

Profitability of Fertilizer Use for *Citrus* Production in Teso Sub-Region, Eastern Uganda

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Abstract

Citrus is an important commercial crop in Uganda, especially the Eastern region. However, in spite of the increasing regional demand, *citrus* productivity is still low, attributed to pest and diseases, soil moisture stress, and low soil fertility, among others. Efforts to improve soil fertility are limited by inadequate supply of organic fertilizers due to competing demands. In addition, there is inadequate information on inorganic fertilizer requirements for *citrus* production in Uganda. The objective of this study was to develop optimum fertilizer recommendations for *citrus* production for Eastern Uganda. The study was conducted in Teso region, Eastern Uganda. Fertilizer (NPK, 17:17:17) was randomly applied to Hamlin, Valencia and Washington varieties with fertilizer and variety factorially arranged for each farm and *citrus* age range, replicated three times. Fertilizer rates were 0, 139, 278 and 556 kg NPK/ha for the 4 - 7-year old trees, and 0, 278, 556 and 1111 kg NPK/ha for the mature (8 years and above) trees. For a given variety, each fertilizer rate was applied onto three representative trees per farmer, six farmers per district. Results showed that yields and net profits were highest for variety Hamlin, and nearly the same for varieties Washington and Valencia. Fertilizer application increased fruit yield and profits for both the 4 to 7-year and 8 and above-year-old trees, with highest yield and profitability values observed at 556 kg NPK/ha. These results suggest applying 556 kg NPK/ha to *citrus* per year as an optimum fertilizer rate for *citrus* production in Teso region. The fertilizer should be applied in smaller splits of 800, 600, and 600 grams per tree, applied in April, June, and August.

Keywords

Citrus Varieties, Climate-Smart Agriculture, Cost-Effectiveness, Fertilizer Recommendations, Soil Fertility Management

1. Introduction

Citrus is an important commercial crop in Uganda, especially the Eastern region. However, production and productivity are still low. Current production is estimated at 6.4 MT/ha (28 kg/tree) compared to the desired 30 MT/ha (100 kg/tree) [1]. Low production and productivity are attributed to rampant diseases, pests, and moisture stress. In addition, low soil fertility grossly limits *citrus* productivity. Indeed, deficiency symptoms for N, P, Mg, Zn, Mn are common in many farmers' orchards. Although some farmers use manure and crop residues, these are in short supply and cannot entirely address the extensive soil fertility challenge. At the same time, there is paucity of information on fertilizer requirements for *citrus* in Uganda.

Research worldwide has developed fertilizer recommendations for *citrus* to address soil-limiting nutrients. In South Africa, RSA [2] recommended that young *citrus* trees must be planted in deeply dug, well-drained soil with compost, but no inorganic fertilizer. Starting 1 year after planting, the trees should receive three split applications, each of 300 g NPK (8:1:6), then increased to 500 g as the tree grows. This should be increased yearly until trees are fully mature and receive 2.5 kg NPK (8:1:6) per tree per application.

In Ethiopia, FAO [3] recommended three split applications each of 50 g (Urea and DAP) per tree in the first year, and this should be doubled in the second and subsequent years. Fertiliser should be applied before flowering and during the fruiting stage. In the USA (Florida) [4] recommends the application of 70 kg N/ha/year (or 411 g NPK 17:17:17) in 4 to 6 splits on young trees (1 year), applied as granular fertilizer. This amount should be doubled in the second, then tripled in the third year. In addition, potassium should be applied at a K₂O rate equal to 1.25 times the N rate. Furthermore, phosphorus should be added, depending on the soil test. In India, annual fertilizer requirements for the orange tree are 120 to 200 kg N/ha, 30 to 45 kg P/ha, and 60 to 150 kg K/ha [5]. Fertilizer application should start in February with 2 - 3 kg of N-P-K (12-12-17) per tree, followed by a second application of 1 - 2 kg N-P-K per tree during the fruit setting stage (May-June), then a final application of 1 - 2 kg during the fast-growing stage of the fruits (July-August). In Kenya [6] recommends application of 120 to 200 kg N and 120 to 200 kg K per hectare per year for 4 to 7-year-old trees. For older trees (8 years and above), application of 140 - 250 kg N and 140 to 250 kg K per hectare per year is recommended.

