soil [101]. The results are in conformity with the findings of [102] who stated that the application of chicken manure increases leaf width in sweet pepper. The increase in leaf width may be attributed to the release of macro and micronutrients by poultry manure during the course of microbial decomposition. This could be further explained that poultry manure contains Calcium (Ca), Magnesium (Mg), Zinc (Zn), and Manganese (Mn) in higher levels which improved the growth performance of *Capsicum*. Similar results were reported by [102] [103] [104] who indicated that there was a higher and more rapid release of nutrients from

poultry manure-amended soil as compared to the other treatment groups [105].

4.4. Effects of Chicken, Goat, and Cow Manure on the Prevalence of Whiteflies

The application of chicken manure, cow manure, and goat manure led to a significant ($P < 0.05$) reduction in the prevalence of white flies (**Figure 3**). In week three after the application of manure and fertilizer, plots treated with chicken manure had the lowest prevalence of white flies (1.33). This is followed by plots treated with goat manure significantly at $P < 0.05$ (**Figure 3**). The same trend was shown in week five for plots treated with chicken manure and goat manure in the prevalence of aphids reported by mean of 1 and 1.2 respectively (**Table 4**). On the other hand, the results revealed that in week 3, plots treated with chicken manure significantly ($P < 0.05$) led to the lowest prevalence of white flies of 1.2 (**Figure 3**). Similar results are depicted in week five for plots treated with both chicken and goat manures on the prevalence of white flies by a mean of 1.4. Whereas, in week five Cow manure increased the prevalence of whiteflies by a mean of 2. The results revealed that cow manure does not possess sufficient ability to increase resistance against pest and disease infestation. Thus, does not reduce pest infestation in tomato fields. Chicken manure has been used for decades as an organic fertilizer for growing a wide range of vegetables due to its ability to increase resistance against insects [106]. [64] also reported a reduction in herbivory pests due to the application of organic manure. This is due to the reason that increasing soluble nitrogen levels in plants from organic manure sources can decrease their resistance to insect pests.

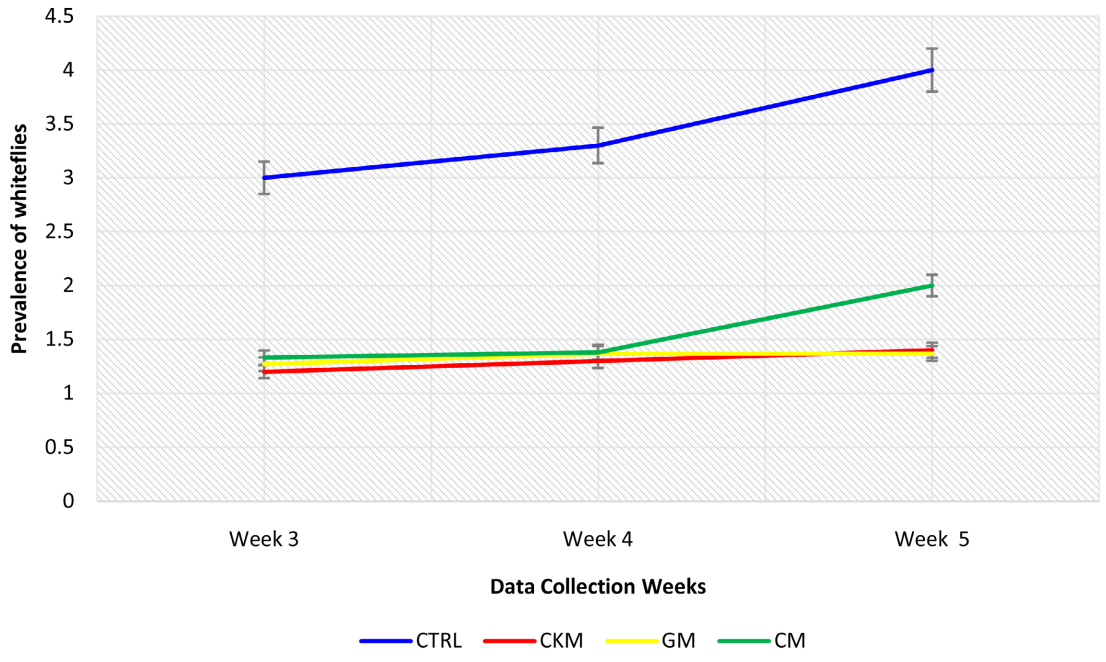

Figure 3. Mean whiteflies score.