However, the literature is silent on *citrus* varietal differences in fertilizer response. In addition, owing to differences in soils and climate, global fertilizer recommendations need to be adapted to local (Ugandan) conditions, taking into consideration the cost, soil nutrient status, crop response, farmers' resource endowment, and market

dynamics and thereby develop a cost-effective fertilizer recommendation package. The objective of this study was to determine *citrus* fruit yield and profitability following the application of different NPK rates, and thereby develop optimum fertilizer recommendations for *citrus* production in Uganda.

2. Materials and Methods

2.1. Description of the Experimental Sites

The study was conducted in Soroti, Kalaki, Ngora, and Kumi districts, all located in Eastern Uganda. These districts lie within the cattle corridor, a region characterized by lower rainfall compared to the other parts of the country. The area receives 600 to 900 mm average rainfall, bimodally distributed. The main season runs from March to May with a peak in April, and a second season from August to November with a peak in October. The main dry seasons are June to July and December to February, with February being the peak of the dry season. Temperature ranges from 15°C to 32.5°C [7].

2.2. Field Survey on *Citrus* Production and Marketing

The study started off with a field survey to understand *citrus* farmers' production practices in Teso region (Soroti, Kalaki, Ngora, and Kumi districts) during 2021. To achieve this, a cross-sectional study design was employed to assess five *citrus* production parameters namely *citrus* production and productivity, agronomic practices (production and post-harvest handling), profitability, market dynamics, and challenges and opportunities. The study was conducted on 120 farmers and 12 Key informants. Data collection tools used included household interview questionnaires, FGD guides, and key informant interview guides.

Participants were selected based on having been in *citrus* production for at least three years and planted at least 50 *citrus* trees. *Citrus* farmers were interviewed individually in their homesteads to enable the researcher make field observations and validate responses on parameters such as pest and disease incidences and severity, number of productive trees, etc. Three focus group discussions with between 6 - 12 participants and 12 key informant interviews were also conducted to augment the household survey findings. The key informants interviewed included 1 input dealer, 1 local processor, 3 *citrus* fruits retailers, 6 sub-county and district officials, and 1 farmer cooperative leader. The data collected from this survey was entered and analyzed using SPSS software version 23.

2.3. Field Setup for the Fertilizer Experiment

Six farmers having *citrus* trees within the age ranges of 4 - 7 and >8 years after planting were selected from each of the four districts (Soroti, Kalaki, Ngora & Kumi). Farmer selection was based on good orchard management in terms of pest and disease control, weed control, and pruning, among others. In each of the selected farmer's fields, three representative trees of a given *citrus* variety were selected. Tree selection was based on the *citrus* variety, age, and overall appearance

(healthy and generally representative of other trees).

Experimental variables included: the *citrus* variety (Hamlin, Valencia, and Washington), age (years) after planting, and fertilizer (NPK, 17:17:17) rate. For the young, (4 to 7-year-old) *citrus* trees, fertilizer (NPK 17:17:17) was applied at 0, 138.9, 277.8, and 555.6 kg/ha/year representing 0, 500, 1000, and 2000 g per tree. For a given farmer, a given fertilizer rate was applied on three representative trees of each *citrus* variety. Each fertilizer rate was split into three smaller portions (40%, 30% & 30%), applied during April, June, and August of 2022 and 2023. Thus, the rate of 500 g per tree was applied as 200, 150, and 150 g; 1000 g per tree was applied as 400, 300, and 300 g while 2000 was applied as 800, 600, and 600 g, applied in April, June, and August, respectively. Each *citrus* tree was first cleared of any grass, then a 10-cm deep, circular furrow was gently dug along the edge of the tree canopy. Fertilizer was sprinkled within the furrow, and covered with a thin layer of soil. The *citrus* trees were labelled to reflect the variety, age, and quantity of NPK applied. Farmers were cautioned not to add more fertilizer to the tagged, NPK-treated experimental trees.

For trees aged 8 years and above after planting, fertilizer (NPK 17:17:17) was applied at 0, 277.8 555.6, and 1111 kg/ha/year representing 0, 1000, 2000 and 4000 g per tree. Each fertilizer rate was split into three smaller portions as described above. The 1000 g rate was applied as 400, 300, and 300 g per tree; 2000 g per tree was applied as 800, 600, and 600 g per tree, while 4000 was applied as 1600, 1200 and 1200 g per tree, applied in April, June, and August, respectively. Fertilizer application was done in a 10 cm furrow dug along the edge of the canopy as described above, then covered with soil. The *citrus* trees were labelled to reflect the variety and quantity of NPK applied, and farmers were cautioned not to apply more fertilizer on the labelled trees.

All participating farmers were supported by the project and provided with chemicals to control pests and diseases. In addition, farmers were closely monitored to ensure that fields are well maintained in terms of orchard sanitation, weeding and *citrus* pest and disease management. Indeed, farmers made all efforts to manage their orchards properly, control *citrus* pests and diseases.

2.4. Data Collection

Data collected included: date of harvest, the variety, treatment number (corresponding to the quantity of fertilizer applied as per the tree label), quantity of fruits (kg) harvested, and the price sold per bag. Researchers first trained the host farmers, in data recording and provided each farmer with a weighing scale (0 to 100 kg), a notebook, and a pen. The team also worked with farmer group leaders to further train farmers and oversee data collection to ensure good quality. Researchers and group leaders visited the host farmers regularly to monitor orchard maintenance and check on farmers' records. Any areas of improvement were pointed out during such visits. Whenever possible the research team and group leaders measured a standard (marketable) bag of *citrus* fruits on different occasions.

Data on bag weight and farmgate price per bag were used to convert the farmer's *citrus* yield per tree, into monetary equivalents. This enabled the researchers to translate the farmers' records (kilograms) into actual profit obtained from each fertilizer treatment.

2.5. Data Analysis

To ensure that quality representative data is processed, farmers' records from April to August 2022 were excluded from analysis; instead, data from September 2022 to January 2024 were considered. The period from April to August was considered as a time for the *citrus* trees to respond to applied fertilizer and also a phase for farmers to learn and perfect the data recording process. Data on *citrus* tree yields were summed up to obtain kilograms harvested per year. This was converted to kg/ha/year by assuming a tree spacing of 6 m by 6 m. For a given fertilizer treatment, the cumulative profit per tree per harvest was also computed to obtain the Gross revenue (profit). Partial budget analysis [8] was used to compute the profitability of fertilizer use on different *citrus* varieties. Variable costs (VC) were computed from costs for inputs (fungicides, pesticides, manure, foliar, herbicides, etc.), labour for spraying (herbicides, pesticides & fungicides), weeding, manure application, harvesting, loading & off-loading. For a given fertilizer rate, the cost and labour for field application were added to the variable costs to derive the Total Variable Costs (TVC). The TVC was subtracted from the Gross profit to obtain the Net revenue (net profit) associated with a given variety and fertilizer rate. The data were processed in MS Excel and statistically analyzed using Genstat version 11. Duncan's multiple range test at 0.05 probability level was used to separate means when significant differences were evident.

3. Results

3.1. Soil Characteristics

Laboratory results indicated soil in the experimental sites to be moderately acidic, with very low organic matter and phosphorus contents. Soil has low Ca, Mg, and K contents. The texture is predominantly sandy clay loam (Table 1).

Table 1. Selected soil characteristics from the study sites.

| Analytical Lab: | Soil and Plant Analytical Laboratories at NARL | | | | | | | | | |
|-------------------------------|--|-----------------|-----------------|----------------|-------------------|-------------------|------------------|------------------|------------------|-----------------|
| Client: | KOPIA <i>CITRUS</i> M.V PROJECT | | | | | | | | | |
| District: | Soroti, Kalaki, Ngora & Kumi | | | | | | | | | |
| ----- Mehlich 3 ----- | | | | | | | | | | |
| Lab No. | pH | OM | P | Ca | Mg | K | Sand | Clay | Silt | Textural |
| | | % | | -----ppm----- | | | ----- % ----- | | | Class |
| Mean \pm standard deviation | 6.01 \pm 0.41 | 0.06 \pm 0.04 | 5.63 \pm 4.91 | 1443 \pm 253 | 437.2 \pm 104.7 | 259.7 \pm 101.0 | 54.67 \pm 7.38 | 21.08 \pm 3.37 | 23.25 \pm 4.14 | Sandy clay loam |
| Critical values | 5.5 | 3.0 | 36.0 | 1640 | 87 | 73 | | | | |