Table 4. Mean aphids score at different week intervals.

Treatments	Week	Grand mean	F-pr	e.s.d	s.e.d	l.s.d	Cv %	P = 0.05
Control	Week 3	2.47	0.105	0.320	0.453	0.951	19.2	P > 0.05
	Week 4	2.47	0.105	0.320	0.453	0.951	19.2	P < 0.05
	Week 5	3.28	0.199	0.388	0.549	1.158	6.2	P > 0.05
CM	Week 3	1.11	0.053	0.145	0.205	0.430	9.1	P < 0.05
	Week 4	1.12	0.053	0.145	0.205	0.430	9.1	P < 0.05
	Week 5	1.23	0.837	0.306	0.433	0.910	8.7	P < 0.05
CKM	Week 3	1.00	0.639	0.183	0.258	0.542	9.1	P > 0.05
	Week 4	1.00	0.189	0.222	0.314	0.660	3.2	P < 0.05
	Week 5	1.00	0.189	0.222	0.314	0.660	3.2	P < 0.05
GM	Week 3	1.10	0.639	0.183	0.258	0.542	9.1	P > 0.05
	Week 4	1.20	0.189	0.222	0.314	0.660	3.2	P < 0.05
	Week 5	1.20	0.189	0.222	0.314	0.660	3.2	P < 0.05

4.5. Effects of Chicken, Goat, and Cow Manure on the Prevalence of Aphids

The result indicates that in week three after the application of manure, plots treated with chicken manure lower prevalence of aphids by a mean of 1.00. This was followed by plots treated with goat manure with a mean of 1.10 (Table 4). Similar results are depicted in week five for plots treated with chicken and goat manure which significantly ($P < 0.05$) lowered the prevalence of aphids by a mean of 1.0 and 1.20 respectively (Table 4). On the other hand, the results also revealed that in weeks three and five, plots treated with cow manure significantly ($P < 0.05$) increased the prevalence of aphid infestation by means of 1.11 and 1.23 respectively (Table 4). The result shows that tomatoes grown in plots treated with chicken and goat manures perform relatively well with low aphid pest infestation compared to when cow manure is used. Organic fertilizers have been used in the management of several pests [106]. [64] reported a reduction in aphids due to the application of organic manure. This is due to the reason that increasing soluble nitrogen levels in plants from organic manure sources can decrease their resistance to insect pests. [26] study also noted that high levels of protein amino acids commonly stimulate the growth and fecundity of herbivorous insects. As a general result, using organic fertilizers, especially in composted form had a positive effect on soil health and fertility, which consequently reduced pest infestation [65].

These results were similar to the conclusion by [107], who recorded a low pest population in plots treated by organic amendments. Also, an increase in aphid damage in control plots could have been a result of high temperatures since soils with less organic matter tend to heat up quickly. Research shows that Aphids

Table 5. Mean yield of tomatoes per plot under different manure applications.

Treatments	Season 1	Season 2	Mean yield difference (t/ha)
	Mean Yields (t/ha)	Mean Yields (t/ha)	
Control	17.91	22.06	4.15
CM	24.00	27.28	3.28
CKM	39.30	49.49	**10.19**
GM	33.23	38.93	**5.70**

adapt to high temperatures and can increase their developmental rate from temperatures ranging from 27˚C and above which could be the cause of the results in control plots [108].

4.6. Effects of Selected Manure on Yields of Tomatoes

The result shows that the application of chicken manure increased fruit yield with a higher total fruit yield of 39.30 and 49.49 t/ha in both seasons respectively (Table 5). The trend is followed by the application of goat manure with 33.23 and 38.93 t/ha for both seasons respectively (Table 5). On the other hand, the application of cow manure results in the lowest tomato yield reported by 24 and 27.28 t/ha total yield of tomatoes in both seasons (Table 5). This low tomato yield in cow manure plots could be ascribed to the low dissolution of the organic matter for the tomato plants' nutrient access. The improved tomato yields in Chicken manure are attributed to soil quality highly rich in organic matter. The study results are in line with the findings of [106] who stated chicken manure increases the yield of tomatoes. This could also be attributed to the presence of micro-organisms which enhance the increase of photosynthetic efficiency, biological nitrogen fixation, nutrient availability over time, and nutrient uptake as emphasized by [109]. In addition, [110] showed that the increase in yield could be attributed to the improvement of both soil moisture retention and the potential of nutrient supply (with macro and micronutrients). Soil-applied chicken manure inoculated with beneficial micro-organisms significantly increased soil-living microorganisms' number and activity, and provided necessary nutrients in available forms in the root zone, consequently improving the absorption and accumulation of mineral contents in plant tissue and hence increasing crop yield [111].