3.2. Results of the Total Variable Costs Analysis

Results of the field survey showed that the Variable Costs (excluding inorganic fertilizer) amounts to Uganda Shillings 1,872,567 (equivalent to US \$513) per hectare per year [1]. Variable costs (VC) included costs for inputs (fungicides, pesticides, manure, foliar, herbicides, etc.), labour for spraying (herbicides, pesticides & fungicides), weeding, manure application, harvesting, loading & off-loading. The cost of purchase and field application of NPK (17:17:17) at different rates was added to the VC to obtain the Total Variable Costs (TVC). During the time of this study (2022), fertilizer prices rose sharply in Uganda compared to the ones in 2021. The price of NPK (17:17:17) rose from the normal price of UGX 130,000 (US \$35.616) in 2021 to (US \$60.274) in 2022, representing a 69% increase. This definitely affected profitability at farm level. For this reason, two profitability scenarios are presented, one for the normal fertilizer price in 2021 (when the baseline study was conducted), and another for the fertilizer prices in 2022-23 (when the field experiment was done). The TVC values were subtracted from the Gross revenue to obtain the Net profit realized by the farmer through the use of NPK fertilizer on *citrus*.

3.3. Citrus Yield and Profitability as Affected by Difference in Varieties for Young (4- to 7-Year-Old) Trees

Highly significant ($P < 0.001$) differences in *citrus* yields were observed between varieties (Table 2). Yields were significantly higher for var. Hamlin compared to Washington and Valencia (Table 3). The farmers' net profit also varied significantly among varieties ($P < 0.001$) (Table 2). Results showed that Net profit was highest from var. Hamlin compared to Washington and Valencia during both years (Table 3). However, the Net profit from Washington was not significantly ($P > 0.05$) different from Valencia. The lowest Net profit was observed from var. Washington, but this was not significantly ($P > 0.05$) different from that of Valencia.

Table 2. ANOVA Table for the Effect of variety and fertilizer application rate on the yield and profitability of young (4- to 7-year-old) *citrus* trees.

| Source | df | Yield, kg/ha | Net profit-2021 | Net profit-2022 |
|--------------------|----|--------------|-----------------|-----------------|
| | | P-value | | |
| Variety | 2 | <0.001 | 0.001 | 0.001 |
| Fertilizer rate | 3 | <0.001 | 0.005 | 0.046 |
| Variety*Fertilizer | 6 | NS | NS | NS |

Table 3. *Citrus* yields and profitability as affected by differences in varieties for young (4- to 7-year-old) trees.

| Variety | Yield, kg/ha | Net profit-2021 | Net profit-2022 |
|---------|---------------------|-------------------|-------------------|
| Hamlin | 26,962 ^a | 2769 ^a | 2649 ^a |

Continued

| | | | |
|-----------------------|---------------------|-------------------|-------------------|
| Valencia | 14,563 ^b | 1344 ^b | 1224 ^b |
| Washington | 12,256 ^b | 953 ^b | 833 ^b |
| LSD _(0.05) | 4161 | 605.6 | 605.6 |

Means followed by the same superscript within the same column are not significantly different ($P = 0.05$).

3.4. Effect of Fertilizer Application on *Citrus* Yields for Young (4- to 7-Year-Old) Trees

Highly significant ($P < 0.001$) response to fertilizer application was observed in *citrus* yield (Table 2). *Citrus* yields increased with fertilizer application, with the highest yield (26.47 t ha^{-1}) observed at $555.6 \text{ kg NPK ha}^{-1}$ (Figure 1). Results show that *citrus* yields for $138.9 \text{ kg NPK ha}^{-1}$ were not significantly different from the control. However, application of 277.8 kg and $555.6 \text{ NPK ha}^{-1}$ resulted in significantly ($P < 0.001$) higher yields compared to the control).

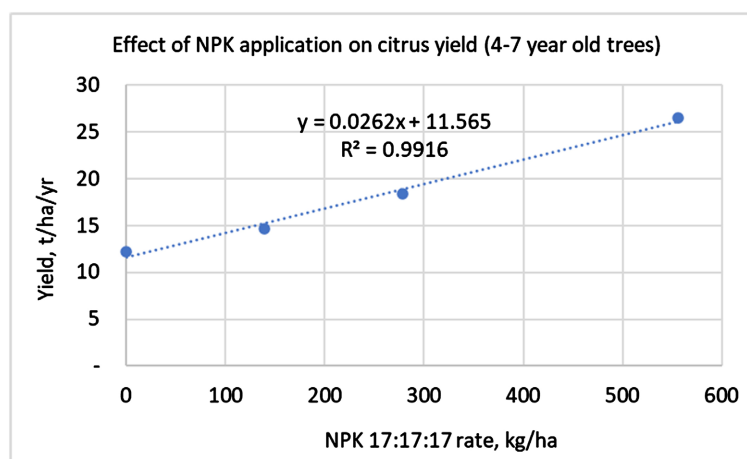


Figure 1. Effect of fertilizer application on *citrus* yields for young (4- to 7-year-old) trees.

3.5. Profitability of Fertilizer Use in *Citrus* Production, for Young (4- to 7-Year-Old) *Citrus* Trees

Fertilizer application increased farmers net profit during both 2021 ($P < 0.001$) and 2022 ($P = 0.046$). Results show that net profits increased linearly with the increasing rate of NPK (17:17:17) applied during both years, with the highest values observed at 555.6 kg ha^{-1} (Figure 2). Owing to the increased fertilizer prices, farmers' net profit was lower in 2022-23 compared to 2021, at all rates of fertilizer. It is also worth noting that when low fertilizer rates (138.9 & 277.8 kg/ha) were applied, the resulting net profit was not significantly different from the control during both years; a significant increment in net profit was observed at a higher rate of 555.6 kg/ha . This result implies that applying low fertilizer rates (138 & 276 kg NPK/ha) is not profitable, rather, a farmer is better off applying a higher (NPK) fertilizer rate.

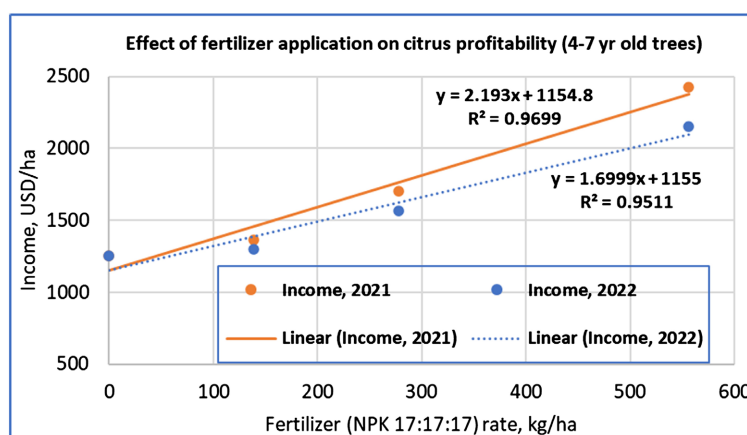


Figure 2. Effect of fertilizer application on farmers Net profit for young (4- to 7-year-old) trees.

3.6. Citrus Yield and Profitability as Affected by Difference in Varieties for Mature (8 Years and above) Trees

Highly significant ($P < 0.001$) differences in *citrus* yield were observed between varieties (Table 4). Yields were highest for var. Hamlin compared to Valencia and Washington. However, yields for Valencia and Washington were not significantly different (Table 5). Correspondingly, net profits were significantly higher for var. Hamlin compared to Valencia and Washington, during both years. Net profits for Valencia and Washington were not significantly different.