5. Conclusions and Policy Implications/Recommendations

This paper investigated the impacts of chicken, goat, and cow manure treatments on tomato plant growth response to height, leaf length, and leaf width, as well as fruit yield. The study results indicated that the use of specific types of manure had a significant impact on various aspects of tomato plant performance, including plant height, leaf length and width, pest damage score, and yields. In re-

lation to meeting its objective, the effectiveness of chicken, goat, and cow manure on selected growth parameters of tomato plants, showed that chicken manure had a notable influence on all these parameters compared to the use of goat and cow manure. It was found to be particularly effective in improving the overall performance of tomatoes in Mundri County. The growth traits, such as plant height, leaf length, and width, increased accordingly due to the nutrients present in the applied manure. When the effectiveness of the use of chicken, goat, and cow manure on the prevalence of selected pests was evaluated, the findings revealed that plots treated with chicken manure experienced minimal damage caused by aphids and whiteflies. This means chicken manure reduces infestation by insect pests. Thus, accelerated plant growth and consequently outcompeted pest damage.

Nevertheless, tomato yields increased significantly with chicken manure application as compared to goat and cow manure application. Therefore, Chicken manure was found to be more effective in increasing tomato yields as it is a highly soluble fertilizer that improves plant growth and root development, leading to increased leafy yields. Therefore, for faster results chicken manure was recommended. Based on the study results, it can be concluded that if the objective is to promote vegetative growth and maximize yield, chicken manure is the most beneficial among the different types of manure (goat and cow) evaluated. This is primarily due to the high nutritional content of chicken manure in tomato plants, which facilitates faster growth, increased leafy yields, and enhanced resistance to pests. Chicken manure readily releases essential nutrients such as Nitrogen, phosphorus, and Potassium (NPK), which are crucial for the vegetative growth of tomatoes, and these nutrients are directly absorbed by the plants from the soil mixed with the manure. Based on the analysis and interpretation of the experiment, it was found that the use of chicken manure had a positive impact on the growth and yield of tomato plants. Additionally, it resulted in a reduction in the prevalence of aphids and whiteflies infestation, which are pests that can harm tomato plants and reduce yields. This positive effect is attributed to the nutrient-rich composition of chicken manure, which promotes vegetative growth and overall plant development. Therefore, several recommendations are drawn to various horticulture stakeholders as stated henceforth: To maintain soil health and promote optimal tomato growth, farmers are encouraged to apply at least 10 tons per hectare of chicken manure. This particular amount is suggested due to its easy release, environmental friendliness, and ability to enhance vegetative growth; Farmers should consider incorporating chicken manure during plant production to achieve maximum tomato yields, as it contains high nutrient content that supports better plant growth, vigor, and ultimately, higher yields; the government and other horticulture stakeholders should provide subsidies and extensions inputs and services such as provision of improved seeds and training to increase farmers' farming capacities; to increase in the production of tomatoes as vegetable, the government should promote its production by for-

mulating proper agricultural policy that favours even smallholders' farmers participation in vegetable/tomato production. Our study strongly recommends that future tomato growers/farmers should consider mixing different animal manures in proportion to ascertain their effectiveness in tomato growth parameters and yield performances. Lastly, since the study was conducted in a single location, it recommends the importance of replicating the experiment in several locations in South Sudan for comparative research studies. Therefore, further studies should be conducted in different agroecological zones with varying conditions to validate and confirm the consistency of these findings.

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Conflicts of Interest

The authors declared no conflicts of interest, confounding factors, or any external concern about this study for its publication.

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Appendix: Experimental Field Photos (Credits: Abu Rufas)


Land preparation, seedbed management, and tomato seedling transplanting (season 1)


Tomato fruit/tree counts, height, leaf length, leaf width measurement; and pest infestation search scenario


Tomato harvesting, Fruit load and yield management, and parameters measurement continue in season 2.