Table 4. ANOVA table for the effect of variety and fertilizer application rate on the yield and profitability of mature (8 years and above) *citrus* trees.

| Source | df | Yield, kg/ha | Net profit-2021 | Net profit-2022 |
|----------------------|----|--------------|-----------------|-----------------|
| | | | P value | |
| Variety | 2 | 0.001 | <0.001 | <0.001 |
| Fertilizer rate | 3 | 0.006 | 0.012 | 0.001 |
| Variety * Fertilizer | 6 | NS | NS | NS |

Table 5. *Citrus* yield and profitability as affected by difference in varieties (8 years & older).

| Variety | Yield, kg/ha | Profit (USD/ha), 2021 | Profit (USD/ha), 2022 |
|-----------------------------|---------------------|-----------------------|-----------------------|
| Hamlin | 49,797 ^a | 5285 ^a | 5046 ^a |
| Valencia | 22,814 ^b | 855 ^b | 615 ^b |
| Washington | 22,045 ^b | 919 ^b | 679 ^b |
| LSD_(0.05) | 5041 | 395.9 | 395.9 |

Means followed by the same superscript within the same column are not significantly different ($P = 0.05$).

3.7. Effect of Fertilizer Application on the Yield and Profitability of Citrus (8 Year & above)

Fertilizer application increased *citrus* yield, with significant differences observed at

rates as low as 278 kg/ha over the control (**Figure 3**). Increasing fertilizer rate to 555.6 and 1111 kg/ha increased *citrus* yield, although the resulting yields were not significantly higher than the level obtained at 278 kg/ha. It is worth noting that *citrus* yields for the 278, 556 and 1111 kg/ha rates were statistically not different, suggesting that the benefits of fertilizer use were observed more at lower fertilizer rates and not the highest value of 1111 kg/ha. This result clearly shows that fertilizer rates as high as 1111 kg/ha are not worthwhile. Application of 278 kg NPK/ha resulted in a slight increase in *citrus* net income during both years, but the values were not significantly different from the control (**Figure 4**). Raising the fertilizer rate to 556 kg/ha resulted in no significant change in farmers net income compared to the control treatment. Further fertilizer increments to 1111 actually depressed farmers net income significantly over the control during both years. Owing to the higher fertilizer prices during 2022, the net income was much lower during 2022 compared to 2021 at all rates of NPK applied.

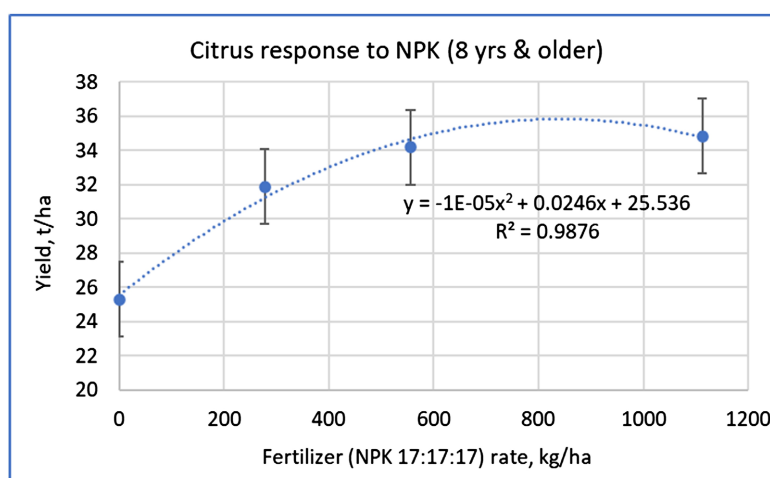


Figure 3. Effect of fertilizer application on the *citrus* yield (8 years & older trees).

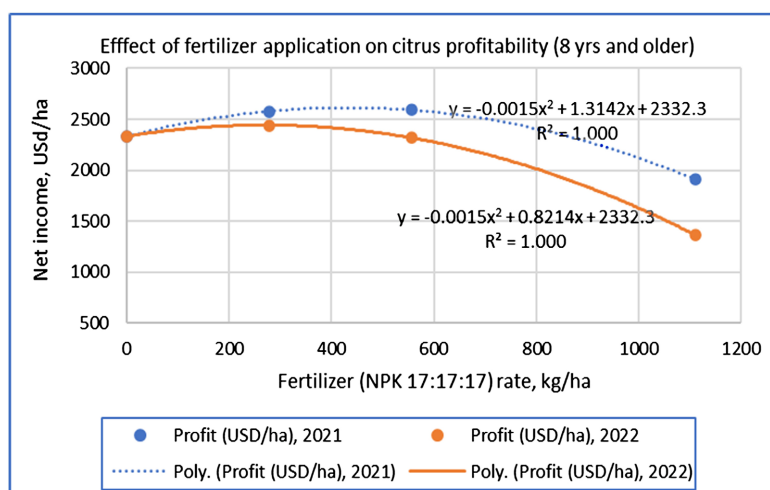


Figure 4. Effect of fertilizer application on *citrus* farmers Net profit (for 8 years and above old trees).

4. Discussion, Conclusions & Recommendations

4.1. Discussion

Based on the soil analytical results, the soils in the study area would benefit from the use of organic materials such as manure and crop residues, supplemented by inorganic fertilizers. However, organic fertilizers are low in quantities, and in addition, the high temperatures accelerate their decomposition rates. On the other hand, inorganic fertilizers are costly to many farmers.

Results of this study show that *citrus* fruit yields varied among varieties, with Hamlin giving significantly higher yields compared to Washington and Valencia, both for the 4 to 7, year-old and the 8 years and above old trees. Consequently, net profits were higher for Hamlin compared to Valencia and Washington. Fertilizer application significantly increased fruit yield and profitability for both the 4 - 7 year and 8 and above year-old *citrus* trees. Within the fertilizer rates used in this study, yields were highest at 556 kg/ha, resulting into the highest profitability during both years. These findings suggest that application of 556 kg NPK/ha is most economically optimum for *citrus* production in Teso region; higher rates are not profitable, for both the 4 - 7, year-old and 8 and above, year-old trees. Previous studies have recommended that fertilizer amount per tree should be increased as the tree matures in age. In Kenya for example, [9] recommended application of 400 g CAN and 500 g TSP per tree for 4 - 5-year-old *citrus* trees, while for trees 5 years and older, 600 g CAN/tree and 1000 g TSP/tree was recommended. In another Kenya study, [6] recommends that for fruit bearing *citrus* trees grown on light to medium soils at 5 m by 4.5 m spacing, at a target yield of 60 ton/ha, fertilizer should be applied as 650 - 950 kg N, 250 kg P₂O₅, and 650 - 1000 kg K per hectare per year. However, [10] advised that as *citrus* trees mature, their nutritional needs will reduce. Indeed, results from this study show that the optimum fertilizer requirements for *citrus* is 556 kg NPK/ha (equivalent to 2 kg NPK/ha/yr), whether 4 - 7 year or 8 years and older.

In USA (Florida), [4] recommended application of 70 kg N/ha/year (or 411 kg NPK 17:17:17) in 4 to 6 splits, on young trees (1 year), applied as granular fertilizer. This amount should be doubled in the second, then tripled in the third year. In addition, potassium should be applied at a K₂O rate equal to the 1.25 times the N rate. Furthermore, phosphorus should be added, depending on the soil test. Based on this recommendation, the 4 - 7-year-old *citrus* trees would receive four splits of at least 1.0 kg per tree, giving a total 4.0 kg NPK (17:17:17) per year. This recommendation is twice the optimum rate of 2 kg per tree per year which our study has found as the optimum for *citrus* production in Teso region.

4.2. Conclusions and Recommendations

Soil fertility is one of the major factors limiting *citrus* production in Eastern Uganda. In order to sustain production and meet the growing regional demand for fruits, there is need for use of fertilizer. This study has demonstrated that fertilizer (NPK) use improves *citrus* yield and profitability, for both the young and old trees. Based on the findings of this study, for optimum *citrus* yield and profitability, the

following recommendations are drawn.

- For young fruit bearing (4 - 7 years), apply 556 kg NPK (17:17:17)/ha/year (equivalent to 2000 grams per tree per year), irrespective of the variety. The fertilizer should be split into three smaller portions of 800, 600 & 600 g NPK per tree, applied in April, June and August per year.
- For mature trees (8 years and above) apply 556 kg NPK (17:17:17)/ha per year (equivalent to 2000 grams per tree per year). The fertilizer should be split into three smaller portions of 800, 600 & 600 g NPK per tree, applied in April, June and August per year.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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